Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

FEASIBILITY DESIGN REPORT
BOWNESS FLOOD BARRIER PROJECT
STORMWATER ASSESSMENT AND MITIGATION

Prepared for:
KLOHN CRIPPEN BERGER LTD. AND THE CITY OF CALGARY

Prepared by:
MATRIX SOLUTIONS INC.

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FEASIBILITY DESIGN REPORT

BOWNESS FLOOD BARRIER PROJECT

STORMWATER ASSESSMENT AND MITIGATION

Prepared for Klohn Crippen Berger Ltd. and the City of Calgary, April 2021



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CONTRIBUTORS

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EXECUTIVE SUMMARY

Matrix Solutions Inc. was retained by Klohn Crippen Berger Ltd. (KCB) to provide engineering support for the Bowness Flood Barrier Project (the Project) on behalf of the City of Calgary (the City). The Study Area for the Project is the established urban neighbourhood of Bowness, located within the northwest quadrant of Calgary, Alberta. Several areas, especially the residential properties along Bow Crescent NW, are prone to flooding caused by elevated Bow River water levels. KCB was tasked with designing a flood barrier wall or berm (the barrier) to protect the Study Area from potential overland river flooding. The proposed barrier is located above the riverbank of the Bow River on private properties roughly extending between the CP Rail tracks and Shouldice Bridge. The number of required properties, alignment, and the height of the proposed barrier are being refined as part of the feasibility-level design.

Matrix was tasked with assessing the impact of the proposed barrier on overland drainage and storm sewer performance and recommending stormwater infrastructure upgrades to mitigate impacts that could result from the implementation of the barrier.

To complete this assessment, Matrix developed a 3-way coupled stormwater model of the Study Area to capture the complex hydraulic interactions between overland flooding of the Bow River, overland drainage, and underground storm sewer networks. The 3-way coupled model consists of the following DHI software models: a MIKE URBAN model of the storm sewer network, a MIKE HYDRO riverine model of the Bow River, and a MIKE 21 overland flow model of the surface topography. This level of detail in model representation was required for this project to assess and mitigate any potential for increased stormwater flood risk to the community with the barrier in place.

Mitigation options proposed took into consideration constrained land availability, location, level of service (LOS) of existing infrastructure, and stakeholder inputs. Three mitigation options were selected for further analysis, design, and modelling:

Option 1 – Flood Barrier with Permanent Pumping, Minor Temporary Pumping, and Underground Storage
(1 permanent pumping station; 1 temporary pumping location, dispatched on demand; 2 underground storage units; back-of-lot drainage mitigation)

Option 2 – Flood Barrier with Temporary Pumping
(30 temporary pumps, dispatched on demand; back-of-lot drainage mitigation)

Option 3 – Flood Barrier with Temporary Pumping and Underground Storage
(28 temporary pumps, dispatched on demand; 4 underground storage units; back-of-lot drainage mitigation)

Mitigation options were evaluated via the 3-way coupled model to optimize functionality and fine-tune suitable locations for proposed stormwater infrastructure upgrades. These options were further

evaluated using high-level criteria that considered, but were not limited to, proposed LOS improvements, environmental and social impacts, constructability, and economic considerations. Matrix recommends that “Option 2 – Flood barrier with Temporary Pumping” should be pursued if the project proceeds to the next phase of design.

It is also recommended that the performance of the stormwater systems of the Bowness community be evaluated under the City’s Community Drainage Improvements program to evaluate and propose prioritized drainage improvements for problem locations within the broader Bowness community that are not caused by the proposed barrier, which is beyond the scope of this current project.

LIST OF ACRONYMS AND ABBREVIATIONS

1D	One dimensional
2D	Two dimensional
CB	Catchbasin
CDI program	Community Drainage Improvements program
DSSP	Development site servicing plan
HGL	Hydraulic grade line
HWL	High water line
ICD	Inlet control devices
Imp.	Impervious
KCB	Klohn Crippen Berger Ltd.
LOS	Level of service
MH	Manhole
PCSWMM	Personal Computer Stormwater Management Model
Perv.	Pervious
PS	Pump station
QVD	Combination of overland flow rate, velocity, and depth (Q, V, and D)
RoW	Right-of-way
the City	The City of Calgary
the Project	Bowness Flood Barrier Project
UARR	Unit Area Release Rate
US gpm	United States gallon per minute

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1 INTRODUCTION

Matrix Solutions Inc. was retained by Klohn Crippen Berger Ltd. (KCB) on behalf of the City of Calgary (the City), to provide stormwater assessment and mitigation options analysis for the Bowness Flood Barrier Project (the Project). Several areas within the established northwest neighbourhood of Bowness in Calgary, Alberta, are located within the Bow River floodplain and many properties have experienced flood damage over the years.

KCB was tasked with designing an overland flood control barrier (barrier) to protect the Project Study Area (Figure 1 and Figure 2) from future river flooding events. The proposed Bowness Flood Barrier roughly extends from the lands east of the Bowness Rail Bridge (Canadian Pacific Railway) at its northwest end to west of the Shouldice Bridge.

Stormwater management mitigations presented in this report would address drainage within City roads and right-of-ways (RoWs) affected by the proposed Bowness Flood Barrier and closure of flood gates. In addition, mitigation measures would need to ensure that drainage is maintained from backyards where the presence of the barrier would block existing overland flows in the Study Area from draining freely towards the Bow River.

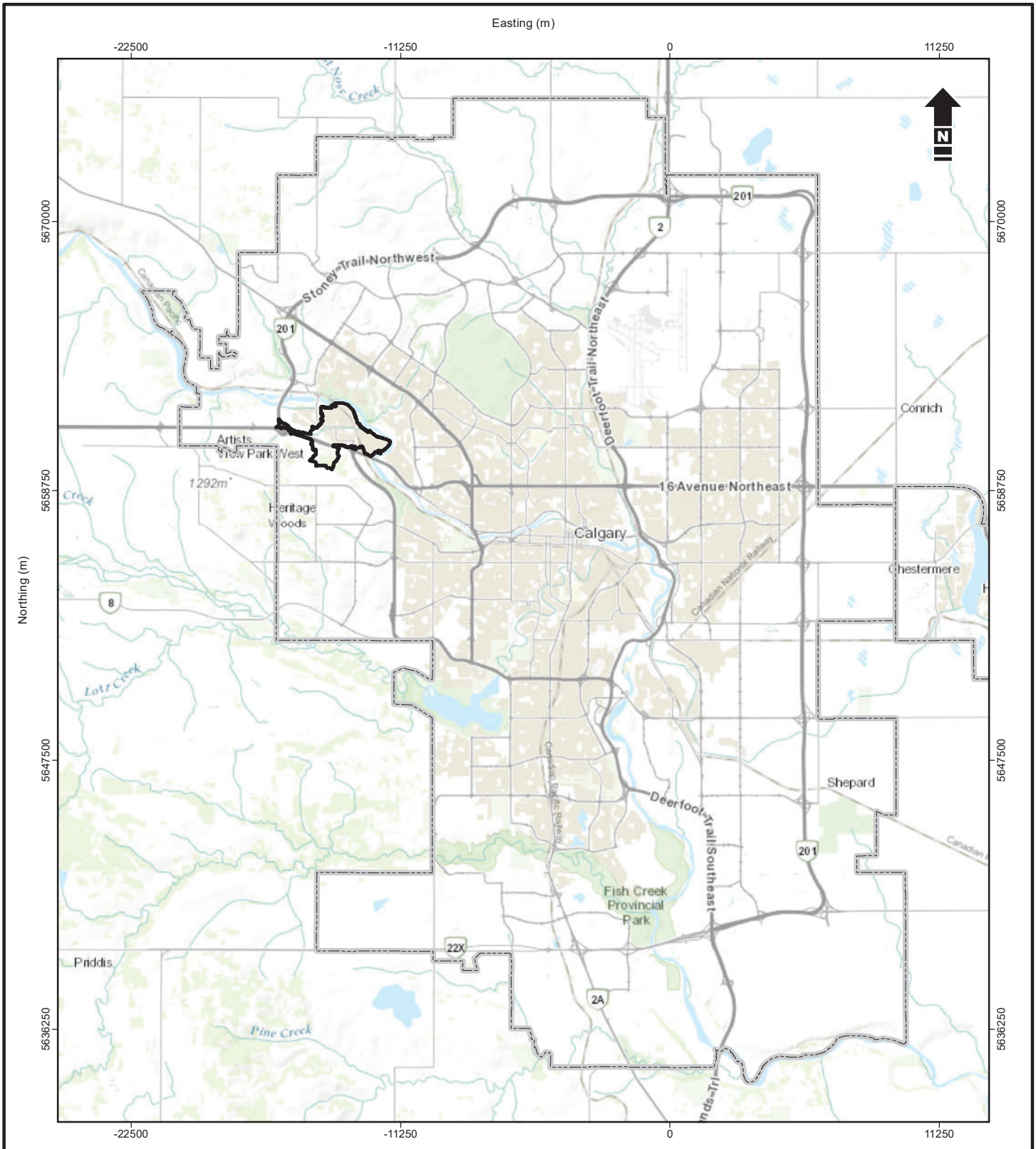
1.1 Objectives

Matrix's project objectives included:

- assessing the impact of the barrier on existing overland and storm sewer network drainage within the Study Area; and
- proposing stormwater infrastructure upgrades to mitigate impacts resulting from implementation of the barriers.

To accomplish these objectives, a detailed assessment of the overland drainage (major system) and underground storm sewer networks (minor system) was required to determine the existing levels of service for a variety of urban pluvial flood (rainfall and its resulting surface water flows) and fluvial flood (river overflow contributions) conditions throughout the Study Area (Figure 2). Additionally, this analysis was required to ensure that implementation of the barrier would not negatively impact surface ponding extents or the level of service (LOS) of the existing storm sewer network and considered the benefits and impacts to properties within the Study Area. As such, Matrix's assessment focused on:

- evaluating the LOS of existing overland drainage and storm sewer systems;
- assessing impacts to overland drainage by the proposed barrier; and
- determining what mitigation measures would be required within the Study Area to maintain or improve the existing levels of service (overland drainage and storm sewer performance) after the implementation of the barrier.



Study Area

Municipal Boundary

Reference: Data obtained from AltaLIS © Government of Alberta and City of Calgary used under license. Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

1:225,000

kilometres

2.5 0 2.5 5

Calgary 3TM WGS 1984 W114

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

City of Calgary
Bowness Flood Barrier Project

Location Plan

Date:	Project:	Submitter:	Reviewer:
February 2021	26638	P. Bishop	A. Chan

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Figure 1

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Easting (m)

-17000 -16000 -15000 -14000 -13000 -12000

Northing (m)

5663000 5662000 5661000 5660000 5659000

NOSE HILL DR NW
BEARSPAW DAM RD NW
Baker Park
Bow River
Bowness Park
Bowness Rail Bridge (CP Rail)
Silver Springs Golf & Country Club
SILVER SPRINGS GA NW
Bowmont Park
SILVERVIEW DR NW
VARSITY ESTATES DR NW
85 ST NW
48 AV NW
44 AV NW
40 AV NW
37 AV NW
34 AV NW
33 AV NW
31 AV NW
24 AV NW
13 AV NW
72 ST NW
77 ST NW
63 ST NW
47 ST NW
BOWNESS RD NW
BOWFORT RD NW
SARCEE TR NW
SARCEE TR SW
BOW CRESCENT NW
BOWWOOD DR NW
HOME RD NW
Shouldice Bridge
Shouldice Athletic Park
201
1
1A
563

B109 B108A B108 B107 B106 B104 B101 B100 B98 B97

N

Study Area
Lots with Proposed Barrier
Outfall
Gated Outfall

Catchbasin Catchments by Model

Bowness Model (MIKE URBAN)
Medicine Hills Pond A Model (PCSWMM)
Medicine Hills Pond C Model (PCSWMM)
Trans-Canada Highway / Bowfort Model (PCSWMM)

Reference: Data obtained from AltaLIS © Government of Alberta and City of Calgary used under license. GDM transportation infrastructure data provided by IHS © 2021 used under license. Imagery (2018) provided by Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community © (2021) used under license.

Catchment data sourced from:

Stantec Consulting Ltd. 2015. Trans-Canada Highway / Bowfort Road Interchange Stormwater Management Report. Prepared for The City of Calgary Transportation Infrastructure. March 2015.

Urban Systems Ltd. 2017. Medicine Hill Extended Detention Pond A Pond Report. Prepared for Trinity Development Group Inc. March 2017.

Urban Systems Ltd. 2017. Medicine Hill Extended Detention Pond C Pond Report – Revised Final. Prepared for Trinity Development Group Inc. March 2017.

1:20,000 metres
200 0 200 400
Calgary 3TM WGS 1984 W114

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

City of Calgary
Bowness Flood Barrier Project

Study Area

Date:	Project:	Submitter:	Reviewer:
April 2021	26638	P. Bishop	A. Chan

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Figure 2

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Matrix's assessment of impacts to existing overland drainage and storm sewer networks was initially based on the preliminary barrier alignment proposed in Associated Engineering's *Permanent Flood Barrier Protection Assessment* report (AE 2018). The barrier design has since been refined and the overall length has shortened. The current proposed barrier alignment used for our assessment spans a total length of approximately 1.9 km, starting from lands east of the Bow Village Crescent NW at the northwest end of the Bowness community extending downstream along the right bank of the Bow River to Shouldice Bridge (Bowness Road). The conceptual barrier alignment has a discontinuous portion between 67 Street NW and east of 60 Street NW dividing the barrier into two separate sections (Figure 2). Properties with a proposed flood barrier are shown as shaded in Figure 2.

1.2 3-Way Coupled Model Approach

Due to the complex interactions between the river, overland drainage, and storm sewer piping networks, Matrix developed a 3-way coupled stormwater model of the Study Area using DHI's MIKE models.

The 3-way coupled model consists of models based on the following DHI software packages:

- A MIKE URBAN model of the storm sewer networks including contributing catchment areas, catchbasins (CBs), manholes (MHs), sewers, and outfalls (minor system).
- A MIKE HYDRO riverine model of the Bow River through the Study Area.
- A MIKE 21 overland flow model of the surface topography (major system).

MIKE URBAN is an urban water modelling system that offers the US EPA SWMM engine or MIKE one dimensional (1D) for modelling subcatchment hydrology, pipe network hydraulics, and water quality elements. MIKE HYDRO is a dedicated river modelling system that simulates fully-hydrodynamic flows in open channels and hydraulic structures. For this Bowness Project, modelling in MIKE HYDRO was carried out in 1D to reduce modelling complexity. MIKE 21 is a two dimensional (2D) surface water modelling system capable of detailed representation of overland flow in an urban environment. Finally, the MIKE FLOOD software was used to couple the three models, allowing them to dynamically exchange flow between each system.

This level of detail in model representation of the Study Area was required for this Project to assess and mitigate any potential for increased stormwater flood risk to the community with the barrier in place. For example, if high water levels are expected in the Bow River, City crews would close stormwater outfall flood gates to prevent flood waters in the river from backing up into the community through the existing underground storm sewer network. To maintain the flood protection integrity of the proposed barrier, the flood gates at selected outfalls will need to be closed to prevent river water from flooding streets behind the barrier via the storm sewer manholes and catchbasins. To prevent stormwater flows from being trapped within storm sewers and ponding on roadways (when outfall gates are closed), additional pumping efforts (permanent and/or temporary) would be required to collect and discharge flows to the

river side of the barrier. Additional mitigation measures could include underground storage, storm sewer diversions, and/or storm sewer upgrades.

This report summarizes the methodology used to develop and couple the three model components, discusses model validation steps, presents the performance of the existing storm drainage system, assesses mitigation options for Study Area stormwater flows, discusses LOS improvements for the mitigation option, evaluates the advantages and drawbacks of each mitigation option, and provides recommendations for next steps.

2 OVERVIEW AND BACKGROUND INFORMATION

2.1 Overview of the Study Area Catchments

The overall Project Study Area (approximately 480 ha) includes four general catchment areas within northwest and southwest Calgary (Figure 2) that all slope north east to the Bow River. The highest elevations and steepest portions of the Study Area are located in the southwest corner of the overall Project Study Area. Three external catchment areas (Trans-Canada Highway/Bowfort; Medicine Hills Pond A; and Medicine Hills Pond C) slope to the northeast toward the Bowness catchment.

The Bowness catchment (approximately 334 ha) includes the established residential community of Bowness and is composed of single family and multi-family residential, schools, and commercial areas. This catchment generally slopes north and east toward the Bow River. The south portion of the Bowness catchment includes the steep Bow River Valley escarpment, which lies between the Bowfort Road commercial area and 33 Avenue NW. The rest of the catchment is relatively flat and drains toward the Bow River. A map of the Study Area's topography is shown on Figure 10 in Section 3.3.2. Details of the modelled catchments are described in Section 3.1.1.

2.2 Overview of the Existing Storm Drainage System

Current storm sewer infrastructure within the Bowness catchment was originally designed between the 1950s and 1980s; the earliest noted installation was 1960 and the median was 1984. The entire storm sewer network measures approximately 28.4 km. Existing storm sewer pipe sizes range from 100 mm to 1500 mm diameter for circular pipes and from 500 mm × 900 mm to 2400 mm × 1800 mm for reinforced concrete box conduits (Box Ducts). Statistics of the modelled storm sewer networks (pipes diameters greater than 300 mm) are described in Section 3.1.2.1.

2.3 Proposed Barrier Alignment

The proposed Bowness Flood Barrier is intended to protect existing properties that are in the Bow River floodplain. The proposed barrier is to be a combination of floodwalls, retaining walls, and berms. The barrier design was developed based on property owner feedback, existing site constraints, and technical

studies, including a spatial analysis to develop a path of least impact on existing vegetation, habitat, and structures, while maintaining continuity of the barrier alignment (KCB 2020a). Detailed alignment and design of the barrier will be developed in consultation with the affected property owners.

The barrier was designed with a 0.5 m freeboard above the design flood water level based on a design discharge of 1,230 m^3/s. This design discharge provides a level of protection against a 1:200 year attenuated peak discharge with future upstream mitigation, which is equivalent to a 1:20 year naturalized discharge, as described in the Bowness Flood Control Barriers Hydrotechnical Assessment Report (KCB 2020b). The alignment of the proposed barrier considered the avoidance of existing buildings, avoidance of or limited utility impacts, and avoids encroachment into the floodway, wherever possible.

Stormwater mitigation options, including back-of-lot drainage mitigations, developed as part of this report are intended to be constructed as part of the Bowness Flood Barrier. The mitigation options presented would be designed such that stormwater drainage and flooding is not worsened in any areas within the community, but rather meets or improves upon existing conditions.

2.3.1 Back-of-Lot Drainage

The proposed barrier interrupts the existing drainage patterns on many of the affected lots that would prevent surface runoff from draining from the back-of-lots to the Bow River. Mitigation along these back-of-lots would be implemented to ensure continuance of stormwater drainage for these areas to prevent flooding or extended periods of saturation of the backyards after a rainstorm or snowmelt event.

Proposed mitigations to manage rear yard drainage interrupted by the barrier will be unique to the affected lots as the solution will need to be customized based on the barrier alignment, localized topography, type of barrier (floodwall, retaining wall, or earthen berm), proximity to buildings, and property owner feedback. The details of these measures will be part of future phases of design.

It is estimated that the majority of the rear yards with the barrier located closer to the river can be drained by culverts. These culverts may be installed at strategic locations and drainage from rear yards directed to these culverts at the toe of the barrier. One anticipated option includes some regrading of the rear yard of properties to facilitate surface flows to the culverts. Any penetrations of the barrier will be designed to avoid back-flooding (i.e., gates).

Where grades permit and there is space available for a storm sewer easement, some properties may be outfitted with catchbasins to collect back-of-lot drainage from the rear yards to direct runoff to the City's storm sewers along Bow Crescent NW. Additionally, deployable barriers are required to facilitate access across the barrier for lawn mowers, wheel chairs, and pedestrian access. Lots could be graded slightly to drain to these openings in the barrier.

For properties where the barrier located in close proximity to a residential dwelling, a customized solution can be developed that could include the above mitigation measures, as well as minor modifications to

local grading, redirection of eavestrough downspouts to the river-side of the barrier, or the addition of catchbasins within the property.

Back-of-lot drainage details for each lot will be assessed during future design of the barrier.

2.4 Data Collection

The following reports were obtained from the City for this Project:

- Associated Engineering (AE). 2018. *City of Calgary Permanent Flood Barrier Protection Assessment*. April 2018.
- Associated Engineering (AE). 2016. *Northwest Inner City Drainage Study – Sunnyside Review*. March 2016.
- City of Calgary. 2018. *Flood Control Barriers Design and Construction, Design Basis Memorandum. Version 1.*
- Golder Associates (Golder). 2015. *Bow River and Elbow River: Hydraulic Model and Flood Inundation Mapping Update.*
- Golder Associates (Golder). 2014. *Basin-Wide Hydrology Assessment and 2013 Flood Documentation: Bow River and Elbow River.*
- Stantec. 2015a. *Trans-Canada Highway/ Bowfort Road Interchange Stormwater Management Report* Revised Final. June 3, 2015.
- Stantec. 2015b. *Trans-Canada Highway/ Bowfort Road Interchange Contract 1: Roadworks, Detours, Utilities, Retaining Walls, and Bridge Issued for Construction Drawings (Tender 15-1035).* May 5, 2015.
- Urban Systems Ltd. 2018a. *Medicine Hill Phase 1A Gateway District Revised Final 5 Construction Drawings*. January 22, 2018.
- Urban Systems Ltd. 2018b. *Medicine Hill Phase 1C Town Centre District Revised Construction Drawings*. February 14, 2018.
- Urban Systems Ltd. 2017a. *Medicine Hill Phase 1B Village District Revised Final 3 Construction Drawings*. May 29, 2017.
- Urban Systems Ltd. 2017b. *Medicine Hill Extended Detention Pond A Pond Report* Revised Final. March 21, 2017.
- Urban Systems Ltd. 2017c*. Medicine Hill Extended Detention Pond C Pond Report* Revised Final. March 21, 2017.

- Urban Systems Ltd. 2016. *TransCanada Highway/Sarcee Trail Interchange SWMR*. May 5, 2016.
- Urban Systems Ltd. 2015a. *Trinity Hills (Winsport) - Revised Staged Master Drainage Plan*. Revised Final. May 11, 2015.
- Urban Systems Ltd. 2015b. *Contract for the Construction of Trans Canada Highway and Sarcee Trail Interchange Improvements*. Issued for As-built. December 5, 2017.
- Urban Systems Ltd. 2015c. *Trinity Hills Revised Staged Master Drainage Plan* (LOC2014-0080). May 11, 2015.

Digital data from the City included LiDAR, digital elevation model (DEM) data, bathymetry data, digital aerial survey, legal survey, ownership parcel, land use, impervious (2016) cover, City-owned utilities (storm, sanitary, and water), hydrography, and 2018 orthophotos.

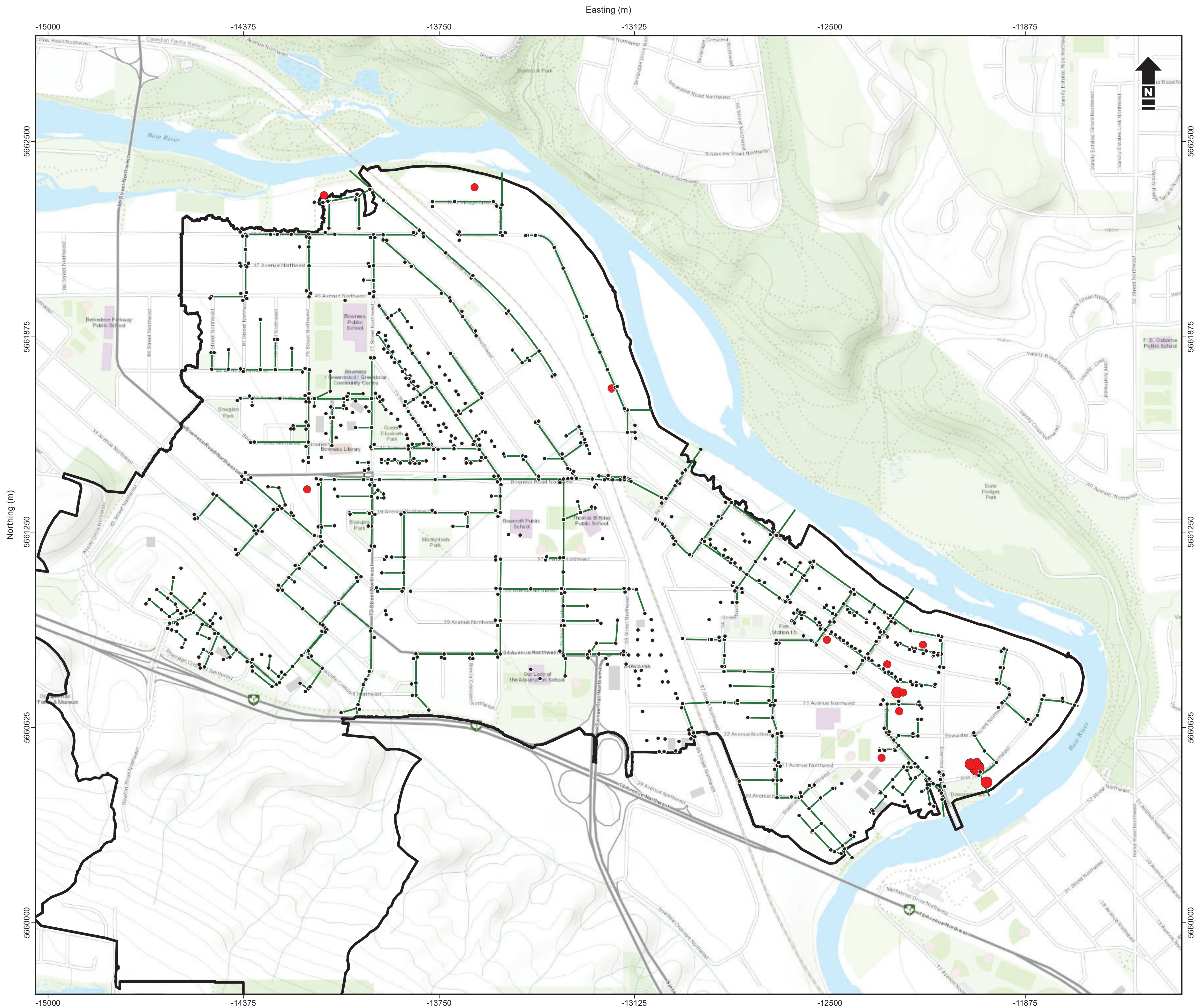
In addition, the Bowness community has a large number of private developments (i.e., commercial, multifamily residential, and institutional) that have onsite stormwater management/CBs and roof drainage systems. Of the over 250 private development sites in the Study Area, approximately 70 development site servicing plans (DSSPs; previously known as mechanical site plans) were obtained from the City (the oldest plans were from 1972, newest was from 2011). Information from the DSSPs were used in the modelling in order to properly represent flows in the major and minor systems (i.e., onsite CBs, inlet control devices [ICDs], storm service connections, etc.).

No stormwater flow monitoring data was available for the Study Area.

2.5 Recorded Flooding Complaints

The City provided its database of flooding reports recorded by its 3-1-1 municipal phone service, which has handled inquiries and requests for non-emergency service calls, or reports of non-emergency problems. Flooded area complaints are recorded when standing water builds up during rain events in places such as streets, lots, and fields. These complaints may also include slow draining traplows and low areas around curb returns with CBs that inundate and do not appear to drain due to blockage or storm sewer surcharge. The 3-1-1 flooding data are categorized as: Flooded Areas, Drainage Complaints, CB Complaints, and Basement Flooding.

For the Study Area, the 3-1-1 flooding complaints data is limited as records were only available since 2013. There was a total of 21 available 3-1-1 flooding reports in the available record that correspond to recorded rainfall events (Figure 3).



Study Area

Storm Sewer

Modelled Storm Manhole/Catchbasin

311 Flood Reporting Location

Number of Reports Per Address

- 1
- 2
- 4

Reference: Data obtained from AltaLIS © Government of Alberta and City of Calgary used under license.Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community.

1:12,500 metres

125 0 125 250

Calgary 3TM WGS 1984 W114

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

City of Calgary
Bowness Flood Barrier Project

Reported Flooding Locations

Date:	Project:	Submitter:	Reviewer:
February 2021	26638	P. Bishop	A. Chan

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Figure 3

I:\CityOfCalgary\26638\FiguresAndTables\FLD\2018\Report\Final_Report\Figure-3-Reported_Flooding_Locations.mxd - Tabloid_L - 12-Feb-21, 04:16 PM - sylam - TID005

Flood complaints were grouped into two clusters: the first is a grouping of complaints located north-east of John Hextall Park and the second is a grouping of complaints located near the intersection of Bowwood Drive NW and 33 Avenue NW. Other flood-related calls were recorded along Bow Crescent NW, Bow Village Crescent NW, and Bow Green Crescent NW. The 3-1-1 flooding complaints were used to qualitatively validate the modelling as the flood complaint locations coincided with modelled flooding areas. Figure 3 also shows the number of occurrences of flooding complaints in the case where more than one flooding complaint was recorded at the same address for different days/years.

2.6 Groundwater Interaction

The Hydrogeological Characterization and Groundwater Flow Modelling Report (KCB 2021) demonstrated that pumping wells can address the localized areas of groundwater that may potentially come to surface during a flood.

Groundwater infiltration into the stormwater system, whether through cracks in pipes and manholes, leaky pipe joints and connections, and weeper holes, is expected to be low in relation to the typical 1:2 year or 1:5 year, 4-hour design storm events. AEP's Standards and Guidelines for Municipal Waterworks, Wastewater and Storm Drainage Systems (AEP 2012) specifies an allowance of 0.28 L/s/ha for infiltration of wet-weather infiltration and inflows into the sanitary sewer system. While the amount of groundwater contributing to storm sewers is largely dependant on age/condition of the storm sewer infrastructure, and there are no known studies that have quantified groundwater contributions into Calgary's storm sewers, storm sewer systems are assumed to intercept more groundwater than sanitary sewer systems. However, the groundwater contribution into storm sewers will be minimal and is expected to be a small fraction (i.e., 1-2%) of the typical 70 L/s/ha and upwards of over 120 L/s/ha of stormwater conveyed by storm sewers for the typical 1:2 year or 1:5 year, 4-hour design storm events. During river flooding events when the flood gates are closed, pumps will be used to dewater the storm sewers to discharge to the Bow River using appropriate design pump rates to accommodate the volumes of water from the amount of runoff generated from the expected design storm events, from possible infiltration and inflows due to elevated groundwater, and from possible sump pumps from properties along Bow Crescent discharging onto yards and streets. It should be noted that during rainfall events, an elevated hydraulic head in the storm sewer system will also act to limit the amount of groundwater that can infiltrate.

Additionally, KCB's 2021 report indicated that during flood events, the proposed Bowness barrier will not increase groundwater levels and will marginally reduce groundwater levels in areas close to the river with northwestern and southeastern Bowness (KCB 2021).

Further investigation on groundwater contributions to storm sewers could be carried out as part of future design if necessary.

3 INDIVIDUAL MODEL DEVELOPMENT

The Study Area was defined by the extent of the minor system (storm sewer) network to existing outfalls along and immediately adjacent to the barrier, as well as the major system (overland drainage) components that would be impacted by implementation of the proposed barrier. Additionally, riverine impacts were modelled to evaluate potential backwater impacts on the proposed barrier.

The 3-way coupled model approach (1D urban, 2D overland, 1D river) allows interactions and feedback from one component (e.g., riverine flooding) to be considered by other components (e.g., minor drainage via storm sewers or major drainage via overland flow paths). This allows a fully integrated analysis of both the major and minor systems. The 3-way model was used to identify specific problem areas including, existing flooding, excessive ponding in traplows, or where there is insufficient capacity in the existing storm sewer network to convey stormwater from frequent smaller storms without significant pipe surcharge or surcharge to surface. A 3-way coupled model is the most comprehensive approach to evaluate existing flood risks and assess strategies to effectively mitigate the additional localized flood risks posed by the construction of a flood control barrier in the Bowness neighbourhood.

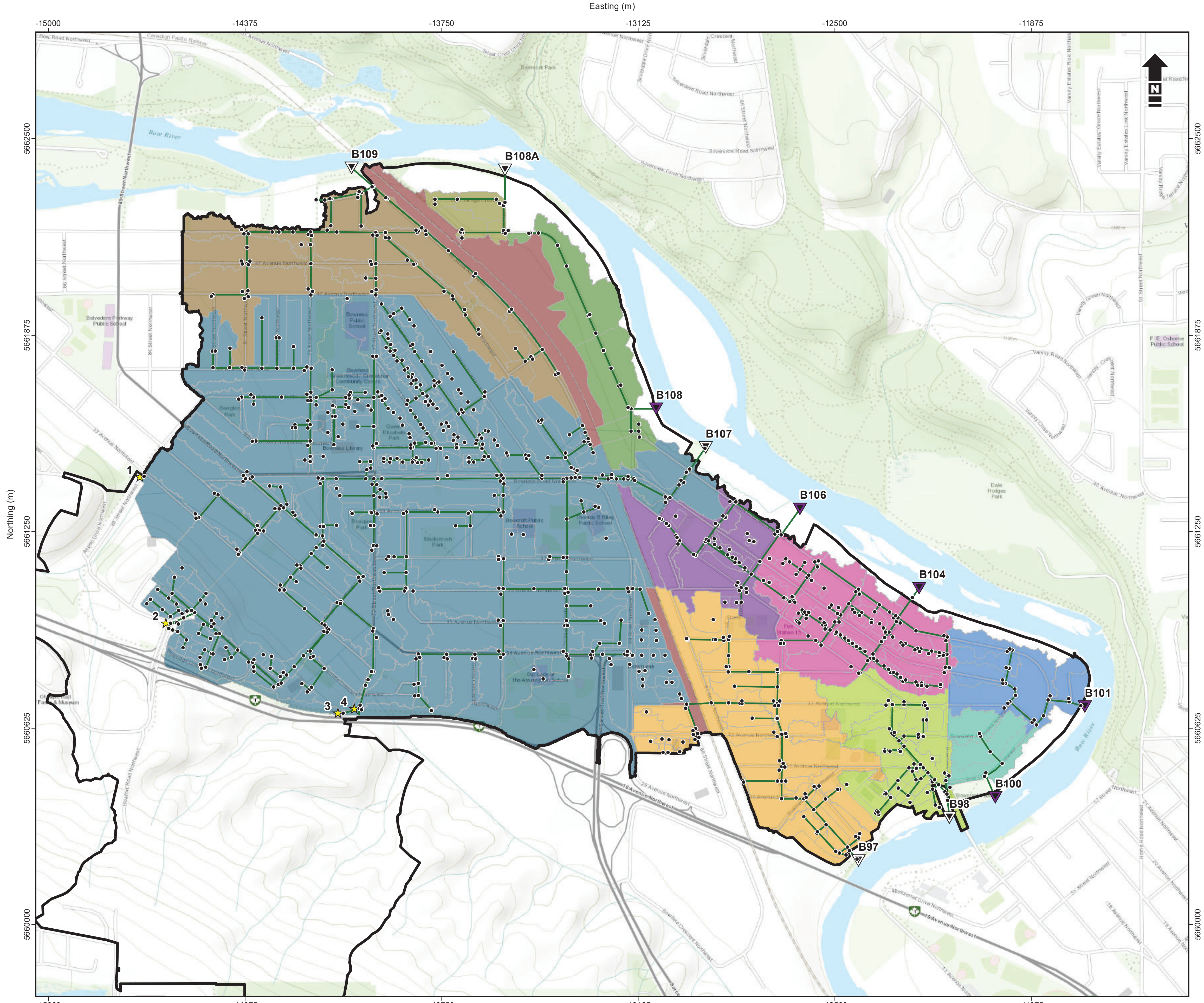
The minor system modelling domain was defined by identifying both storm sewers that drain to outfalls impacted by the proposed barrier alignment, as well as those immediately adjacent to the proposed barrier that could potentially be impacted by the proposed barrier during flood events. The total catchment areas draining directly to these ten modelled outfalls is approximately 321 ha (Figure 4), which represents approximately 66% of the entire 480 ha Study Area. An additional 13 ha is located along the railway corridor and does not drain directly to an outfall but was included in the model to adequately represent surface flooding.

Apart from the railway areas (13 ha), only catchments draining to the minor system (321 ha) are included, for a total area of 334 ha in the MIKE URBAN model. Catchments draining directly to the Bow River are not explicitly modelled since they do not contribute flow to the storm sewers. With a barrier in place, runoff from these areas adjacent to the river would be handled with back-of-lot drainage measures, discussed in Section 2.3.1.

The remaining 30% of the Study Area represents additional upstream external catchment areas and proposed developments south of the Study Area (i.e., the Medicine Hills development Pond A and Pond C south of the Trans-Canada Highway/16 Avenue NW and the Trans-Canada/Bowfort Road Interchange development). The hydrologic model component for the minor system included contribution of flows from these external catchments into these storm sewer systems.

The coupled model also considered adjacent drainage areas that would contribute overland flows carrying-over or spilling from external catchments (i.e., carryover flows from the Trans-Canada Highway/Bowfort Road Interchange area draining north along 83 St NW and east into the B107 outfall catchment).

Figure 4 shows locations of external catchment contributions presented in Section 3.1.1.3.



Study Area
Storm Sewer
Location of External Catchment Contribution
Modelled Storm Manhole/Catchbasin
Outfall
Gated Outfall

Outfall Catchments

B97
B98
B100
B101
B104
B106
B107
B108
B108A
B109
Railroad Area (No outfall)

Catchments delineated through automated and manual methods in an ESRI environment by MSI.

Reference: Data obtained from AltaLIS © Government of Alberta and City of Calgary used under license. Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community.

1:12,500 metres
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Calgary 3TM WGS 1984 W114

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

City of Calgary
Bowness Flood Barrier Project

MIKE URBAN Model Schematic
Pipe Network and Catchments

Date:	Project:	Submitter:	Reviewer:
March 2021	26638	P. Bishop	A. Chan

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Figure 4

I:\CityOfCalgary\26638\FiguresAndTables\FLD\2018\Report\Final_Report\Figure-4-MIKE_URBAN_Model_Schematic_Pipe_Network_and_Catchments.mxd - Tabloid_L - 22-Mar-21, 03:42 PM - sylam - TID005

3.1 Hydrology and Minor System Hydraulics (MIKE URBAN)

Both the hydrology and the minor systems hydraulics components are represented in the MIKE URBAN model. The development of the catchment hydrology and the storm sewer network included the following steps:

- Established design storm rainfall events.
- Delineated urban catchments.
- Determined the extent of the contribution from external catchment areas.
- Assigned appropriate hydrologic parameters for each catchment.
- Compiled sewer network data (CBs, MHs, pipes, and outfalls).
- Connected catchments to sewer network.
- Assigned boundary conditions at outfalls.
- Performed model validation and sensitivity analyses.

A schematic showing the MIKE URBAN pipe network, CBs, and catchments by outfall is provided in Figure 4. The hydrology model component of the MIKE URBAN model is presented in Section 3.1.1 and the minor system hydraulics component is presented in Section 3.1.2.

3.1.1 Hydrology

3.1.1.1 Design Storm Rainfall Events

The minor systems in the Bowness Study Area were likely designed for either the 1:2 year or the 1:5 year design storm events, depending on the design standard at the time of construction. Therefore, the rainfall time series utilized in the MIKE URBAN models included the 1:2 and 1:5 year, 4-hour Chicago distribution design storms.

Rainfall hyetographs were applied to all catchments, based on the 2011 *City of Calgary Stormwater Management & Design Manual* (The City 2011). A 1:50 year, 4-hour Chicago design storm was also simulated for model testing purposes.

The Northwest Inner City Drainage Study – Sunnyside Review report (AE 2016) assessed the joint probabilities of Bow River flood events with extreme rainfall events. AE found that the majority of high intensity rainfall events occurred when the Bow River was experiencing less than a 1:2 year flood (AE 2016).

3.1.1.2 Catchment Delineation

The catchment areas were delineated using the City's LiDAR-based DEM surface and a set of automated GIS-based hydrologic analysis tools to process the data and delineate catchments to each CB or grated top MH. CBs reported in the City's database were mostly reflective of field conditions; however, some

CB locations noted in the GIS database were corrected. Missing CBs identified through aerial imagery, Google Street View, or ground-truthing were added to the City's GIS database.

Where necessary, manual adjustments were made to the catchment boundaries to refine the automated process based on spatial data (parcel boundaries and outfall locations), as well as site-specific knowledge (e.g., site drainage on large commercial properties and private developments with DSSPs available). A review of the topology of the boundaries was conducted to ensure there were no gaps or overlaps between adjacent catchments.

Catchments in areas along the banks of the river and along the CP railway that are not associated with a storm sewer (e.g., lots adjacent to the Bow River directly draining to the river) were also delineated to ensure a comprehensive account of the runoff within the Study Area.

3.1.1.3 External Catchment Contributions

The model domain included additional areas south of the Bowness community that drain into the Study Area outfall systems (Figure 2). These areas had been previously modelled in PCSWMM and included the Medicine Hills development Pond A and Pond C south of the Trans-Canada Highway (16 Avenue NW; Urban Systems Ltd. 2017b, Urban Systems Ltd. 2017c) and the Trans-Canada Highway/Bowfort Road Interchange development; Stantec 2015a, 2015b). Updates to the PCSWMM models were required to ensure consistency and cohesion with the remainder of the Study Area model. This included overlapping catchments, missing contributing areas (i.e., drainage from commercial private development sites from the Bowfort Road area) that were not incorporated in the Trans-Canada Highway/Bowfort PCSWMM model (Stantec 2015a), or where the modelling was not reflective of the as-built drawings and/or recent Google Streetview imagery (e.g., CBs along Bowfort Road and 83 Street NW that differed from what was in the model). The PCSWMM models were then used to generate flows to represent contributions from external catchments.

Inflow hydrographs to the Bowness MIKE URBAN model were included at the following locations (Figure 4):

- Overland flows resulting from carryover flows north along 83 Street NW (flows from the east curb) into the Outfall B107 catchment at 33 Avenue N (location 1 on Figure 4).

- Minor system flows from Bowfort Road commercial areas to MH at Bowfort Road south of Bowridge Drive (location 2 on Figure 4).

- Minor system flows from the Trans-Canada Highway east to MH at south of the end of 77 Street NW (location 3 on Figure 4).

- Minor system flows from the Medicine Hills Ponds A and C to the upstream end of the 77 Street NW storm sewer (80 m southwest of the intersection of 77 Street NW and Bowcliffe Crescent NW) (location 4 on Figure 4).

3.1.1.4 Catchment Hydrologic Parameters

Each catchment was assigned hydrologic attributes including catchment length, catchment slope, percent pervious area, percent impervious area, and roughness (Manning's n).

For large catchments (> 4 ha), the catchment length and slope parameters were calculated from manually-located flow paths within these catchments. For the remaining smaller catchments, lengths were approximated by dividing catchment area by catchment perimeter. The mean slopes for the smaller catchments were calculated from the DEM.

The catchments were each subdivided into pervious and impervious land use types consistent with MIKE URBAN modelling practice as follows:

- Pervious areas were split into three categories based on the land use classification: woodlot areas, other natural/floodplain areas, and pervious urban areas (i.e., lawns, parks, etc.).

- Impervious areas were classified as either steep (small buildings/residential roofs) or flat (other highly urban areas such as large buildings, parking lots, roads, etc.). Impervious areas were taken from the City's impervious GIS shapefile developed using 2016 data.

A schematic showing the MIKE URBAN perviousness classifications according to land use is provided in Figure 5. This perviousness classification is only shown for catchments that drain directly to the minor system, as in Figure 4. Drainage from areas that currently drain to the Bow River, but would be behind the barrier under proposed conditions, would be mitigated with back-of-lot drainage (see Section 2.3.1).

Manning's n roughness values for the urban catchments were assigned based on land use types grouped by categories defined by Table 3-5 from the SWMM 5 Hydrology Manual (U.S. EPA 2016). These values are summarized in Table 1.

Wetting loss and storage loss values were based on the depression storage losses indicated in the City's *Stormwater Management & Design Manual* (The City 2011).

Horton's Method was used for infiltration and applied based on the City's recommended values: initial infiltration capacity, f_o = 75 mm/hour and final infiltration capacity, f_c = 7.5 mm/hour with a decay rate (k) of 4.14 hour^{-1} (The City 2011).

A summary of the subcatchment hydrology parameters is provided in Table 2, grouped by outfall.

TABLE 1 Urban Catchment Pervious and Impervious, Land Use Type, and Manning's n

Pervious Type	MIKE URBAN Category	Land Use Type	Overland Flow Manning's n
Pervious (Perv.)	Low	Low perviousness areas such as residential lawns and parks	0.050
	Medium	Medium perviousness areas such as natural areas, floodplain	0.075
	High	High perviousness areas such as wood lots	0.090
Impervious (Imp.)	Steep	Residential rooftop areas	0.013
	Flat	Roads, driveways, commercial building rooftop areas	0.017

TABLE 2 Summary of Hydrology Parameters by Outfall

Outfall Catchment	Total # of Subcatchments Modelled	Total Contributing Area (ha)	Average % Imp. (%)	Imp. Steep (ha)	Imp. Flat (ha)	Perv. High (ha)	Perv. Medium (ha)	Perv. Low (ha)
B97	47	30.42	46	1.06	5.60	6.50	0.08	0.00
B98	39	13.23	50	0.38	0.71	2.28	6.29	2.94
B100	4	4.95	47	0.92	1.41	2.61	0.00	0.00
B101	11	9.55	45	1.73	2.58	5.05	0.00	0.20
B104	67	19.99	61	3.34	8.77	7.70	0.00	0.17
B106	25	13.02	55	1.81	5.35	4.82	1.04	0.00
B107	299	182.87	50	26.83	63.88	80.92	5.20	6.05
B108	14	11.88	36	1.55	2.71	6.49	0.44	0.69
B108A	8	3.07	48	0.43	1.05	1.54	0.01	0.04
B109	43	32.18	50	6.54	9.66	15.81	0.11	0.06
Railway Area(1)	4	12.61	9	0.38	0.71	2.28	6.29	2.94

(1): These catchments do not drain to an outfall but are included for completeness.

3.1.1.5 Preliminary Simulations

The MIKE URBAN model was run in standalone format for the following storm events: 1:2, 1:5, and 1:50 year, 4-hour Chicago distribution design storms. The purpose of the preliminary simulations was not to quantify results but rather to ensure that the model was performing as expected before coupling with the remaining components.

The following tasks were completed to validate the MIKE URBAN model:

- Confirmed the ratio of rainfall to runoff was in line with expectations for the Study Area.
- Reviewed flow exchange through the CB lead orifices to ensure an appropriate amount of runoff was entering the storm sewer system.
- Compared areas of storm sewer surcharge against anecdotal evidence (3-1-1 calls; Figure 3).
- Ensured that no model errors or unexpected warnings were reported with the simulations.

The outcome of this preliminary simulation indicated satisfactory model function for the simulated events.

Easting (m)

-15000 -14375 -13750 -13125 -12500 -11875

Northing (m)

5662500 5661875 5661250 5660625 5660000

B109 B108A B108 B107 B106 B104 B101 B100 B98 B97

N

Study Area
Catchbasin Catchment Boundary
Outfall
Gated Outfall

Perviousness Classification

Impervious Flat
Impervious Steep
Pervious High
Pervious Medium
Pervious Low

Catchments delineated through automated and manual methods in an ESRI environment by MSI.

Reference: Data obtained from AltaLIS © Government of Alberta and City of Calgary used under license.Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community.

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Calgary 3TM WGS 1984 W114

Matrix Solutions Inc.
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City of Calgary
Bowness Flood Barrier Project

MIKE URBAN Model
Schematic Perviousness Classification

Date:	Project:	Submitter:	Reviewer:
March 2021	26638	P. Bishop	A. Chan

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Figure 5

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3.1.2 Minor System Hydraulics

The minor system hydraulics included a detailed review of the infrastructure data and associated analysis including:

- storm sewers;
- storm sewer outfalls;
- MHs and CBs; and
- CB interception.

A schematic showing the MIKE URBAN outfalls, pipe network, and CBs/MHs is provided in Figure 4.

3.1.2.1 Storm Sewer Outfalls

The minor system pipes connected to the modelled ten outfalls (Figure 4) drain a total catchment area of approximately 321 ha. Table 3 lists the contributing areas and modelled storm sewer statistics for each outfall.

Five of the outfalls (B100, B101, B104, B106, and B108) are equipped with flood gates which are intended to be closed during river flood events to prevent the Bow River from backing up into the storm sewer system (Figure 4). These flood gates, when closed, were simulated in MIKE URBAN as sealed manholes without outfall characteristics.

3.1.2.2 Storm Sewers

Storm sewer GIS database information provided by the City included pipe location, shape, size, length, material, and the upstream and downstream nodes. The Manning's n roughness applied to each pipe was based on the identified material from the 2011 City of Calgary *Stormwater Management & Design Manual* (The City 2011) for concrete (n =0.013) and PVC (n =0.011).

Quality checks of the GIS pipe network during the development of the model identified several corrections were required (i.e., significant adverse pipe slopes, inverts that do not correspond to other inverts in the MH, other missing elevation or diameter data, etc.). Where data was missing or profiles showed clear errors in the data, Matrix assigned invert elevations based on City of Calgary design standards.

Private development storm sewers within the Study Area were not included in the City's GIS shapefiles; however, these systems play an important role in the overall drainage patterns of the area. In these cases, Matrix manually added pipes and MHs to the model using data provided in DSSPs provided by the City (approximately 70 private development DSSPs were reviewed within the Study Area). Note that not all the private sites (over 250) within the Study Area had DSSPs/Mechanical Site Plans available.

TABLE 3 Existing Outfalls and Modelled Storm Sewer Statistics

Outfall ID	Storm Trunk	Outfall Pipe Diameter (mm)	Material	Flood Gate? (Y = Yes, N = No)	Outfall Invert (m)	Total # of Modelled MHs	Total # of Modelled CBs	Total Length of Modelled Storm Sewers (m)	Average Depth of Cover (m)
B97	63 St NW	750	Concrete	N	1,062.95	40	39	2,363	1.84
B98	Bowwood Dr NW	675	Concrete	N	1,060.95	30	32	1,340	1.60
B100	Bow Cr Park	525	Concrete	Y	1,060.99	4	4	255	1.25
B101	Bowbank Cr NW	675	Concrete	Y(1)	1,061.54	11	13	511	1.28
B104	61 St NW	750	Concrete	Y	1,062.59	55	65	2,546	1.57
B106	64 St NW	600	Concrete	Y	1,063.89	20	31	1,243	1.97
B107	Bowness Rd NW	2400 × 1800	Concrete	N(2)	1,063.10	229	295	15,675	1.97
B108	Bow Cr NW	900	Concrete	Y	1,064.55	9	5	841	1.53
B108A	Bow Village Cr NW	450	Concrete	N	1,066.14	7	7	555	2.21
B109	48 Ave NW	1050	Concrete	N	1,067.73	36	46	3,018	2.00

Notes
MHs = Manholes
CBs = Catchbasins
(1) Flood gate is located in upstream manhole.
(2) Concrete box duct

3.1.2.3 Manholes and Catchbasins

MH and CB locations were imported to MIKE URBAN from the shapefiles provided by the City. As mentioned, some CB locations identified in the City's GIS shapefiles were corrected and misplaced/missing CBs were also added.

MH rim and CB grate elevations were modelled based on the ground surface elevation correlating with the LiDAR-based DEM at each location. Assumed MH invert elevations were based on the lowest connecting pipe invert elevation at each MH. CB outlet pipe inverts were calculated based on grate elevations and assumed a CB barrel depth of 1.2 m.

Generally, MHs were assumed to be 1.2 m in diameter, except where the diameter of a connecting pipe was larger than 1200 mm. In these cases, the diameter of the MH was assumed to be equivalent to the diameter of the largest downstream pipe.

Energy losses at MHs were determined in MIKE URBAN using the F.A. Engelund's energy loss formulation (DHI 2017b).

3.1.2.4 Catchbasin Interception

Interception of stormwater at CBs is controlled either by the amount of static (ponding) head over a CB grate (e.g., CBs in a traplow) or by the amount of kinetic energy of flowing water and depth of flow for CBs installed on a continuous grade (flow-by). In the case of CBs located in traplows, the rate of runoff intercepted into CBs is a function of the depth of ponding in the traplow. If the approach flow rate is greater than the intercepted flow rate into the CB (i.e., inflows exceed outflows), then water will pond on the surface in the traplow. When the traplow storage capacity is exceeded, runoff will spill out of the traplow and flow overland downstream. In the case of flow-by CBs, a portion of the approach flows will be intercepted into CBs and the remainder will bypass and continue to flow downstream.

Relationships of intercepted flow were developed based on CB capture curves and vary at each location depending on the number of CBs, CB types, CB grates, and if an inlet control device was used. Flows in excess of this capture relationship will either pond over the CB or bypass the CB and continue downstream to the next closest CB.

Representative capture curves for flow-by CBs were taken from the *Stormwater Management & Design Manual* (The City 2011) and from previous studies (i.e., Type C, K, K2, K3, Twin C, Twin K, and Twin K3 grates). Figure 6 shows the capture curves for the various types of flow-by CBs present in the Study Area. The interception curve for "Old Style" CBs were assumed to be similar to the Type K CB interception curve.

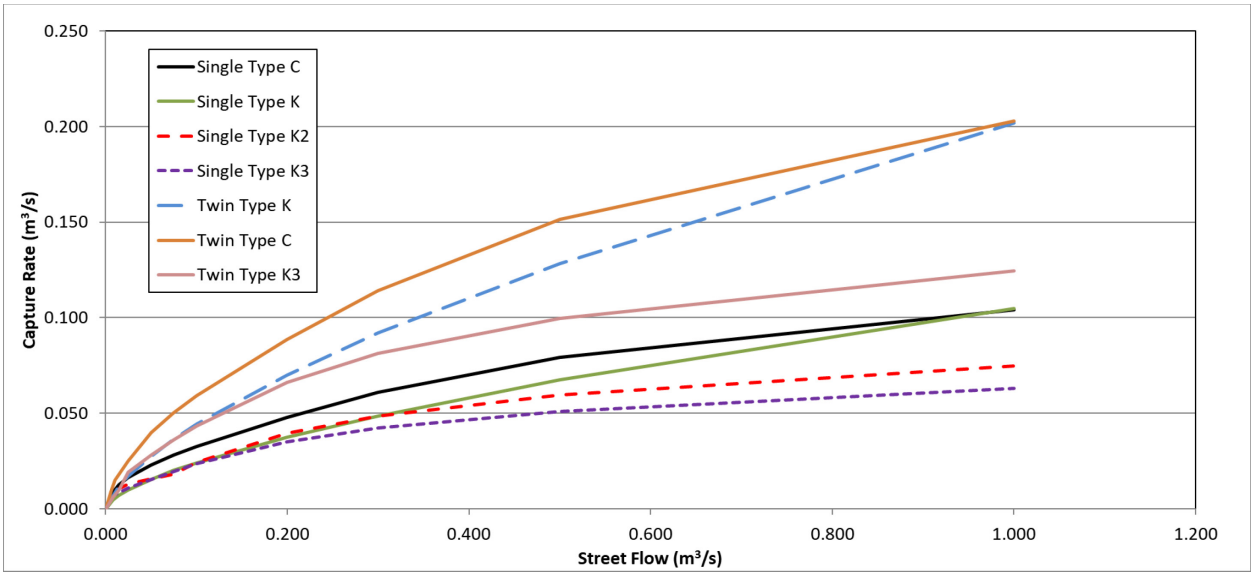


FIGURE 6 Interception Curves for Catchbasins in Flow-by Conditions

This relationship between the depth of ponding in the traplow and the captured flow can be expressed as a combination of the weir equation for low depths of ponding and the orifice equation for larger depths of ponding, while accounting for the hydraulics of the CB barrel and the lead to the storm sewer. Types of CB grates under ponding include those identified as flow-by CBs as well as grated top MHs and TF-E grates (used only in private development sites). Figure 7 shows the interception at CBs under ponding conditions for the various types of CBs present in the Study Area. Interception curves for CBs in private development sites and lanes were assumed to be partially clogged with an assumed 50% reduction in interception.

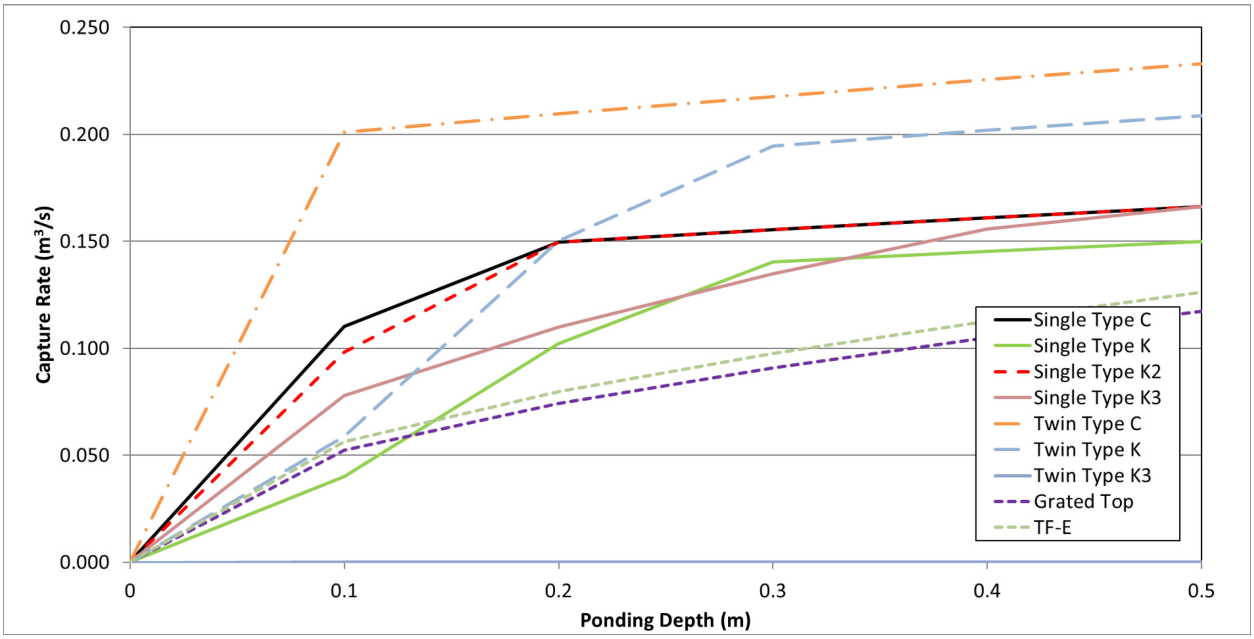


FIGURE 7 Interception Curves for Catchbasins in Ponding Conditions

The City's GIS shapefiles noted three ICDs in City CBs within the Study Area including two ICD R100s and one ICD R50. In addition, one ICD R30 was identified from a DSSP for a private development. Figure 8 shows the interception relationships for the various ICD types used in Calgary (The City 2011).

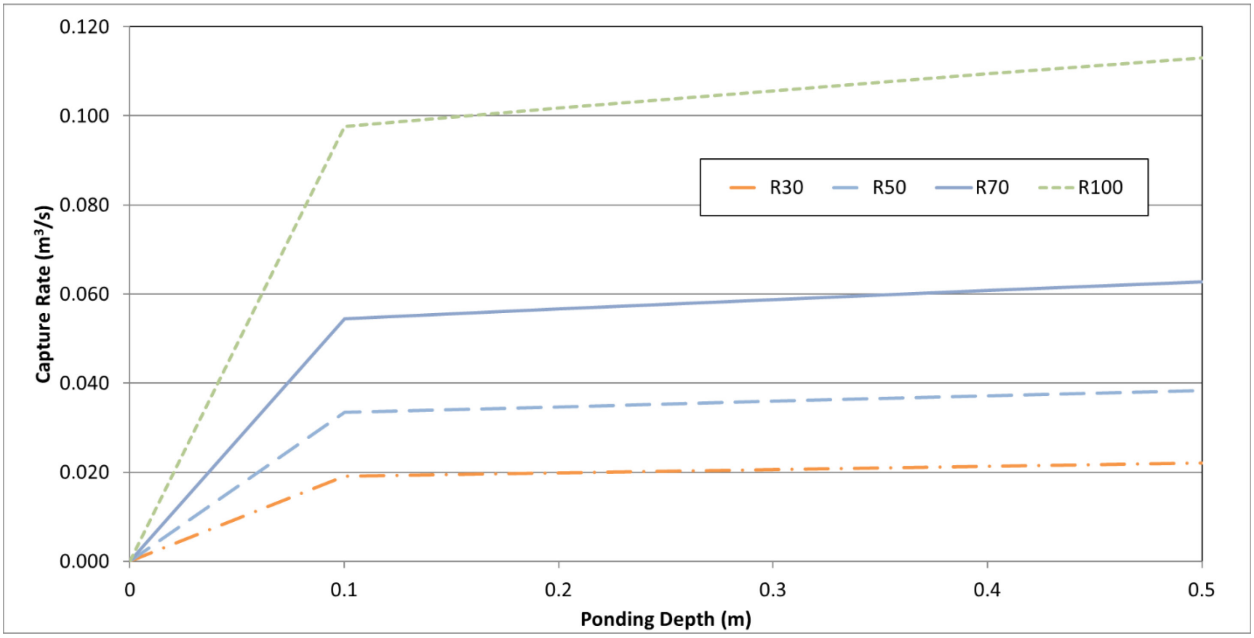


FIGURE 8 Interception Curves for Inlet Control Devices

3.2 Riverine Hydraulics (MIKE HYDRO)

MIKE HYDRO is a dedicated river modelling system that simulates fully-hydrodynamic 1D flow in an open channel and through structures. The full model extents are shown in Figure 9A, and a close-up of the model within the Bowness neighbourhood is shown in Figure 9B.

The development of the 1D MIKE HYDRO riverine model included the following steps:

- Defined channel geometry (centreline, cross-sections).
- Inserted hydraulic structures (i.e., bridge structures).
- Defined channel roughness (Manning's n).
- Assigned boundary conditions.
- Conducted model validation.

A schematic of the MIKE HYDRO riverine model set-up is provided in Figure 9A and Figure 9B, including the river centreline, cross-sections, flow input locations, and boundary conditions.

The Bow and Elbow River 1D HEC-RAS hydraulic model, updated by Golder Associates Ltd. (Golder) in 2014, was provided to Matrix to inform the current study. This HEC-RAS model extends outside of the current study boundary (both upstream and downstream) and includes the Elbow River to the south of the Study Area. The 2014 HEC-RAS model was used to extract the watercourse centreline, cross-section

locations, and structure data for seven crossings of the Bow River. Details of the riverine model input data are provided in the subsections below.

The Project required a new MIKE HYDRO model of the Bow River because the MIKE URBAN software, used to assess the minor system, is part of the MIKE FLOOD set of software and can only be paired with the MIKE HYDRO and MIKE 21 modelling software (see Section 1.2). The MIKE URBAN software is not designed to be coupled directly with HEC-RAS models. Although the existing 1D HEC-RAS (Golder 2014) and 2018 2D HEC-RAS model (KCB 2018) were used to inform the MIKE HYDRO model, they were not used directly.

Another approach to coupling the minor system model to a riverine model is to assign water level boundary conditions at the MIKE URBAN outfalls, using 1D HEC-RAS (Golder 2014) or 2D HEC-RAS (KCB 2018) results. While this does not directly link the models, the boundary conditions would represent the impacts of the river on the pipe network. However, this approach was not used because it would not represent the overland riverine flooding present in existing conditions. To represent this overland riverine flooding, the MIKE HYDRO model must be coupled with the MIKE 21 software, the third component of the MIKE FLOOD software (see Section 3.3).

The three components of MIKE FLOOD (MIKE URBAN, MIKE HYDRO, and MIKE 21) work together to simulate the complex interactions of the minor system, the river, and overland flow, as described in Section 1.2.

3.2.1 Bow River Flows and Boundary Conditions

Boundary conditions are required at the upstream and downstream ends of a river branch of the MIKE HYDRO model. Boundary conditions for the riverine model include inflows at the upstream end and water levels at the downstream model boundary. The modelled river branch extends beyond the Study Area to ensure boundary conditions do not influence flow conditions within the Area of Interest. The 1:5, 1:20, and 1:50 year return period flow rates and water levels from the HEC-RAS model (Golder 2014) were applied as boundary conditions to the MIKE HYDRO model as specified in Table 4. The 1:50 year event was used only for model validation. The river levels evaluated represent a 1:20 year naturalized flow event, however, this is equivalent to a 1:200 year flood event for this area due to anticipated upstream improvements. Further details about upstream improvements and rainfall events are provided in the hydrotechnical assessment report completed by KCB (2020b).

TABLE 4 Flows and Water Level Boundary Conditions

Return Period	Naturalized Peak Flow[(1)] (m^3/s)	Water Level[(2)] (m)
1:5 year	659	1,059.0
1:20 year	1,230	1,060.1
1:50 year	1,660	1,060.8

Notes:
[(1)] Peak flows extracted from HEC-RAS River Station 69342.17, the upstream extent of the MIKE HYDRO model
[(2)] Water levels extracted from HEC-RAS River Station 57756.08, the downstream extent of the MIKE HYDRO model

Easting (m)

270250 271400 272550 273700 274850 276000 277150 278300

Northing (m)

5666050 5664900 5663750 5662600

24.66 232.01 477.85 667.35 900.20 1094.49 1439.49 1869.15 2179.59 2504.33 2981.83 3217.57 3439.24 3571.64 3767.35 3865.13 4014.95 4235.10 4435.91 4598.77 4786.70 4951.72 5158.20 5351.52

Bowness Rail Bridge (CP Rail)

Shouldice Bridge

10309.89 10470.93 10630.76 10912.54 10999.69 11171.34 11366.81 11610.75

N

Study Area
Cross-section
River Centerline
1D Riverine Model Boundary Condition Location

1:23,000 metres
250 0 250 500
NAD 1983 UTM Zone 12N

Reference: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

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City of Calgary
Bowness Flood Barrier Project

MIKE HYDRO Model Schematic

Date:	Project:	Submitter:	Reviewer:
March 2021	26638	P. Bishop	A. Chan

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Figure 9A

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Easting (m)

Northing (m)

-14500 -14000 -13500 -13000

276500 277000 277500 278000 278500

5663000 5662500 5662000 5661500 5661000

5665000 5664500 5664000 5663500

Bowness Rail Bridge (CP Rail)

Shouldice Bridge

5158.20 5245.21 5351.52 5537.15 5672.47 5804.35 6017.58 6164.32 6332.10 6513.44 6600.00 6700.00 6800.00 6900.00 7000.45 7101.87 7205.18 7305.76 7409.59 7508.84 7605.11 7708.33 7808.13 7902.73 8000.00 8104.36 8198.72 8300.00 8400.00 8501.91 8600.00 8700.00 8800.00 8884.43 9001.76 9200.00 9303.03 9405.31 9500.00 9600.00 9700.00 9812.09 9899.78 10007.73 10063.36 10123.90 10213.68 10309.89

Study Area
Cross-section
River Centerline
1D Riverine Model Boundary Condition Location

Reference: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

1:11,000 metres

125 0 125 250

Calgary 3TM WGS 1984 W114

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Bowness Flood Barrier Project

MIKE HYDRO Model Schematic

Date:	Project:	Submitter:	Reviewer:
March 2021	26638	P. Bishop	A. Chan

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Figure 9B

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3.2.2 Channel Geometry

The channel geometry was prepared using available HEC-RAS data, the LiDAR-based DEM, and channel bathymetry as described in the following sections.

3.2.2.1 River Centreline

The river centreline was imported from HEC-RAS (Golder 2014) to the MIKE HYDRO model to generate the river reach. The HEC-RAS model covered a much larger extent than the current Study Area, and therefore the reach was trimmed to the desired extents (Figure 9A and Figure 9B). The MIKE HYDRO model covers a distance of 11.6 km and extends from Bearspaw Dam (HEC-RAS station 69342.17) southeasterly to Shouldice Park (HEC-RAS station 57756.08). The extent of the model is far enough beyond the current Study Area to ensure boundary conditions will not impact flood results in the Area of Interest.

3.2.2.2 Cross-Sections

Terrain from the 2018 LiDAR data was merged with the 2014 bathymetry provided by KCB. Channel cross-sections were cut for the MIKE HYDRO model using the resultant combined DEM at locations that matched the 2014 HEC-RAS model cross-section locations. Cross-sections upstream of the current Study Area were copied directly from the 2014 HEC-RAS model as they were outside the extent of the provided 2018 LiDAR and 2014 bathymetry. The cross-sections spacing ranges from 18.5 m to 477.7 m with finer spacing occurring through the portion of the Study Area where the MIKE HYDRO model will be coupled to the MIKE 21 model. These tightly-spaced cross-sections are also cut from the combined surface. The fine spacing is required to ensure stability between the coupled components. Coarser spacing more typical of 1D modelling was used outside the coupled model extents.

3.2.3 Hydraulic Structures

There are seven bridges within the Study Area that were added to the MIKE HYDRO model as presented in Table 5. The bridge geometry and calculation method were obtained from the existing HEC-RAS model.

At each crossing location, internal bridge cross-sections were applied, which were extracted from the HEC-RAS model. Use of internal bridge cross-sections allows for defining variations in channel geometry and roughness through the structure.

TABLE 5 Bridge Structure Name and Model Location

Bridge ID	HEC-RAS Station (m)	MIKE HYDRO Chainage (m)[(1)]
Stoney Trail Pedestrian Bridge	65,773.31	3,593.52
85 St SW Bridge (Keith Sanatorium Bridge)	64,206.53	5,154.70
Bowmont Pedestrian Bridge	63,564.71	5,797.00
CP Rail Twin Bridge and Side Channel Bridge	63,474.34	5,884.40
Hextall Bridge	59,603.64	9,758.20
Shouldice Bridge	59,582.63	9,780.00
16 Ave (Trans-Canada Hwy) Bridge	59,181.80	10,174.30

Note: [(1)] MIKE HYDRO chainages differ from HEC-RAS stations due to different model extents.

3.2.4 Channel Roughness

The Manning's n roughness distribution from the 2014 HEC-RAS model was reviewed in consideration for MIKE HYDRO roughness input. The roughness distribution in HEC-RAS had several divisions across each cross-section that, upon review of aerial imagery and LiDAR data, did not appear consistent or representative of existing surfaces.

KCB subsequently provided a roughness surface for the channel from their 2D HEC-RAS model (KCB 2018) being developed for this study. These roughness values were calibrated by KCB to measured high water marks during the 2013 flood and therefore were considered suitable for use in the MIKE HYDRO model. Typical values used for modelling purposes are presented in Table 6. In areas where data was unavailable, Manning's n values from the 2014 HEC-RAS model were applied (Chainage 24.66 to 5187.62).

TABLE 6 Channel Manning's n Roughness Values

Land Use	Description	Manning's n Roughness
Watercourse/Channel	• Low flow channel • Extends typically from bank to bank	0.035
Floodplain – Urban Uses (Pervious)	• Municipal parks, playing fields, etc. • Typically located within valley and stream corridors • Assumes regular maintenance	0.040
Floodplain – Natural Areas	• Pasture, meadow, riparian vegetation, brush, and forest • Located within urban and/or rural land use setting • Not subject to regular maintenance • Assumes regeneration of open space type uses including pasture, meadow, and agricultural within floodplain areas	0.070 to 0.100
Undefined Areas	• No data available	As listed in previous HEC-RAS model (Golder 2014)

3.2.5 Preliminary Simulations

The MIKE HYDRO model was also run in standalone format for the 1:5, 1:20, and 1:50 year events. As with the urban model component, the purpose of this was not to quantify results but rather to ensure that the model was performing as expected before coupling with the remaining components. While the 1:5 and 1:20 year events were later used in the assessment of the existing and proposed conditions (Sections 6 and 8), the 1:50 year event was used only for validation purposes of the existing conditions model. The following tasks were completed to validate the MIKE HYDRO model:

- Confirmed that the riverine model was run long enough to reach steady state during the simulations.
- Compared computed water surface elevations against 2014 HEC-RAS model to ensure agreement.
- Ensured that no errors or unanticipated model warnings were reported with the simulations.

The outcome of this preliminary simulation indicated that the MIKE HYDRO model produced satisfactory model results for the modelled events.

3.3 Overland Flow Hydraulic Routing (MIKE 21)

The development of the 2D overland model was completed in MIKE 21 and included:

- preparing topographic surface map (including obstructions and river block);
- creating 2D surface roughness map (Manning's n); and
- assigning boundary conditions.

Figure 10 shows the extent of the 2D domain used in the MIKE 21 model. To ensure the boundary condition assumptions would not impact the results within the Study Area, the 2D domain was set sufficiently larger than the Area of Interest.

3.3.1 Topography

The 2D surface topography was prepared from a DEM which combined the 2018 LiDAR and 2014 bathymetry provided by KCB, as discussed in Section 3.2.2.2. The MIKE 21 surface model was prepared as a rigid grid consisting of square grid cells across the entire 2D domain. For this study, a rigid grid model with a 2 × 2 m cell size is appropriate to sufficiently capture hydraulic controls for overland flow such as roadways and major overland flow routes. The 2D model domain was generated by resampling the DEM to a 2 m cell size.

3.3.1.1 Obstructions

The 2D surface incorporates building footprints as blocked obstructions to ensure water cannot flow through the buildings. The building footprints used to create the blocked obstructions within the 2D domain were based on shapefiles provided by the City.

3.3.1.2 River Block Removal

To couple the MIKE HYDRO and MIKE 21 models, the area occupied by the main channel was removed from the 2D portion of the model to avoid double counting channel flow in both the 1D and 2D models. Therefore, the area in the 2D surface bounded between the left and right banks of each cross-section was also treated as a blocked obstruction in MIKE 21.

Easting (m)

-14375 -13750 -13125 -12500 -11875

Northing (m)

5662500 5661875 5661250 5660625

N

Study Area

Urban Footprint (Roads, Buildings, Parking Lots)

Ground Elevation (m)

High : 1160

Low : 1060

Reference: Data obtained from AltaLIS © Government of Alberta and City of Calgary used under license. LiDAR acquired through the City of Calgary used under license. Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community.

1:11,500

metres

125 0 125 250

Calgary 3TM WGS 1984 W114

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City of Calgary
Bowness Flood Barrier Project

MIKE 21 Model Schematic

Date:	Project:	Submitter:	Reviewer:
March 2021	26638	P. Bishop	A. Chan

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Figure 10

I:\City Of Calgary\26638\Figures And Tables\FLD\2018 Report\Final_Report\Figure-10-MIKE_21_Model_Schematic.mxd - Tab:bd_L - 22-Mar-21, 03:47 PM - sylam - TID005

3.3.2 Surface Roughness

A spatially distributed map of Manning's n roughness values was created to reflect the different surface materials and vegetation throughout the 2D model domain. The Manning's n roughness map was developed based on data provided by KCB for areas that overlap with the 2D HEC-RAS model, and the City's land use data (Table 7) for areas outside KCB's model domain. The Manning's n roughness file has the same cell size and dimension as the 2D surface topography file.

TABLE 7 Manning's n Roughness Values

Land Type	Manning's n
Bare land	0.04
Floodplain	0.05
Neighbourhood Block	0.049
Paved Surface	0.016
River Island	0.07
Roads	0.014
Vegetated (Medium, High)	0.08
Vegetated (Low)	0.06
Water (including Pond, River)	0.03

3.3.3 Boundary Conditions

The boundary conditions for the 2D model were assigned based on site conditions. The available options for assigning boundary condition options include either open or closed boundaries, wherein flow will be permitted to exit the system or be blocked, respectively. Since the inflows to the system and outflows from the system will be handled in the MIKE HYDRO model, all 2D model boundaries were closed, meaning no flow was permitted to exit the 2D domain via overland routes. Since the 2D domain was set sufficiently larger than the Study Area, this approach ensures there are no edge effects impacting the Area of Interest.

4 MIKE FLOOD COUPLED MODEL

The 3-way coupled model (MIKE FLOOD model) was developed to establish an understanding of existing flood risk and levels of service in the Study Area (existing conditions model) and compare with the flood risk and LOS under ultimate conditions with the proposed barrier and stormwater mitigation measures in place (proposed conditions model).

Once the MIKE URBAN, MIKE HYDRO, and MIKE 21 model components were developed, the 3-way coupling was completed in MIKE FLOOD, in which the following tasks were performed:

- Coupled the MIKE URBAN (1D urban) and MIKE 21 (2D overland) models.
- Coupled the MIKE HYDRO (1D riverine) and MIKE 21 (2D overland) models.
- Coupled the MIKE URBAN (1D urban) and MIKE HYDRO (1D riverine) models.

- Conducted a sensitivity analysis of the 3-way model.
- Performed model validation.

4.1 MIKE URBAN to MIKE 21 Coupling

CBs and MHs in the MIKE URBAN model were coupled to the 2D overland model such that inflow and surcharge to and from the nodes can be dynamically exchanged between the two components. This allows for surcharged sewers to discharge onto the 2D overland flow model where it may either pool on the surface or flow in the direction of the topography. It also allows for flooding on the 2D surface to re-enter the 1D urban model via these nodes when capacity permits in the minor system.

The CBs and MHs were coupled to the 2D model grid cell coinciding with the location of the CB or MH of interest. The rate of flow exchange between CB and MH inflow and surcharge is detailed in the following sections.

4.1.1 Catchbasin Inflow

Each CB in the 1D urban model (including the combined CB and MHs) was coupled to the 2D overland flow model using a curb inlet coupling method. The curb inlet method uses a depth versus flow relationship to control the rate at which water on the 2D surface can enter the CB. CB inflow is described in greater detail in Section 3.1.2.4.

4.1.2 Catchbasin Surcharge

The outflow (surcharge) from the CBs was estimated using an orifice equation to calculate the rate at which water from the CB will surcharge onto the 2D overland flow model. The orifice settings for the CBs were determined using the CB opening dimensions and an orifice discharge coefficient of 0.3 which assumes low efficiency caused by drag from many small openings. The maximum flow parameter was set equal to the maximum CB inflow based on the depth versus flow curve for the grate type.

4.2 MIKE HYDRO to MIKE 21 Coupling

The MIKE HYDRO model was coupled to the MIKE 21 model using the lateral weir coupling option. Using this option, the flow exchange was calculated using a standard weir equation based on the higher elevation of either the 1D or 2D model at that location. Lateral links were established on the right bank of the Bow River to allow flow exchange to occur with the Study Area. The left side of the river is outside the Study Area and therefore was not included in the 2D domain.

In the proposed conditions model, the MIKE 21 model was not coupled to the MIKE HYDRO model because the flood barrier is at higher elevations than the 1:20 year Bow River flood water levels. Regardless, there are portions of the Study Area that were still subjected to riverine flooding (e.g., on the river-side of the barrier and northwest of the B108A outfall); the flood depth and risk maps for each mitigation option

(Section 8.2) show this additional riverine risk. If a subsequent analysis is required for a larger riverine storm event, the MIKE HYDRO to MIKE 21 coupling would need to be updated.

4.3 MIKE URBAN to MIKE HYDRO Coupling

In the existing conditions models, the outfalls from the MIKE URBAN model (i.e., stormwater outfalls) were connected to the MIKE HYDRO riverine network to allow for a two-way exchange of water between the urban and riverine systems. All outfalls from MIKE URBAN were connected to the 1D riverine model at the chainage of the river cross-section located nearest to the outfall. The calculated water levels from MIKE URBAN and MIKE HYDRO were compared and the difference was used to determine the direction of flow exchange; water flows from the urban system to the river under normal drainage conditions and flows from the river into the urban system under backwater conditions. As a result, the MIKE HYDRO model becomes the downstream boundary condition for MIKE URBAN outfalls.

In the proposed conditions model, the MIKE URBAN model was not coupled directly to the river. Instead, the river water levels were assigned as boundary conditions on all open outfalls. This equivalent set-up allowed for more efficient modelling of alternatives.

4.4 Model Validation

The MIKE URBAN model was validated with typical best-practice standards because storm sewer flow monitoring data was not available. Under 1:2 year and 1:5 year, 4-hour design storms, the storm sewer hydraulic grade lines (HGLs) were assessed relative to pipe capacity. The larger 1:50 year, 4-hour design storm was modelled to ensure model stability in larger events. Significant storm sewer surcharge to surface was observed in the 1:50 year, 4-hour design storm event, as expected.

The MIKE HYDRO model results of the Bow River water levels were compared with the model results from the 2D HEC-RAS conducted by KCB (KCB 2018). Differences in water levels were seen and expected between the 2D model results (2D HEC-RAS) and the 1D model (1D MIKE HYDRO). The key reason for these differences was the super-elevation of the river water levels around curves in the river (water levels on the inside bend lower than outside bend) that is represented in the 2D modelling. For the 1:20 year Bow River flows, the 2D HEC-RAS water level results were on average 0.11 m higher than the 1D MIKE HYDRO model water levels at all of the outfalls within the Study Area. The water levels at the outfalls located on the outside bends were predictably higher in the 2D HEC-RAS model results. For outfalls on the outside bend (B108, B107, B106, B104, and B98), the 2D HEC-RAS water level results were between 0.12 to 0.35 m higher than the 1D MIKE HYDRO model water levels. Conversely, the water levels at the outfalls located on the inside bends (B109, B108A, B101, and B100) were predictably lower (between 0.08 to 0.16 m lower) in the 2D HEC-RAS model results than the 1D MIKE HYDRO model results. These differences were deemed acceptable, and reflective of the differences between a 1D and 2D model and the difference between their model engines. Other differences can be also be attributed to the gridded versus channel cross-section representation of the Bow River bathymetry. Note that the correlation between the MIKE

HYDRO model and the 2D HEC-RAS model does not confirm the correctness of either model. Instead, the correlation in results ensures that differences in surface flooding cannot be attributed to the differences between the MIKE HYDRO and 2D HEC-RAS model.

The 2D MIKE 21 model cannot be validated as a standalone component since it does not generate any flows. Instead, it must be assessed with the context of being coupled to other models. As part of this assessment, surface flooding was compared to the locations of flood-related 3-1-1 calls (see Section 2.5).

4.5 Sensitivity Analysis

To further assess the robustness of the 3-way model, a sensitivity analysis was conducted to assess:

- the impact of riverine water levels on the minor system and surface flooding, and
- the sensitivity of the model to Manning's n values on river water levels.

Using the 3-way coupled model, the effect of higher river water levels on the MIKE URBAN and MIKE 21 model results was assessed assuming all flood gates were open. As mentioned, during model validation, KCB's 2D HEC-RAS water levels in some areas were approximately 0.12 to 0.35 m higher than the MIKE HYDRO water levels. To assess how an increase in river water levels would affect the minor system and surface flooding in the MIKE FLOOD model, the Bow River discharge in the MIKE HYDRO model was increased until a corresponding increase in river water levels of approximately 0.3 m was observed. This value was achieved with an increase in the flow rate from the 1:20 year flow (1,230 m^3/s) to 1,415 m^3/s. This 0.3 m average increase in water levels primarily increased riverine flood depths. There was a small increase in ponding depths in traplows (for example, a 2 cm increase at the Bowness Road NW / CN Rail underpass) and a slightly greater area of inundation. The impact of increased river water levels on ponding depth in traplows diminished with distance from the river. This analysis shows that although the river water levels impact ponding depths, the difference in water levels between the MIKE HYDRO and 2D HEC-RAS model would not substantively change the results of the MIKE FLOOD model or the assessment of the minor system. As such, the results of the sensitivity analysis were deemed reasonable.

The sensitivity of the model to Manning's n was also assessed to account for the difference model approaches. As described in Section 3.2.4, values for Manning's n from the 2014 1D HEC-RAS model were used in areas where roughness values were not available, upstream of where the MIKE HYDRO model was coupled to the 2D surface, from cross-sections 24.66 to 5245.10. The model had low sensitivity to this change in Manning's n, thus providing added confidence in the approach of using the 2014 HEC-RAS 1D Manning's n in this section of the model.

5 DESIGN CRITERIA

Various design conditions were applied to the existing conditions and proposed conditions models with the overall objective of preventing worsened flood conditions due to the proposed barrier. The design conditions outline the typical storms (urban and riverine) that occur within the Study Area. The results of these model runs were assessed using the City's recommended design criteria, including LOS and flood risk.

5.1 Design Conditions

Two design conditions were considered for the assessment of the storm sewer network (minor system). These design conditions were developed by AE for the Sunnyside area (AE 2016) and were used to represent the combined probabilities of flooding on the Bow River, accounting for flooding derived from rainfall and stormwater flows on the urban catchments.

Both design conditions simulate overland runoff from a typical urban storm event (1:2 and 1:5 year, 4-hour design storms). However, Design Condition 1 assumes a smaller river flood event (1:5 year) that allows urban flows to outfall into the Bow River. Design Condition 2 assumes a larger river flood event (1:20 year) that results in backwater in the storm sewer pipes and reduces the ability of these pipes to drain to the Bow River. Table 8 below summarizes the modelled design condition scenarios. The river flood events were represented as steady-state to ensure that the peak of the urban storm event aligns with the peak of the river flood.

Under Design Condition 2, outfall gates (five gates in the existing conditions models and four gates in the proposed conditions models, see Section 7.2) would be closed to prevent river flows from backing up into the storm sewer network. Stormwater generated from within the Study Area would be temporarily stored within the pipe network and be allowed to surcharge above the crown of the pipe until relieved by pumping (permanent or temporary). It was assumed that outfall gates would remain closed until after river levels recede to acceptable levels (i.e., when water levels recede to outfall inverts).

TABLE 8 Design Condition Modelled Scenarios

Design Condition	Rainfall (Urban Model)	Bow River Naturalized Flow [(1)]	Outfall Gates
1	1:2 year, 4-hour storm	1:5 year flood (659 m^3/s)	Open
	1:5 year, 4-hour storm		
2	1:2 year, 4-hour storm	1:20 year flood (1,230 m^3/s)	Closed[(2)]
	1:5 year, 4-hour storm		

Note:
[(1)] Steady state flow rates were used to conservatively ensure that the peak of the river flood event aligns with the peak of the urban storm.
[(2)] Only five outfalls currently have flood gates: B100, B101, B104, B106, and B108.

The Bow River return periods (1:5 year for Design Condition 1; 1:20 year for Design Condition 2) represent flows under current conditions. Note that the 1:20 year naturalized flood event of 1,230 m^3/s is equivalent to the 1:200 year attenuated peak discharge with future upstream mitigation (as described in the Bowness Flood Control Barriers Hydrotechnical Assessment Report (KCB 2020)). In other words, with no upstream mitigation the proposed barrier design would offer protection up to the 1:20 year river flood. With future upstream mitigation, and flow attenuation achieved through an agreement between the Province of Alberta and TransAlta, the proposed barrier would offer protection up to the 1:200 year flood event.

5.2 Implemented Design Criteria

The objective for this stormwater assessment and mitigation project is to ensure that any existing stormwater management issues within the Study Area are not made worse by the implementation of the proposed barrier. Through discussions with the City, this objective was further defined in terms of two design criteria:

Design Criteria 1 – For all MHs, the proposed conditions HGLs should not exceed the existing conditions HGLs for the same storm event.

Design Criteria 2 – For all MHs in outfall catchments with gated outfalls, the proposed conditions HGLs at all manholes for Design Condition 2 (1:5 year, 4-hour design storm event, 1:20 year river flood event, outfall flood gates closed) should not exceed the greater of:

1. Surface Grades/Elevations, or
2. HGLs under Design Condition 1 (1:5 year, 4-hour design storm event with a 1:5 year Bow River flood event, all outfall gates open).

It is important to note that only four urban rainfall-river flood combinations were evaluated based on the design conditions presented in Table 8. It is recommended that a wider range of design storm events be considered if design of the Project progresses to ensure that the proposed conditions HGLs do not exceed the existing conditions HGLs for both smaller and larger events, using different combinations of urban storm and river flood return periods. Particular attention should be given to the impact of any proposed storm sewer relief connections, and gating (both of outfalls and in storm sewer relief connections).

5.3 Additional Evaluation Criteria

Model results for the existing and proposed conditions were also evaluated against a series of storm drainage criteria:

- LOS design standards.
- Flood risk, which includes:

1. traplow ponding depths should not exceed 0.3 m for Arterial roads (Bowness Road) and 0.5 m for all other roads in the Study Area (The City 2011); and
2. combinations of overland flow, velocity, and depth (QVD) should not exceed the Alberta Environment and Parks (AEP) criteria (The City 2011).

These measures of drainage system performance are presented in the subsections below. Although these metrics can be used to assess the performance of the system, it was not an objective of this phase of the Project to meet the design criteria throughout the Study Area.

5.3.1 Storm Sewer Network Level of Service Criteria

The storm sewer network (minor system) within the Study Area was constructed at various stages over a span of 70+ years under different governing design criteria. In older sections of the community (1950s and prior), the Rational Method was generally used to design storm sewers to convey the 1:2 year design storm event. Those sections built between the 1950s and 1990s typically used the 1:5 year design storm event to size storm sewers. Developments that were constructed after the 1990s began to use the Unit Area Release Rate (UARR) Method to design storm sewers. The major system (overland) conveys flows from extreme storm events that are in excess of what the minor system can convey. The major system is designed to convey flows for the 1:100 year design storm event.

Under current design standards, new developments within Calgary use ICDs at CBs to control and restrict flows to the pre-determined UARR flows and prevent surcharge up to the 1:100 year, 4-hour design storm event. Runoff not captured by the CB is conveyed overland as major system flows. Due to the design era, there are very few measures in place within the Study Area to restrict interception of flows into the minor system at the CBs. As a result, stormwater runoff contributions via CBs can often exceed the capacity of the storm sewers during larger rainfall events. This can result in surcharging of the storm sewers under these larger events.

Based on the City's current storm sewer design criteria, the following LOS evaluation criteria were adopted as a metric for this report to assess the storm sewer network performance:

- LOS Primary Evaluation Criteria – Surcharge of the storm sewers is acceptable during the 1:5 year, 4-hour design storm event so long as the HGL does not reach or exceed the surface/road grade.

- LOS Secondary Evaluation Criteria – Where possible, the HGL should be 2.5 m below grade or within the storm sewer pipe during the 1:5 year, 4-hour design storm event.

Note that LOS evaluation criteria are guidelines only, meeting of LOS evaluation criteria under proposed conditions was not a primary objective of this study. The LOS evaluation criteria were developed with the City to ensure consistency with other flood mitigation projects. As such, there are locations within the Study Area which do not meet the LOS evaluation criteria under proposed conditions.

5.3.2 Flood Risk Mapping

The performance of the overland surface network (major system) was compared against the City's criteria for maximum depth of ponding on roads (The City 2011). For the scenarios modelled, overland flow and ponding depths were classified into the following categories:

- Depth ≤ 0.05 m (Acceptable)
- 0.05 m < Depth ≤ 0.30 m (Acceptable)
- 0.30 m < Depth ≤ 0.50 m (Acceptable but not preferred; Not Acceptable for arterial and major roads)
- Depth > 0.50 m (Not Acceptable)

Ponding depths greater than 0.50 m within public road right-of-ways (RoWs) were considered unacceptable.

Overland flows were also assessed using AEP's QVD criteria, as shown in Table 9 and Figure 11, for the permissible combinations of depth and velocity that a 20-kg child would be able to withstand for overland flow (Alberta Environmental Protection 1999; The City 2011). Higher water velocities have a lower permissible depth since they pose a greater risk. Mapping of QVD values are either acceptable (depth less than or equal to the permissible depth for a given velocity) or not acceptable (depth greater than the permissible depth for a given velocity).

TABLE 9 Permissible Depths under Various Overland Water Velocities for Submerged Objects

Water Velocity (m/s)	Maximum Permissible Depth (m)
0.5	0.80
1.0	0.32
2.0	0.21
3.0	0.09

Notes:
Based on 20-kg child and concrete-lined channels. Larger persons may be able to withstand deeper flows.
Table reproduced from City of Calgary *Stormwater Management and Design Manual* (2011).

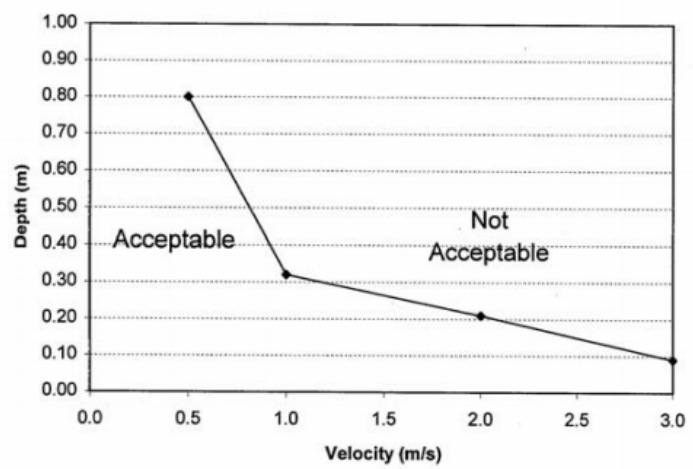


FIGURE 11 Permissible Depths under Various Overland Water Velocities for Submerged Objects

Notes:
Based on 20-kg child and concrete-lined channels. Larger persons may be able to withstand deeper flows.
Figure reproduced from the City of Calgary *Stormwater Management and Design Manual* (2011).

In order to evaluate flood risk improvements between existing and proposed conditions, nine Areas of Interest within the Study Area were identified for comparison. Table 10 describes the location of each Area of Interest. Ponding depth exceedances within the public road RoW were evaluated at each Area of Interest and QVD criteria exceedance were further evaluated at Area of Interests #1, #4, #5, and #7 only. Based on the results of each modelled scenario and design condition, each Area of Interest was assessed to determine whether ponding in the public RoW exceeded a depth of 0.50 m and/or whether QVD criteria was exceeded at each Area of Interest.

TABLE 10 Selected Areas of Interest for Flooding Assessment(1)

Areas of Interest	Location Description (Nearby Outfall)
Ponding in public RoWs exceeds a depth of 0.50 m	
1	Bowness Rd NW underpass of CP Rail Crossing
2	81 St and 46 Ave NW (SE corner of intersection)
3	69 St NW cul-de-sac north of 48 Ave NW [Outfall B109]
4	North section of Bow Cres NW (from Y-intersection with 67 St NW to T-intersection at Bow Village Cres NW) [between Outfalls B108 and B108A]
5	Bowbank Cres NW [Outfall B101]
6	T-intersection of Bow Cres NW and 33 Ave NW
7	South section of Bow Cres NW (from Bowness Rd NW to 260m east of Bowness Rd NW)
8	John Hextall Park [Outfall B100]
9	Alley between Bow Cres NW and Bowwater Cres NW, approx. 80m to 200m east of Bowness Rd NW
QVD criteria is exceeded	
1(2)	Bowness Rd NW underpass of CP Rail Crossing
4(2)	North section of Bow Cres NW (from Y-intersection with 67 St NW to T-intersection at Bow Village Cres NW) [between Outfalls B108 and B108A]

Areas of Interest	Location Description (Nearby Outfall)
5[(2)]	Bowbank Cres NW [Outfall B101]
7[(2)]	South section of Bow Cres NW (from Bowness Rd NW to 260m east of Bowness Rd NW)

Notes:
[(1)] Exceedances are for Design Condition 2 (1:5 year, 4-hour design storm), since this event showed the largest number of criteria exceedances. Results for other events are shown in Table 12.
[(2)] Repeated locations

6 EXISTING CONDITIONS RESULTS

Existing or current conditions scenario assumes no barrier or stormwater mitigation measures have been implemented. Four existing conditions model runs were prepared as per the design condition scenarios described in Table 8 in Section 5.1. The existing conditions model results were reviewed through evaluating the LOS performance of the storm sewer network (minor system results based on the 3-way coupled model) and reviewing overland inundation maps that show surface ponding depths anticipated within the Study Area. Existing conditions HGL profiles of outfalls within the Study Area are presented in Appendix A.

6.1 Existing Storm Sewer Network Level of Service

The existing conditions minor system LOS performance for Design Condition 1 (1:2 year and 1:5 year, 4-hour design storm event) are shown on Figures 12 and 13, respectively. These figures illustrate where the minor system meets the LOS primary criteria (no surcharge to surface) and LOS secondary criteria (HGL ≤2.5 m below grade or within the pipe).

Under existing conditions, the modelled minor systems in the Study Area are all providing less than a 1:2 year, 4-hour LOS. Figure 12 shows that for all outfall catchments, some degree of surcharge is occurring in all trunks for the 1:2 year, 4-hour design storm event and a 1:5 year river level (Design Condition 1). With the exception of outfall catchments B108A and B108, all the other modelled outfall catchments experience some instances where surcharge occurs to surface. Under a 1:5 year, 4-hour design storm event and a 1:5 year river level (Design Condition 1) the extent of surcharge in the storm trunks is more pronounced with surcharge to surface occurring at more locations (Figure 13).

Under the higher 1:20 year river level (Design Condition 2), there is significantly more surcharge within minor system pipe segments, surcharge to surface at MHs and overland flooding in low-lying portions of the Study Area as presented in Section 6.2.

A summary of the existing conditions LOS at minor system nodes (MHs) is provided in Table 11. The red, yellow, and green colours in the table header correspond to the LOS symbology used in Figures 12 and 13. As expected, the number of nodes which are surcharged to surface is higher during the 1:5 year, 4-hour storm event as this storm event produces a larger amount of rainfall and subsequent overland runoff.

Easting (m)

-15000 -14375 -13750 -13125 -12500 -11875

Northing (m)

5662500 5661875 5661250 5660625 5660000

B109 B108A B108 B107 B106 B104 B101 B100 B98 B97

1 2 3 4 5 6 7 8 9

Bow River

Bowness

Study Area
Storm Sewer
Area of Interest
Outfall
Gated Outfall

Level of Surface - 1:2 Year Event

- Surcharged to Surface
- Surcharged with HWL 0.0 - 2.5 m BG
- Surcharged with HWL >2.5 m BG or Not Surcharged

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

Reference: Data obtained from AltaLIS © Government of Alberta and City of Calgary used under license. Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

1:12,500 metres
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Calgary 3TM WGS 1984 W114

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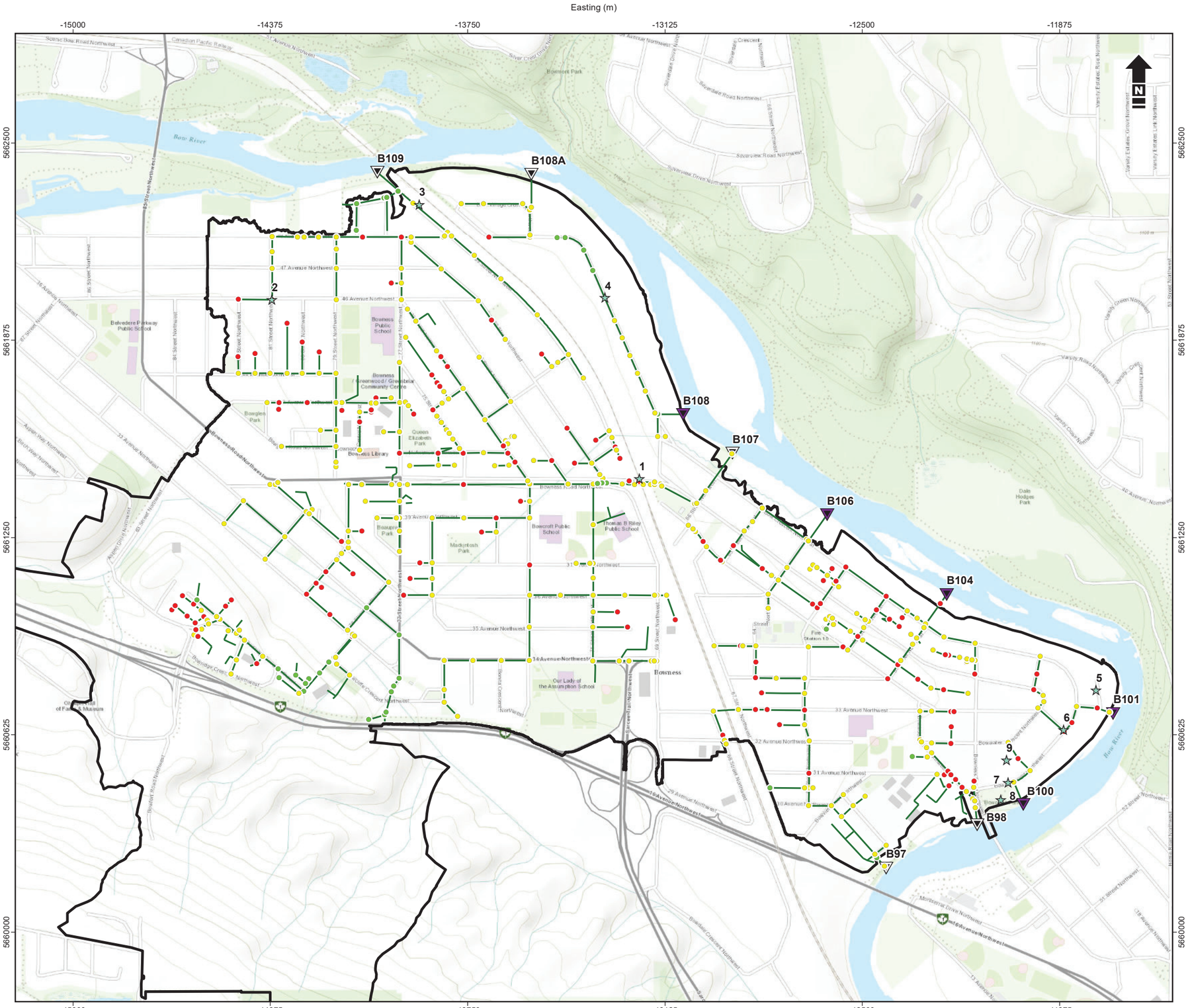
Storm Sewer LOS - Existing Conditions 1:2-year, 4-hour Design Storm Event (Design Condition 1 - Flood Gates Open)

Date:	Project:	Submitter:	Reviewer:
February 2021	26638	P. Bishop	A. Chan

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Figure 12

I:\City\Calgary\26638\Figures\AndTables\FLD\2018\Report\Final_Report\Figure-12-Storm_Sewer_LOS_Existing_Conditions_1_to_2_Year_4-Hour_Design_Storm_Event_Design_Condition_1_Flood_Gates_Open.mxd - Tatlod_L - 16-Feb-21, 09:43 AM - sylam - TID05



Study Area
Storm Sewer
Area of Interest
Outfall
Gated Outfall

Level of Surface - 1:5 Year Event

- Surcharged to Surface
- Surcharged with HWL 0.0 - 2.5 m BG
- Surcharged with HWL >2.5 m BG or Not Surcharged

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

Reference: Data obtained from AltaLIS © Government of Alberta and City of Calgary used under license. Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community.

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metres
125 0 125 250
Calgary 3TM WGS 1984 W114

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Bowness Flood Barrier Project

Storm Sewer LOS - Existing Conditions 1:5-year, 4-hour Design Storm Event (Design Condition 1 - Flood Gates Open)

Date:	Project:	Submitter:	Reviewer:
February 2021	26638	P. Bishop	A. Chan

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Figure 13

I:\City Of Calgary\26638\Figures And Tables\FLD\2018 Report\Final_Report\Figure-13-Storm_Sewer_LOS_Existing_Conditions_1_to_5_Year_4-Hour_Design_Storm_Event_Design_Condition_1_Flood_Gates_Open.mxd - Tatlod_L - 16-Feb-21, 09:44 AM - sylam - TID005

TABLE 11 Level of Service Summary (Existing Conditions)

Outfall Catchment	1:2 year, 4-hour			1:5 year, 4-hour		
	# of Nodes Surcharged to Surface	# of Nodes Surcharged with HGL 0.0 – 2.5 m BG	# of Nodes Surcharged with HGL >2.5 m BG or Not Surcharged	# of Nodes Surcharged to Surface	# of Nodes Surcharged with HGL 0.0 – 2.5 m BG	# of Nodes Surcharged with HGL >2.5 m BG or Not Surcharged
B97	8	21	4	10	22	1
B98	5	16	1	11	10	1
B100	1	3	-	1	3	-
B101	5	6	-	5	6	-
B104	17	33	3	21	30	2
B106	2	16	-	3	15	-
B107	30	155	28	62	139	12
B108	-	6	3		6	3
B108A	-	7	-	1	6	-
B109	2	25	9	7	25	4
TOTAL	**70**	**288**	**48**	**121**	**262**	**23**

Notes:
HGL = Hydraulic Grade Line
BG = Below Ground

6.1.1 Existing Storm Sewer Network Level of Service Summary

The low LOS performance of the existing storm sewer system within the Study Area is similar to that of other older communities in Calgary. This low LOS can be attributed to the following:

- Storm drainage infrastructure originally designed between the 1950s and 1980s that used outdated design philosophies and simplistic design methods (e.g., Rational Method). Design methods did not evaluate the way the entire system operated hydraulically. There was often no consideration given to complex hydraulics, backwater effects, or interactions between the major and minor systems.
- Inadequate storm sewer capacities and flat grades.
- Intensification within the catchments over the years (e.g., infill developments) increasing overall imperviousness of the catchment and therefore the amount of runoff.
- Large numbers of small private development sites (Figure 4) such as multi-family infill developments that have one or more CBs located onsite to control runoff but have limited or no onsite detention storage to control and restrict flows.

HGL plots of the main storm sewer trunk to each outfall are provided in Appendix A.

6.2 Existing Conditions Flood Depth and Risk Mapping

Flood risk depths and maps were evaluated for the existing conditions scenarios to establish a depth and risk baseline. This baseline allowed for evaluation of mitigation options since both depth and risk should not worsen under the proposed conditions. Figures 14 to 17 show the overland inundation mapping for the 1:2 year and 1:5 year, 4-hour storm events under each design condition (1:5 year and 1:20 year river levels). Inundation depths are grouped into the criteria categories as outlined in Section 5.3.2. These categories follow the City's criteria for overland flow on roads (The City 2011), which are intended for the 1:100 year design storm event.

Figures 18 to 21 show the flood risk assessment for the 1:2 year and 1:5 year, 4-hour storm events under each design conditions based on AEP's QVD criteria (Alberta Environmental Protection 1999). Flood risk was categorized as being either acceptable or not acceptable.

Under Design Condition 1 (1:5 year river level), the Study Area was characterized with generally low flooding along existing roads, as would be expected for older communities. There was indication of flooding at traplows and surcharging in areas where CB/MH capacity was exceeded (refer to HGL profiles in Appendix A). There was negligible riverine flooding in the Study Area, except for one location within the backyard of properties along the north section of Bow Crescent NW, located approximately 300 m south east of Outfall B108A.

Under Design Condition 2 (1:20 year river level), the Study Area experienced more extensive riverine flooding, particularly in two low-lying (Figure 10) and flood-prone locations in the B100/B101 catchment (from the John Hextall pedestrian/cycle bridge to approximately 950 m upstream along Bow Crescent NW) and the B108A/B108 catchment (from the B108 outfall to approximately 1,300 m upstream along Bow Crescent NW). For these two areas, there was little difference between the 1:2 year and 1:5 year, 4-hour results as high river water levels were the main cause of flooding (refer to HGL profiles in Appendix A). The highest modelled flood depths correlated with the locations of flood-related 3-1-1 calls, acting as further validation of the modelling results. The impact of riverine flooding further supports the need for the barrier.

Easting (m)

-15000 -14375 -13750 -13125 -12500 -11875

Northing (m)

5662500 5661875 5661250 5660625 5660000

B109 B108A B108 B107 B106 B104 B101 B100 B98 B97

1 2 3 4 5 6 7 8 9

Study Area
Area of Interest
Outfall
Gated Outfall

Depth of Ponding (m)

Depth ≤ 0.05 m (Acceptable)
0.05 m < Depth ≤ 0.30 m (Acceptable)
0.30 m < Depth ≤ 0.50 m (Acceptable but not preferred)
Depth > 0.50 m (Not Acceptable)

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

Reference: Data obtained from AltaLIS © Government of Alberta and City of Calgary used under license. LiDAR acquired through the City of Calgary used under license. Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community.

1:12,500 metres
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Calgary 3TM WGS 1984 W114

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Bowness Flood Barrier Project

Maximum Depth of Ponding - Existing Conditions
1:2-year, 4-hour Design Storm Event and 1:5-year Bow River Flood
(Design Condition 1 – Flood Gates Open)

Date:	Project:	Submitter:	Reviewer:
April 2021	26638	P. Bishop	A. Chan

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Figure 14

I:\City Of Calgary\26638\Figures And Tables\FLD\2018 Report\Final_Report\Figure-x-x-Maximum Depth_of_Ponding_Existing_Conditions.mxd - Tabloid_L - 09-Apr-21, 08:48 AM - sylam - TD005

Easting (m)

-15000 -14375 -13750 -13125 -12500 -11875

Northing (m)

5662500 5661875 5661250 5660625 5660000

B109 B108A B108 B107 B106 B104 B101 B100 B98 B97

1 2 3 4 5 6 7 8 9

Study Area
Area of Interest
Outfall
Gated Outfall

Depth of Ponding (m)

Depth ≤ 0.05 m (Acceptable)
0.05 m < Depth ≤ 0.30 m (Acceptable)
0.30 m < Depth ≤ 0.50 m (Acceptable but not preferred)
Depth > 0.50 m (Not Acceptable)

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

Reference: Data obtained from AltaLIS © Government of Alberta and City of Calgary used under license. LIDAR acquired through the City of Calgary used under license. Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community.

1:12,500 metres
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Calgary 3TM WGS 1984 W114

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City of Calgary
Bowness Flood Barrier Project

Maximum Depth of Ponding - Existing Conditions
1:5-year, 4-hour Design Storm Event and 1:5-year Bow River Flood
(Design Condition 1 – Flood Gates Open)

Date:	Project:	Submitter:	Reviewer:
April 2021	26638	P. Bishop	A. Chan

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Figure 15

I:\City\Calgary\26638\Figures\AndTables\FLD\2018\Report\Final_Report\Figure-x-x-Maximum Depth_of_Ponding_Existing_Conditions.mxd - Tabloid_L - 09-Apr-21, 08:49 AM - sylam - TID005

Easting (m)

-15000 -14375 -13750 -13125 -12500 -11875

Northing (m)

5662500 5661875 5661250 5660625 5660000

B109 B108A B108 B107 B106 B104 B101 B100 B98 B97

1 2 3 4 5 6 7 8 9

Study Area
Area of Interest
Outfall
Gated Outfall

Depth of Ponding (m)

Depth ≤ 0.05 m (Acceptable)
0.05 m < Depth ≤ 0.30 m (Acceptable)
0.30 m < Depth ≤ 0.50 m (Acceptable but not preferred)
Depth > 0.50 m (Not Acceptable)

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

Reference: Data obtained from AltaLIS © Government of Alberta and City of Calgary used under license. LiDAR acquired through the City of Calgary used under license. Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community.

1:12,500 metres
125 0 125 250
Calgary 3TM WGS 1984 W114

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ENVIRONMENT & ENGINEERING

City of Calgary
Bowness Flood Barrier Project

Maximum Depth of Ponding - Existing Conditions
1:2-year, 4-hour Design Storm Event and 1:20-year Bow River Flood
(Design Condition 2 – Flood Gates Closed)

Date:	Project:	Submitter:	Reviewer:
April 2021	26638	P. Bishop	A. Chan

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Figure 16

I:\City Of Calgary\26638\Figures And Tables\FLD\2018 Report\Report Final_Report\Figure-x-x-Maximum Depth_of_Ponding_Existing_Conditions.mxd - Tabloid_L - 09-Apr-21, 08:49 AM - sylam - TD005

Easting (m)

-15000 -14375 -13750 -13125 -12500 -11875

Northing (m)

5662500 5661875 5661250 5660625 5660000

B109 B108A B108 B107 B106 B104 B101 B100 B98 B97

1 2 3 4 5 6 7 8 9

Study Area
Area of Interest
Outfall
Gated Outfall

Depth of Ponding (m)

Depth ≤ 0.05 m (Acceptable)
0.05 m < Depth ≤ 0.30 m (Acceptable)
0.30 m < Depth ≤ 0.50 m (Acceptable but not preferred)
Depth > 0.50 m (Not Acceptable)

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

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1:12,500 metres
125 0 125 250
Calgary 3TM WGS 1984 W114

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

City of Calgary
Bowness Flood Barrier Project

Maximum Depth of Ponding - Existing Conditions
1:5-year, 4-hour Design Storm Event and 1:20-year Bow River Flood
(Design Condition 2 – Flood Gates Closed)

Date:	Project:	Submitter:	Reviewer:
April 2021	26638	P. Bishop	A. Chan

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Figure 17

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Easting (m)

-15000 -14375 -13750 -13125 -12500 -11875

Northing (m)

5662500 5661875 5661250 5660625 5660000

B109 B108A B108 B107 B106 B104 B101 B100 B98 B97

1 2 3 4 5 6 7 8 9

Study Area
Area of Interest
Outfall
Gated Outfall

Flood Risk
Acceptable
Not Acceptable

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

Reference: Data obtained from AltaLIS © Government of Alberta and City of Calgary used under license. LiDAR acquired through the City of Calgary used under license. Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community.

1:12,500 metres
125 0 125 250
Calgary 3TM WGS 1984 W114

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City of Calgary
Bowness Flood Barrier Project

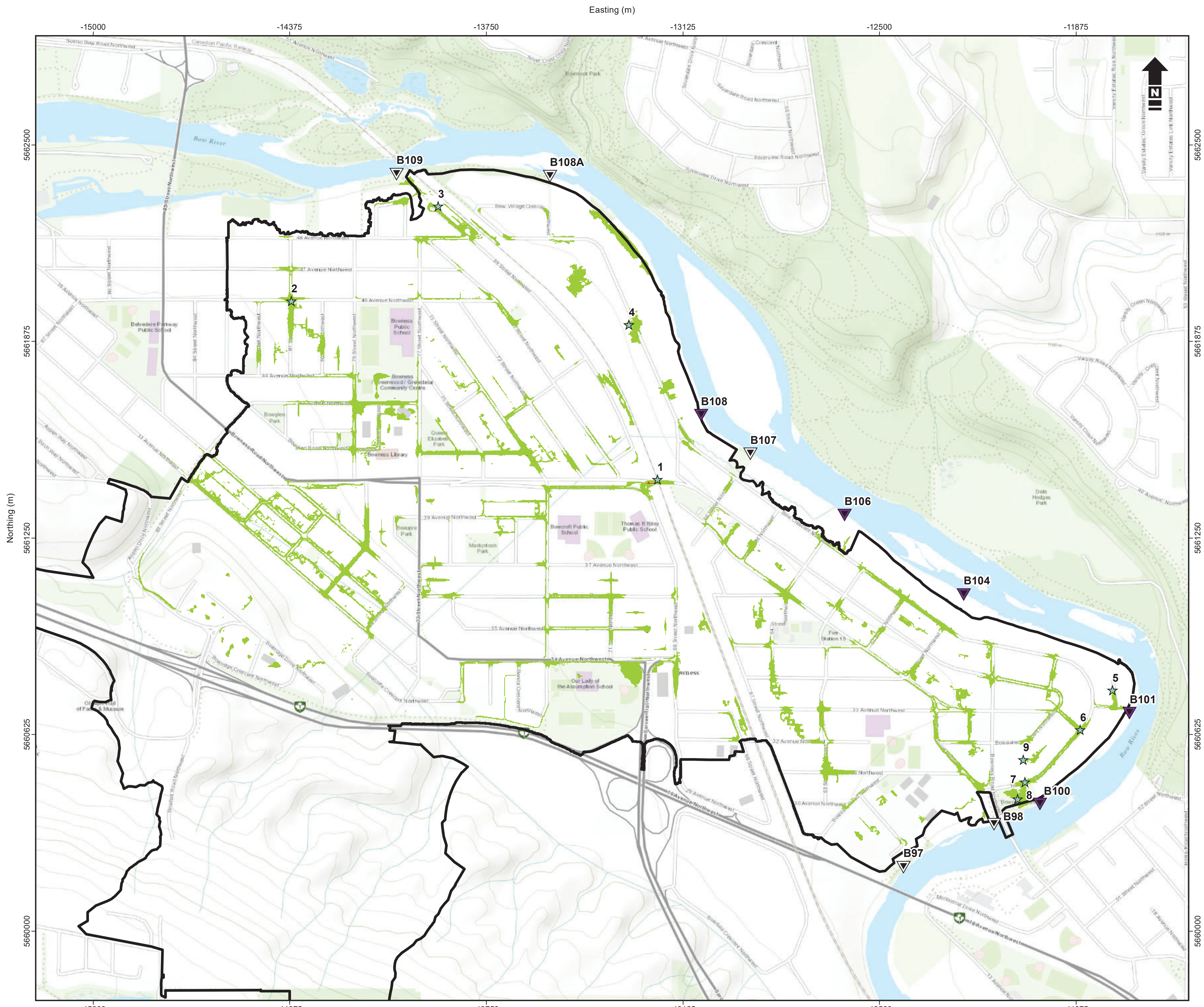
Flood Risk Mapping – Existing Conditions
1:2-year, 4-hour Design Storm Event and 1:5-year Bow River Flood
(Design Condition 1 – Flood Gates Open)

Date:	Project:	Submitter:	Reviewer:
April 2021	26638	P. Bishop	A. Chan

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Figure 18

I:\City Of Calgary\26638\Figures And Tables\FLD\2018 Report\Final_Report\Figure-x-x-Flood_Risk_Mapping_Existing_Conditions.mxd - Tabloid_L - 09-Apr-21, 08:52 AM - sylam - TID005



Flood Risk

Acceptable

Not Acceptable

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

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1:12,500 metres
125 0 125 250
Calgary 3TM WGS 1984 W114

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City of Calgary
Bowness Flood Barrier Project

Flood Risk Mapping – Existing Conditions
1:5-year, 4-hour Design Storm Event and 1:5-year Bow River Flood
(Design Condition 1 – Flood Gates Open)

Date:	Project:	Submitter:	Reviewer:
April 2021	26638	P. Bishop	A. Chan

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Figure 19

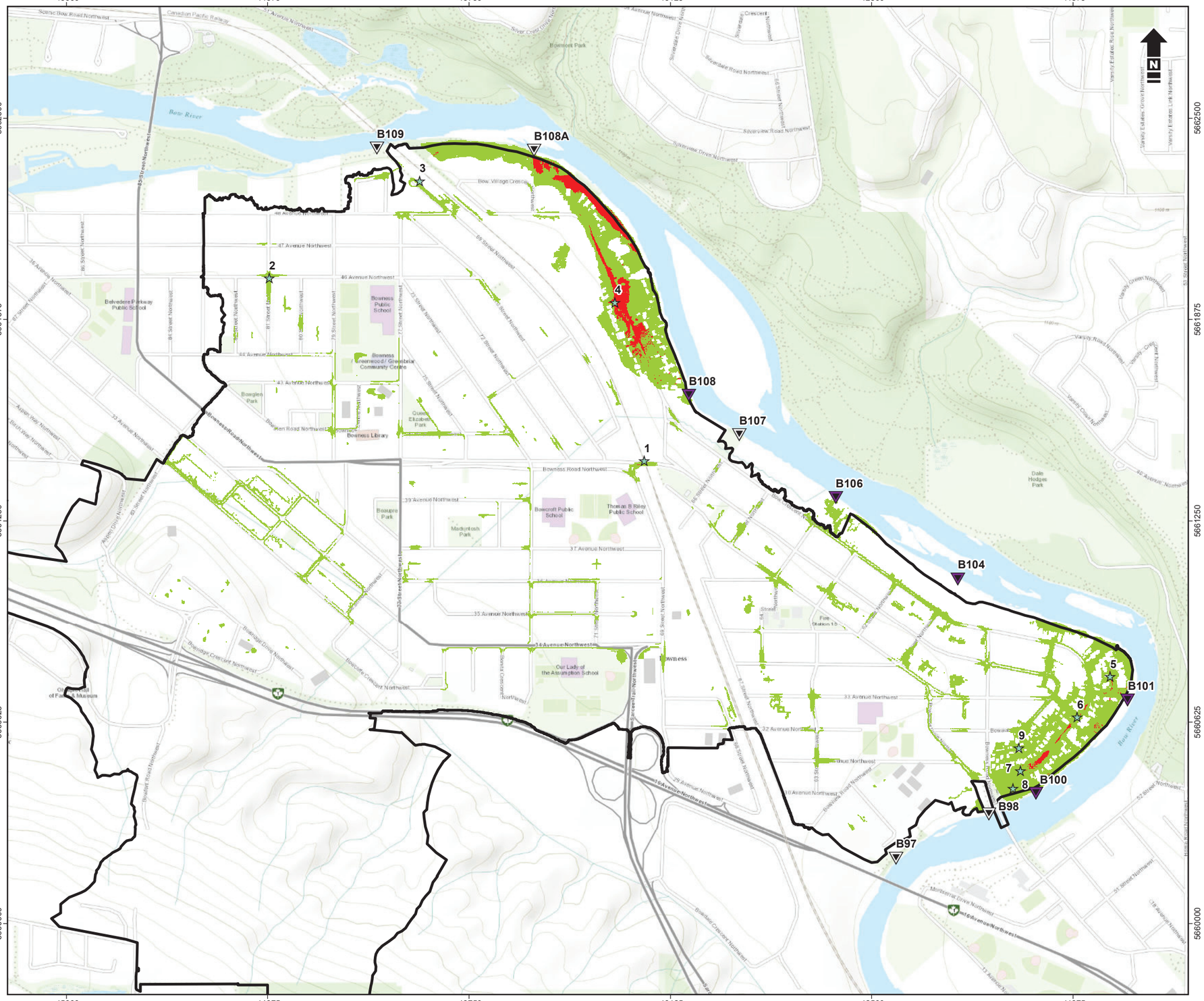
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Easting (m)

-15000 -14375 -13750 -13125 -12500 -11875

Northing (m)

5662500 5661875 5661250 5660625 5660000



Study Area
Area of Interest
Outfall
Gated Outfall

Flood Risk

Acceptable
Not Acceptable

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

Reference: Data obtained from AltaLIS © Government of Alberta and City of Calgary used under license. LiDAR acquired through the City of Calgary used under license. Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community.

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metres
125 0 125 250
Calgary 3TM WGS 1984 W114

Matrix Solutions Inc.
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City of Calgary
Bowness Flood Barrier Project

Flood Risk Mapping – Existing Conditions
1:2-year, 4-hour Design Storm Event and 1:20-year Bow River Flood
(Design Condition 2 – Flood Gates Closed)

Date:	Project:	Submitter:	Reviewer:
April 2021	26638	P. Bishop	A. Chan

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Figure 20

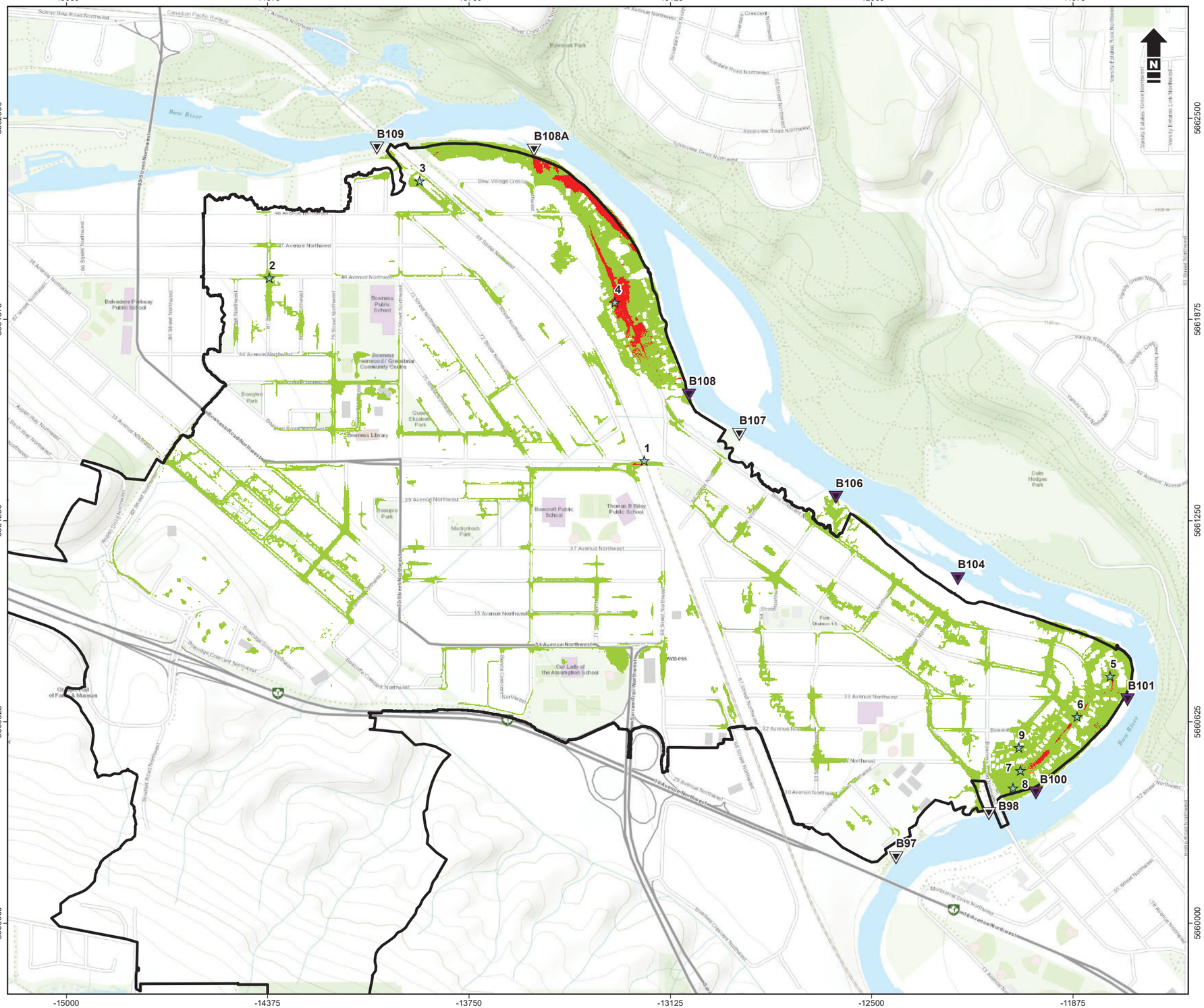
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Easting (m)

-15000 -14375 -13750 -13125 -12500 -11875

Northing (m)

5662500 5661875 5661250 5660625 5660000



Study Area
Area of Interest
Outfall
Gated Outfall

Flood Risk

Acceptable
Not Acceptable

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

Reference: Data obtained from AltaLIS © Government of Alberta and City of Calgary used under license. LiDAR acquired through the City of Calgary used under license. Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community.

1:12,500 metres
125 0 125 250
Calgary 3TM WGS 1984 W114

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

City of Calgary
Bowness Flood Barrier Project

Flood Risk Mapping – Existing Conditions
1:5-year, 4-hour Design Storm Event and 1:20-year Bow River Flood
(Design Condition 2 – Flood Gates Closed)

Date:	Project:	Submitter:	Reviewer:
April 2021	26638	P. Bishop	A. Chan

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Figure 21

I:\City\Calgary\26638\Figures\Andtables\FLD\2019\Report\Final_Report\Figure-x-x-Flood_Risk_Mapping_Existing_Conditions.mxd - Tabloid_L - 09-Apr-21, 08:54 AM - sylam - TID005

The additional evaluation criteria described in Section 5.3 was used to assess the extent of inundation (Figures 14 to 17) and flood risk (Figures 18 to 21). The criteria of ponding on the public roads and QVD criteria exceedance were used as metrics to evaluate the existing conditions and to later assess each proposed mitigation option (Section 7). Under the Project objectives, criteria exceedances do not worsen under proposed conditions; risks of stormwater flooding within the Study Area are not made worse by the implementation of the proposed barrier. Nonetheless, some criteria exceedances may remain under proposed conditions, but are not caused by the proposed barrier. Table 12 lists locations where criteria exceedances were observed under each design condition. Because the focus of this Project was on urban flooding, criteria exceedances caused directly by river water levels were not included as part of the evaluation.

6.2.1 Flood Risk Mapping Summary

Results from four existing conditions model scenarios were reviewed (Figures 18 to 21) in order to assess the flood risk at each Areas of Interest. Table 12 summarizes the flood risk assessment for each Area of Interest under each design condition. Cells highlighted in green indicate that the criterion has not been exceeded at the Area of Interest. Cells highlighted in red indicate a criterion exceedance at the Area of Interest.

Under Design Condition 1, ponding depth criteria was exceeded at Location IDs 1 and 2. There were no QVD criteria exceedances.

Under Design Condition 2, ponding depth criteria was exceeded at all nine location IDs. QVD criteria was exceeded at all four locations selected for assessment.

The larger number of criteria exceedances under Design Condition 2 compared to Design Condition 1 is reflective of high river water levels and their impact on the minor system, and the impact of closing existing flood gates without any pumping considerations. The increased amount of urban flooding under Design Condition 2 compared to Design Condition 1 is most notable in the B100, B101, and B104 catchments. These three catchments are gated, but not currently mitigated through pumping.

HGL profiles of the existing storm sewer network (refer to Appendix A) further underline the impact of high river water levels under Design Condition 2. Surcharged storm sewers are provided no relief while existing flood gates are closed.

Results from the proposed conditions model scenarios were also reviewed in order to assess the flood risk at each Area of Interest. A reduction in criteria exceedance (i.e., a red highlighted cell under existing conditions switching to a green highlighted cell under proposed conditions) would indicate an improvement to flooding risks as a result of implementation of the proposed mitigation option measures.

TABLE 12 Flooding Assessment at Areas of Interest (Existing Conditions)

Area of Interest	Location Description	Design Condition 1[1]		Design Condition 2[2]	
		1:2 year	1:5 year	1:2 year	1:5 year
Ponding in the public RoWs exceeds a depth of 0.50 m					
1	Bowness Rd NW underpass of CP Rail Crossing				
2	81 St and 46 Ave NW (SE corner of intersection)				
3	69 St NW cul-de-sac north of 48 Ave NW [Outfall B109]				
4	North section of Bow Cres NW (from Y-intersection with 67 St NW to T-intersection at Bow Village Cres NW) [between Outfalls B108 and B108A]				
5	Bowbank Cres NW [Outfall B101]				
6	T-intersection of Bow Cres NW and 33 Ave NW				
7	South section of Bow Cres NW (from Bowness Rd NW to 260m east of Bowness Rd NW)				
8	John Hextall Park [Outfall B100]				
9	Alley between Bow Cres NW and Bowwater Cres NW, approx. 80 m to 200 m east of Bowness Rd NW				
QVD criteria is exceeded					
1[3]	Bowness Rd NW underpass of CP Rail Crossing				
4[3]	North section of Bow Cres NW (from Y-intersection with 67 St NW to T-intersection at Bow Village Cres NW) [between Outfalls B108 and B108A]				
5[3]	Bowbank Cres NW [Outfall B101]				
7[3]	South section of Bow Cres NW (from Bowness Rd NW to 260 m east of Bowness Rd NW)				

Notes:
RoWs – right-of-ways
[1] 1:5 year river level, gates open
[2] 1:20 year river level, gates closed
[3] Repeated locations

While ponding in back-of-lots was not specifically assessed in this study, one location with notably high ponding depths under existing conditions (no barrier) was identified approximately 200m southeast of the intersection of Bow Crescent NW and Bow Village Crescent NW. For these areas, ponding depths exceed 0.5 m in the Design Condition 1, 1:2 year, 4-hour design storm. Flooding at this location is caused by runoff from back-of-lots of properties along Bow Crescent NW, which ponds in a low area (see Figures 14 through 17). Flooding is contained within these rear yards and does not appear to pose significant risk to existing dwellings (areas adjacent to the CP Rail west of Bow Crescent NW and south of Bow Village Crescent NW) and are not a result of the proposed barrier or overland riverine flooding.

7 PROPOSED CONDITIONS IMPROVEMENTS

As discussed in Section 1.1, the objective for this stormwater assessment and mitigation project is to ensure that any existing stormwater management issues within the Study Area are not made worse by the implementation of the proposed barrier. With the barrier in place overland drainage, generated from

within the Study Area, would be prevented from freely flowing toward the Bow River along several existing surface flow paths. As well, with the barrier in place, certain outfalls will need to be equipped with flood gates that, when closed as a result of a threshold flood event, will prevent river water levels from back-flooding up the storm sewer network and causing surface flooding of lands behind the barrier. In addition to outfall gates, mitigation options will be required to meet the design criteria as outlined in Section 5.2 to address any increase in overland flooding that would result from the proposed barrier with the outfall flood gates closed.

7.1 Outfalls that Require Flood Gates

Discussions with the City and KCB determined that outfalls in the Study Area should only have flood gates if the water levels in the storm sewer network resulting from a 1:20 year river water flood event only (i.e., with no urban storm flow contributions) would exceed MH rim elevations and causing surface flooding at MHs.

Figure 22 shows the MHs where the 1:20 year Bow River water level would exceed MH rim elevations and result in overland flooding. The associated HGL plots are presented in Appendix B and include existing conditions HGLs for reference. Table 13 summarizes these results and presents recommendations for outfall flood gates. Existing outfall flood gates are included for comparison. No changes to outfall flood gates are recommended with the exception of B106. We suggest that the flood gate at Outfall B106 not be closed when river water levels are less than or equal to the 1:20 year river flood event since the 1:20 year river water levels (with no urban storm flow contributions) do not surcharge to surface at the storm manholes.

TABLE 13 Outfall where Flood Gates are Required

Outfall Catchment	1:20 year Bow River Water Level Surcharges to Surface in Catchment (Y = Yes, N = No)	Outfall Flood Gate Required (Design Condition 2) (Y = Yes, N = No)	
		Recommended	Existing
B100	Y	Y	Y
B101	Y	Y	Y
B104	Y	Y	Y
B106	N	N	Y
B107	N	N	N
B108	Y	Y	Y
B108A	Y[(1)]	N	N
B109	N	N	N
B98	N	N	N
B97	N	N	N

Notes:
[(1)] The 1:20 year river water level would surcharge to surface by only approximately 0.10 m at B108A at the first upstream manhole; not enough to warrant a flood gate on the outfall. This manhole is located within the pathway RoW off Bow Village Crescent NW immediately west of the end of the proposed barrier, and at the top of an embankment that slopes down to the river, through existing greenspace.

Easting (m)

-15000 -14375 -13750 -13125 -12500 -11875

Northing (m)

5662500 5661875 5661250 5660625 5660000

B109 B108A B108 B107 B106 B104 B101 B100 B98 B97

Study Area
Storm Sewer
Outfall
Gated Outfall

Manholes: Surcharge to Surface in 1:20-year Bow River Flood Event

Surcharge to Surface
No Surcharge to Surface

Reference: Data obtained from AltaLIS © Government of Alberta and City of Calgary used under license. Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community.

1:12,500

125 0 125 250 metres

Calgary 3TM WGS 1984 W114

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

City of Calgary
Bowness Flood Barrier Project

Riverine Surcharge to Surface 1:20-year Bow River Flood

Date:	Project:	Submitter:	Reviewer:
March 2021	26638	P. Bishop	A. Chan

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Figure 22

I:\City Of Calgary\26638\Figures And Tables\FLD\2018 Report\Final_Report\Figure-22-Riverine_Surcharge_to_Surface_1_to_20_Year_Bow_River_Flood.mxd - Tabloid_L - 22-Mar-21, 03:48 PM - sylam - TID005

In other catchments, where the 1:20 year Bow River water level does not surcharge to surface at storm MHs, a flood gate on the outfall is not required.

7.2 Proposed Options

Based on the analysis of the existing conditions model and preliminary flood risk mapping, various mitigation or improvement options were considered in order to maintain the flood protection integrity of the barrier, while also reducing the occurrence of stormwater ponding upstream of the barrier. To address overland flooding caused by urban storm flow contributions during Design Condition 2 (1:20 year river flood event) and the proposed barrier, three mitigation options were explored:

- **Option 1 – Barrier with Permanent Stormwater Pump Station at B100, Temporary Pumping at B108, and Underground Storage:** requires the construction of one permanent stormwater pump station within John Hextall Park located at corner of Bow Crescent NW and Bowness Road NW (upstream of Outfall B100) and one temporary pumping location near the intersection of Bow Crescent NW and 66 Street NW (adjacent to Outfall B108). This option would require storm sewer interconnections and diversions within the existing storm sewer network and upgrades to Outfalls B100 and B104.

- **Option 2 – Barrier with Temporary Pumping Only:** A total of 30 individual temporary pumps would be required at five locations near four outfalls equipped with flood gates along the flood barrier (B100, B101, B108, and B104 with two pumping locations). Temporary pumps would be rented by the City on a multi-year contract with a pump supplier to ensure that the required quantity of temporary pumps would be available on stand-by to be deployed should a flood event occur. The temporary pumps would be mobilized to site during a flood event; no permanent pumping infrastructure would be installed within the community as part of Option 2.

- **Option 3 – Barrier with Temporary Pumping and Underground Storage:** Similar to Option 2 but with reduced pumping requirements at Outfall B104, but still requiring five temporary pumping locations in the catchments of the four gated storm outfalls along the flood barrier (B100, B101, B108, and B104 with two pumping locations). A total of 28 individual temporary pumps would be required. This option requires the construction of four underground storage units within the municipal RoWs. The underground storage serves to reduce the required pumping capacity at Outfall B104.

All options assume the construction of the proposed barrier along the rear yards. Discharge of stormwater from the pump stations (permanent or temporary) would be passed through (permanent) or over the top (temporary) of the barrier to the Bow River. The following section discusses the design conditions, common design components, and the details of each of the mitigation options.

7.2.1 Option 1: Barrier with Permanent Stormwater Pump Station at B100, Temporary Pumping at B108, and Underground Storage

7.2.1.1 Permanent Stormwater Pump Station at B100

Option 1 proposes that one permanent stormwater pump station (PS) and one temporary PS be implemented in addition to the flood barrier as shown in Figure 23 and Figure 24. Construction requirements for a proposed permanent PS include, but are not limited to, adjacent or within close proximity to the Bow River, adequate property size to accommodate the PS building footprint, and access to existing utilities.

The Study Area is a mature, developed neighbourhood with very few options for viable PS sites. Two open space options that were assessed as potential locations were John Hextall Park (corner of Bowness Road NW and Bow Crescent NW) near Outfall B100 and Tony and Ruby Schmaltz Park (intersection of Bow Crescent NW and 66 Street NW) near Outfall B107.

John Hextall Park is the proposed location for PS1 (Figure 24) because a pump station at that location would be able to service multiple catchments requiring flood mitigation (B100, B101, and B104), and would also be at a lower elevation than its contributing catchment areas, thus requiring less energy to operate. PS1 would have a building footprint of approximately 20 m × 30 m and would service the B100 catchment, as well as the B101 and B104 catchments through proposed minor system interconnections (Figure 24, Section 7.2.1.3). Two duty pumps (and one stand-by pump) are recommended within PS1, each with a pumping rate of 0.31 m^3/s to service the 1:5 year, 4-hour design storm. Design information for PS1 is provided in Table 14. Stormwater would be pumped from PS1 via a force main for discharge into the Bow River. The force main may need to be constructed through the berm, since the barrier has 0.5 m freeboard from the 1:20 year river water level. Details of the PS1 force main should be confirmed in future phases of design.

Pumping from PS1 would not be required during a 1:5 year river level (Design Condition 1) and therefore, it has been designed to operate under a 1:20 year river level (Design Condition 2). The proposed PS will operate only when the four gated outfalls are closed. Under smaller river flood events, a proposed sluice gate near B104 would be closed to convey flows from the west portion of the B104 catchment to the gravity outfall. This sluice gate would be opened under a 1:20 year river water level to convey additional flows to PS1. This sluice gate will prevent overloading of the proposed downstream gravity system discharging to Outfall B100. The proposed gravity system will convey flows from B101 and the east portion of B104 to Outfall B100 during both Design Conditions 1 and 2. Under a 1:20 year river water level when the outfall flood gates are closed, a second sluice gate to PS1 would be opened to divert flows to the PS1 wet well/underground storage chamber and activate the pumps.

Plot 1:1 = Tabloid (11)

BOW RIVER

OUTFALL B108A

BOW VILLAGE CRES

RAILROAD

48 AVE NW

46 AVE NW

BOW CRES NW

99 ST NW

78 ST NW

72 ST NW

44 AVE NW

75 ST NW

77 ST NW

MH 400013615
# of Pumps: 4
Q_{pump}: 0.252 m^3/s

OUTFALL B108

TP-B108

MH 400013316
# of Pumps: 4
Q_{pump}: 0.252 m^3/s

RAILROAD

OUTFALL B107

41 AVE NW

BOWNESS RD NW

68 ST NW

72 ST NW

BOW RIVER

OUTFALL B106

BOW CRES NW

66 ST NW

65 ST NW

64 ST NW

BOWNESS RD NW

LEGEND

- Property Lines
- Existing Storm Network
- Existing Sanitary Network
- Existing Water Network
- Lots with Proposed Barrier
- Existing Manholes for Proposed Temporary Pumping
- TP-B100 — Proposed Temporary Pumping Location ID
- MH ###### / # of Pumps: 2 / Q_{pump}: 0.126 m^3/S — City of Calgary Manhole ID; Proposed Temporary Number of Pumps; Total Pump Capacity
- Proposed Temporary Pump Outlet Hose Alignment
- Proposed CB /w Sump (CB Lead connected to Storm Main)

Notes:
1. The proposed barrier design has not been finalized.

1 : 5,000
50 0 50 100 metres
CANA83-3TM114

REFERENCE: 2018 DEM, 2013-2014 Bathymetry Contours, Existing Utilities and 24025S34_SID Image Provided by Klohn Crippen Berger.

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

CITY OF CALGARY
BOWNESS FLOOD BARRIER PROJECT

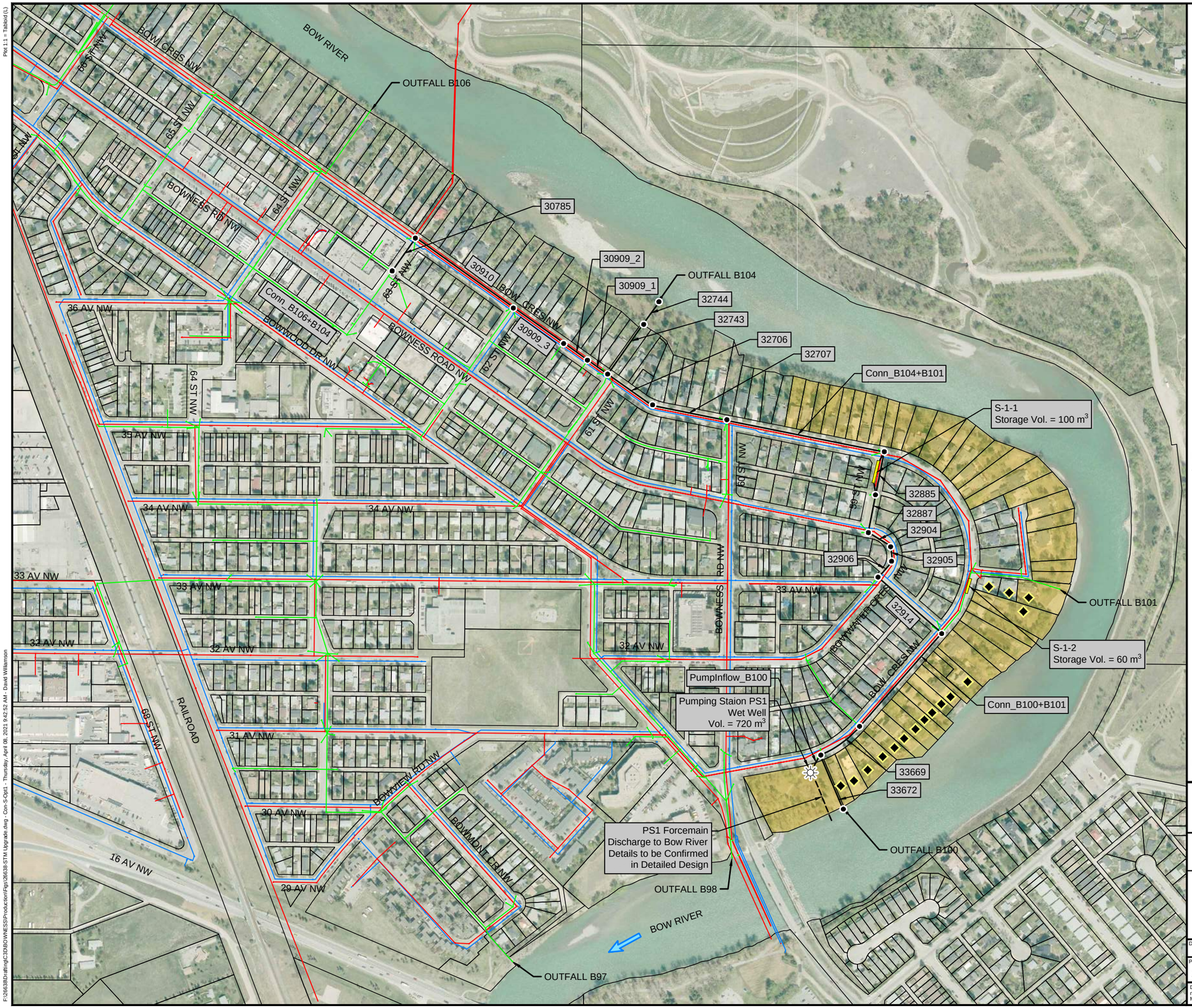
STORMWATER CONCEPT PLAN
NORTH AREA
OPTION 1

DATE:	TECHNICAL:	REVIEWER:	DRAWN:
April 2021	A. Sordi	A. Chan	K. Weiler

PROJECT:	REVISION:	FIGURE:
26638	A	23

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LEGEND

- Property Lines
- Existing Storm Network
- Existing Sanitary Network
- Existing Water Network
- Lots with Proposed Barrier
- Proposed Storm Sewer
- Proposed Storm Manhole
- Proposed Pumping Station
- Proposed Pumping Station Forcemain Discharge to Bow River
- Proposed Underground Vault
- Proposed CB /w Sump (CB Lead connected to Storm Main)
- 32706 Part ID

Notes:
1. The proposed barrier design has not been finalized.

1 : 5,000
50 0 50 100 metres
CANA83-3TM114

REFERENCE: 2018 DEM, 2013-2014 Bathymetry Contours, Existing Utilities and 24025S34_SID Image Provided by Klohn Crippen Berger.

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CITY OF CALGARY
BOWNESS FLOOD BARRIER PROJECT

STORMWATER CONCEPT PLAN
SOUTH AREA
OPTION 1

DATE:	TECHNICAL:	REVIEWER:	DRAWN:
April 2021	A. Sordi	A. Chan	K. Weiler

PROJECT:	REVISION:	FIGURE:
26638	A	24

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TABLE 14 Option 1 Permanent Pump Station (PS1) Details

Pump Station	Location	Contributing Catchments	Contributing Area (ha)	Number of Pumps	Total Pumping Capacity (m^3/s)	Wet Well Volume (m^3)
PS1	John Hextall Park (Bowness Road and Bow Crescent NW)	B100, B101, B104[(1)]	34.6	2 duty + 1 stand-by	0.62	720

Notes:
[(1)] There is an existing interconnection between the B104 and B106 catchments 20 m northwest of 63 Street NW, between Bowness Road NW and Bowwood Drive NW. Consequently, PS1 provides some hydraulic benefit to B106.

Pumping from PS1 was only considered under the 1:5 year and 1:20 year river flood event. While the pumping station was designed for a 1:20 year naturalized discharge additional analysis of other combinations of urban storms and river water levels would be required to determine the range of events in which the PS1 pumping station could provide benefits.

7.2.1.2 Temporary Stormwater Pumping at B108

Pumping will also be required at the B108 outfall (see Figure 23). However, due to the limitations of infrastructure conflicts, and the presence of an existing sanitary lift station at 6764 Bow Crescent NW, a permanent stormwater PS could not be sited near Outfall B108. As such, temporary pumps were considered instead. These temporary pumps would need to be rented annually and mobilized by City crews during flood events to mitigate flooding within the catchment. Temporary pumps were assumed to be trailer mounted 6" diameter vacuum assisted diesel-powered centrifugal pumps. Each temporary pump is assumed to have an optimal pump rate of 1,000 US gpm (0.063 m^3/s). Discharge hoses (ranging up to 300 m in length) would run through available easements and discharge into the Bow River. Suction hoses would draw stormwater from existing storm MHs closest to the outfall. The temporary PS location (at the corner of Bow Crescent NW and 66 Street NW, referred to as TP-108) was chosen to minimize the required pumping hose lengths, minimize head losses, and avoid the need for larger pumps. Information for the temporary pumping location TP-108 is provided in Table 15.

TABLE 15 Option 1 Temporary Pumping Location (TP-B108) Details

Temporary Pumping ID	Outfall Catchment[(1)]	Pumping Rate (m^3/s)	Number of Pumps Required	Number of MHs Required for Pumping	Suggested MH Locations for Pumps (# of Pumps in MH)
TP-B108	B108	0.504	8	2	400013316 (4 pumps) 400013615 (4 pumps)

Note:
[(1)] Refer to Table 2 for contributing areas.

7.2.1.3 Minor System Upgrades

In order for the B104 and B101 catchments to benefit from the implementation of the permanent pump station PS1, the following new interconnections and redirections are proposed:

- Interconnection of catchment B104 to B101 along Bow Crescent NW, from 60 Street NW to 59 Street NW (via a proposed 900 mm storm sewer).
- Interconnection of catchment B101 to B100 along Bow Crescent NW, from 33 Avenue NW to the B100 storm main (160 m West of 33 Avenue NW; via a proposed 1,200 mm × 600 mm box duct).
- Redirection (change of drainage direction) of the existing storm sewer along Bow Crescent NW (from 61 Street NW to 60 Street NW; upgraded to a 900 mm storm sewer).

The interconnections between Outfalls B104 to B100 and Outfalls B100 to B101 would remain open under both Design Conditions 1 (1:5 year river levels) and 2 (1:20 year river levels) in order to provide a pathway to direct flows from the east portion of B104 into Outfall B100. A one-way flow regulator (e.g., duckbill valve) is proposed in the B101 network to prevent high river water levels at Outfall B101 from contributing to HGL increases throughout the storm sewer network within catchment B100.

The redirected storm sewer along Bow Crescent NW conveys flows from catchment B104 to the proposed permanent PS1 via the B100 and B101 storm sewer. Previously, this storm sewer directed flow west toward Outfall B104. Under larger events (i.e., 1:20 year river levels; Design Condition 2), when the pumps are active, this redirected pipe will convey flow from the entire B104 catchment (20 ha) southeast toward PS1. To limit flows from B104 to B101/B100 under smaller events (e.g., a 1:5 year river flood event), a sluice gate is recommended at the upstream end of the proposed redirected storm sewer (east of the 61 Street NW and Bow Crescent NW intersection; at the upstream end of pipe 32706 on Figure 24). When closed, this manually operated sluice gate would force the western portion of the B104 catchment toward Outfall B104 (to avoid overloading Outfall B100/B101 with additional flows) and convey only the eastern portion of B104 to the Outfall B100/B101. This eastern portion of B104 includes approximately 3 ha south and east of 61 Street NW and Bow Crescent NW (between 61 Street NW and 60 Street NW). PS1 and TP-B108 alone are not enough to meet design criteria in the B100, B101, and B104 catchments. The benefits of pumping on lowering HGLs diminishes with distance from the PS; therefore, upgrades to storm sewers in catchment B104 are also recommended (Table 16). Similarly, within catchment B101, storm sewer upgrades are recommended to lower the HGL, which would rise due to both closing the flood gate at Outfall B101 (Design Condition 2), and from the increased flows from catchment B104 (both design conditions). The locations of these proposed minor system upgrades are shown in Figures 23 and 24.

TABLE 16 Option 1 Proposed Minor System Upgrades

Location Description	Storm Sewer ID	Pipe Dimensions (mm)		Comments
		Existing	Proposed	
63 Street NW: from 60 m southwest of Bow Crescent NW to Bow Crescent NW	30785	300	450	Upgrade
Bow Crescent NW: from 63 Street NW to 61 Street NW	30910	450	525	Upgrade
	30909	600	750	Upgrade
B104 outfall	32743, 32744	750	900	Upgrade
Bow Crescent NW: from 61 Street NW to 60 Street NW	32706, 32707	450	900	Redirect (reverse flow direction)
Bow Crescent NW: from 60 Street NW to 59 Street NW	Conn_B104+B101	n/a	900	Proposed B104-B101 connector pipe
59 Street NW: from Bow Crescent NW to Bowwater Crescent NW	32885	375	900	Upgrade
	32887	450	900	Upgrade
Bowwater Crescent NW: from 59 Street NW to 33 Avenue NW	32904, 32905, 32906	450	900	Upgrade
33 Avenue NW: from Bowwater Crescent NW to Bow Crescent NW	32914	600	1,200 × 600 CON DUCT	Upgrade
Bow Crescent NW	Conn_B100+B101	n/a	1,200 × 600 CON DUCT	Proposed B100-B101 connector pipe
Bow Crescent NW: from 163 m West of 33 Avenue NW to 120 m East of Bowness Road NW	33669	525	1,200 × 600 CON DUCT	Upgrade
Outfall B100	33672	525	1,200 × 600 CON DUCT	Upgrade

Note:
n/a – not applicable

At the direction of the City, the assessments in this study only considered the combinations of river water levels and urban design storms identified as Design Condition 1 (1:5 year river level, 1:2 year and 1:5 year, 4-hour design storms, gates open) and Design Condition 2 (1:20 year river level, 1:2 year and 1:5 year, 4-hour design storms, gates closed). The effects of these proposed cross connections and sewer redirections could vary based on urban inflow and river water levels. The detailed design of this system will need to consider a comprehensive range and combinations of urban design storms and river water levels to ensure the intended benefits are realized without causing negative impacts.

7.2.1.4 Outfall Upgrades

An upgrade to Outfall B100 is required to accommodate the interconnection from the B104 minor system and its additional 3 ha of contributing area (the eastern portion of B104 only, downstream of the sluice gate at Bow Crescent NW and 61 Street NW). In particular, this outfall upgrade will lower the HGL along the 115 m pipe segment between Bow Crescent NW and Bowwater Crescent NW (located between residential properties). Further analysis is recommended to assess the impact of the interconnections on minor system flows draining toward PS1 under a greater range of design storm events.

An upgrade to Outfall B104 is required as storm sewer upgrades along 63 Street NW and Bow Crescent NW can cause an increase in the HGL at Bow Crescent NW and 61 Street NW, which in turn increases the HGL along 61 Street NW. Outfall upgrades will require regulatory permitting and approval prior to construction. The combination of these upgrades would reduce the HGLs within the storm sewer system in catchments B100, B101, and B104, to meet the design criteria (Section 5.2).

7.2.1.5 Underground Storage

In addition to the proposed pumping, storm sewer upgrades, and interconnections, underground storage is recommended at two locations within the Study Area (Table 17). The proposed underground storage at 59 St NW and Bow Crescent NW (S-1-1) is required to lower the HGL along 59 Street NW, since proposed sewer upgrades in this location are limited by cover constraints. The proposed underground storage at Bow Crescent NW and Bowbank Crescent NW (S-1-2) will address localized exceedance of the design criteria.

TABLE 17 Option 1 Proposed Underground Storage Details

Underground Storage ID	Location	Volume (m^3)
S-1-1	59 St NW and Bow Crescent NW	100
S-1-2	Bow Crescent NW and Bowbank Crescent NW	60

7.2.2 Option 2: Barrier with Temporary Pumping Only

For this option, five temporary pumping locations are required in the catchments of the four gated storm outfalls along the proposed barrier (B100, B101, B104 (two pumping locations), and B108). A total of 30 temporary pumps (distributed between the five pumping locations) are required to adequately address flooding under the design conditions. This option avoids construction, operation and maintenance costs associated with the permanent pump station PS1 proposed in Option 1. These temporary pumps would have the same considerations as the temporary pumps described in Section 7.2.1 (hose length and access to the river via an easement). The proposed locations of these pumping sites are shown on Figures 25 and 26.

The number of pumps required and the number of MHs to be pumped from depend on the contributing flow and sewer depth. Table 18 lists suggested locations for use of temporary, portable pumps. Locations were selected based on proximity of MHs to the discharge location typically via the existing outfall easement. Similar to Option 1, each temporary pump required for Option 2 is assumed to have a pump rate of 1,000 US gpm (0.063 m^3/s). Table 18 lists the portable pump requirements, grouped by outfall. For instance, the B100 catchment (with an area of 5 ha) requires a pumping rate of 0.315 m^3/s to adequately drain flooding conditions during the design event (1:5 year, 4-hour urban storm with 1:20 year river water levels). In order to achieve this required pumping rate, a total of five pumps are needed. These pumps can be divided among two existing MHs; the suggested MHs to use for temporary pumping of this catchment are 400013974 (three pumps) and 400013977 (two pumps).

Plot 1:1 = Tabloid (11)

BOW RIVER

OUTFALL B108A

BOW VILLAGE CRES

RAILROAD

48 AVE NW

46 AVE NW

BOW CRES NW

99 ST NW

78 ST NW

72 ST NW

44 AVE NW

75 ST NW

77 ST NW

41 AVE NW

BOWNESS RD NW

73 ST NW

MH 400013615
# of Pumps: 4
Q_{pump}: 0.252 m^3/s

OUTFALL B108

TP-B108

MH 400013316
# of Pumps: 4
Q_{pump}: 0.252 m^3/s

OUTFALL B107

BOW RIVER

OUTFALL B106

65 ST NW

68 ST NW

64 ST NW

BOWNESS RD NW

LEGEND

- Property Lines
- Existing Storm Network
- Existing Sanitary Network
- Existing Water Network
- Lots with Proposed Barrier
- Existing Manholes for Proposed Temporary Pumping
- TP-B100 — Proposed Temporary Pumping Location ID
- MH ###### / # of Pumps: 2 / Q_{pump}: 0.126 m^3/S — City of Calgary Manhole ID; Proposed Temporary Number of Pumps; Total Pump Capacity
- Proposed Temporary Pump Outlet Hose Alignment
- Proposed CB /w Sump (CB Lead connected to Storm Main)

Notes:
1. The proposed barrier design has not been finalized.

1 : 7,500
metres
75 0 75 150
CANA83-3TM114

REFERENCE: 2018 DEM, 2013-2014 Bathymetry Contours, Existing Utilities, 24025S34_SID Image and Proposed Barrier Wall/Berm Provided by Klohn Crippen Berger.

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BOWNESS FLOOD BARRIER PROJECT

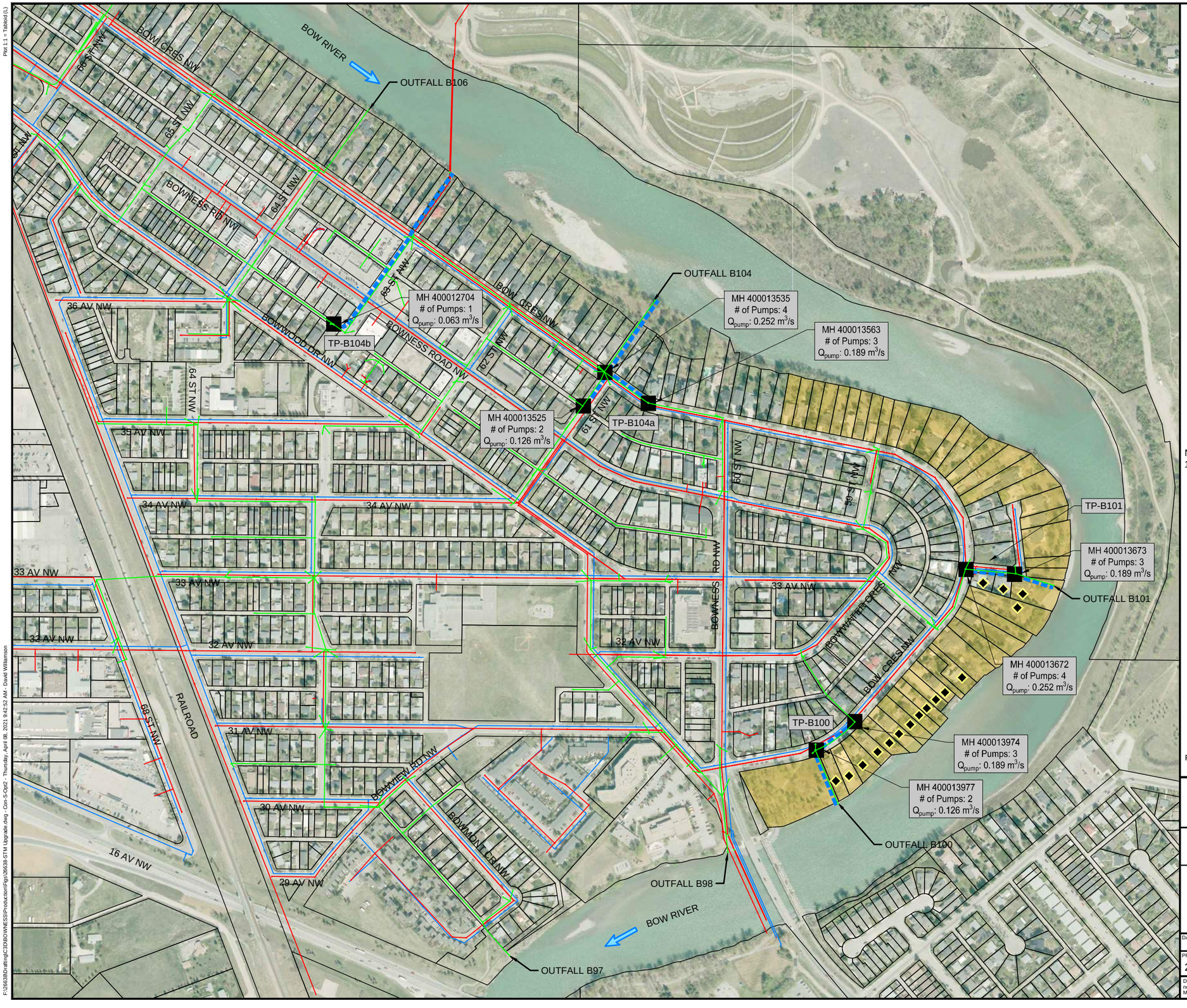
STORMWATER CONCEPT PLAN
NORTH AREA
OPTION 2

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PROJECT:	REVISION:	FIGURE:
26638	A	25

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LEGEND

- Property Lines
- Existing Storm Network
- Existing Sanitary Network
- Existing Water Network
- Lots with Proposed Barrier
- Existing Manholes for Proposed Temporary Pumping
- TP-B100 — Proposed Temporary Pumping Location ID
- MH ###### / # of Pumps: 2 / Q_{pump}: 0.126 m^3/S — City of Calgary Manhole ID; Proposed Temporary Number of Pumps; Total Pump Capacity
- Proposed Temporary Pump Outlet Hose Alignment
- Proposed CB /w Sump (CB Lead connected to Storm Main)

Notes:
1. The proposed barrier design has not been finalized.

1 : 7,500
75 0 75 150 metres
CANA83-3TM114

REFERENCE: 2018 DEM, 2013-2014 Bathymetry Contours, Existing Utilities, 24025S34_SID Image and Proposed Barrier Wall/Berm Provided by Klohn Crippen Berger.

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CITY OF CALGARY
BOWNESS FLOOD BARRIER PROJECT

STORMWATER CONCEPT PLAN SOUTH AREA OPTION 2

DATE:	TECHNICAL:	REVIEWER:	DRAWN:
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PROJECT:	REVISION:	FIGURE:
26638	A	26

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Plot 1:1 = Tabloid (11)
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TABLE 18 Option 2 Temporary Pumping Location Details

Temporary Pumping ID	Outfall Catchment[1]	Pumping Rate (m^3/s)	Number of Pumps Required	Number of MHs Required for Pumping	Suggested MH Locations for Pumps (# of Pumps in MH)
TP-B100	B100	0.315	5	2	400013974 (3 pumps) 400013977 (2 pumps)
TP-B101	B101	0.441	7	2	400013672 (4 pumps) 400013673 (3 pumps)
TP-B104a	B104	0.567	9	3	400013535 (4pumps) 400013563 (3 pumps) 400013525 (2 pumps)
TP-B104b	B104	0.063	1	1	400012704 (1 pump)
TP-B108	B108	0.504	8	2	400013316 (4 pumps) 400013615 (4 pumps)

Note:
[1] Refer to Table 2 for contributing areas.

Notably, hydraulic modelling indicates that Outfall B104 requires the greatest amount of pumping and would need to be pumped from two separate MHs. This large pumping requirement is primarily due to the large catchment size (20 ha) and the diminishing effects of pumping with distance. The primary pumping location (total pumping rate of 9,000 US gpm [0.567 m^3/s]) for B104 could not sufficiently draw down the HGL along 63 Street NW (between Bow Crescent NW and the alley north of Bowness Road NW) due to an undersized 300 mm pipe along this street. Infrastructure changes and permanent upgrades are not considered in the sewer network for Option 2. Therefore, a second pumping location (total pumping rate of 1,000 US gpm [0.063 m^3/s]) is required and the should be located at a MH at 63 Street NW and the alley north of Bowness Road NW, approximately 250 to 300 m from Bow River. Note that the high HGL in B106 and the existing interconnection between the B104 and B106 catchments near this secondary pumping contribute to the high HGL along 63 Street NW. To further pursue this option, planning and easement requirements through privately-owned property will need to be reviewed in future design to facilitate access to the river.

The temporary pumps in Option 2 are only required to be used when the flood gates are closed under Design Condition 2 (1:20 year river levels). Under Design Condition 1 (gates open), temporary pumps are not required. Option 2 for Design Condition 1 is therefore equivalent to the existing conditions scenario for Design Condition 1 (1:5 year river levels) as no onsite infrastructure upgrades are proposed and the Bow River does not directly cause surface flooding in this event (1:5 year Bow River flood water levels, no storm sewer flow contributions).

7.2.3 Option 3: Barrier with Temporary Pumping and Underground Storage

Option 3 is similar to Option 2, but with the addition of four underground storage units to reduce the required pump capacity at Outfall B104 from 0.567 m^3/s (nine 1,000 US gpm [0.063 m^3/s]) to 0.441 m^3/s (seven 1,000 US gpm [0.063 m^3/s] pumps). This results in a total of 28 temporary pumps for all catchments combined, distributed among the catchments, as shown on Figures 27 and 28. The temporary pumps are activated only when the four outfall gates are closed under Design Condition 2 (1:20 year river levels). The storage units would be located within public road RoWs within the B104 catchment (Figure 27). The proposed location of these storage units considers the existing utilities and available space in these RoWs. The reduction in required pumping rates, relative to Option 2, reduces the number of pumps required and the number of MHs to be accessed.

While the objective of this option is to meet design criteria under Design Condition 2 (as per Section 5.2), there is an improvement in the HGL under Design Condition 1 as the proposed underground storage units provide some attenuation and reduction of flows.

Table 19 presents the proposed temporary pumping configuration for catchment B104; pumping for catchments B100, B101, and B108 is identical to Option 2.

TABLE 19 Option 3 Temporary Pumping Location Details

Temporary Pumping ID	Catchment[1]	Pumping Rate (m^3/s)	Number of Pumps Required	Number of MHs Required for Pumping	Suggested MH Locations for Pumps (# of Pumps in MH)
TP-B100	B100	0.315	5	2	400013974 (3 pumps) 400013977 (2 pumps)
TP-B101	B101	0.441	7	2	400013672 (4 pumps) 400013673 (3 pumps)
TP-B104a	B104	0.441	7	2	400013535 (4 pumps) 400013563 (3 pumps)
TP-B104b	B104	0.063	1	1	400012704 (1 pump)
TP-B108	B108	0.504	8	2	400013316 (4 pumps) 400013615 (4 pumps)

Note:
(1) Refer to Table 2 for contributing areas.

Underground storage units are proposed to reduce the pumping requirements in B104 by storing water temporarily to attenuate flows. Proposed locations for these units considered potential conflicts with existing residential service connections (sanitary, water, storm), and were selected to target local criteria exceedances. The details of the storage units are provided in Table 20 and shown in Figure 28.

Plot 1:1 = Tabloid (11)

BOW RIVER

OUTFALL B108A

BOW VILLAGE CRES

RAILROAD

48 AVE NW

46 AVE NW

BOW CRES NW

69 ST NW

78 ST NW

72 ST NW

44 AVE NW

75 ST NW

77 ST NW

41 AVE NW

BOWNESS RD NW

73 ST NW

MH 400013615
# of Pumps: 4
Q_{pump}: 0.252 m^3/s

OUTFALL B108

TP-B108

MH 400013316
# of Pumps: 4
Q_{pump}: 0.252 m^3/s

RAILROAD

OUTFALL B107

BOW RIVER

OUTFALL B106

BOW CRES NW

65 ST NW

66 ST NW

64 ST NW

BOWNESS RD NW

LEGEND

- Property Lines
- Existing Storm Network
- Existing Sanitary Network
- Existing Water Network
- Lots with Proposed Barrier
- Existing Manholes for Proposed Temporary Pumping
- TP-B100 — Proposed Temporary Pumping Location ID
- MH ###### / # of Pumps: 2 / Q_{pump}: 0.126 m^3/S — City of Calgary Manhole ID; Proposed Temporary Number of Pumps; Total Pump Capacity
- Proposed Temporary Pump Outlet Hose Alignment
- Proposed CB /w Sump (CB Lead connected to Storm Main)

Notes:
1. The proposed barrier design has not been finalized.

1 : 7,500
metres
75 0 75 150
CANA83-3TM114

REFERENCE: 2018 DEM, 2013-2014 Bathymetry Contours, Existing Utilities, 24025S34_SID Image and Proposed Barrier Wall/Berm Provided by Klohn Crippen Berger.

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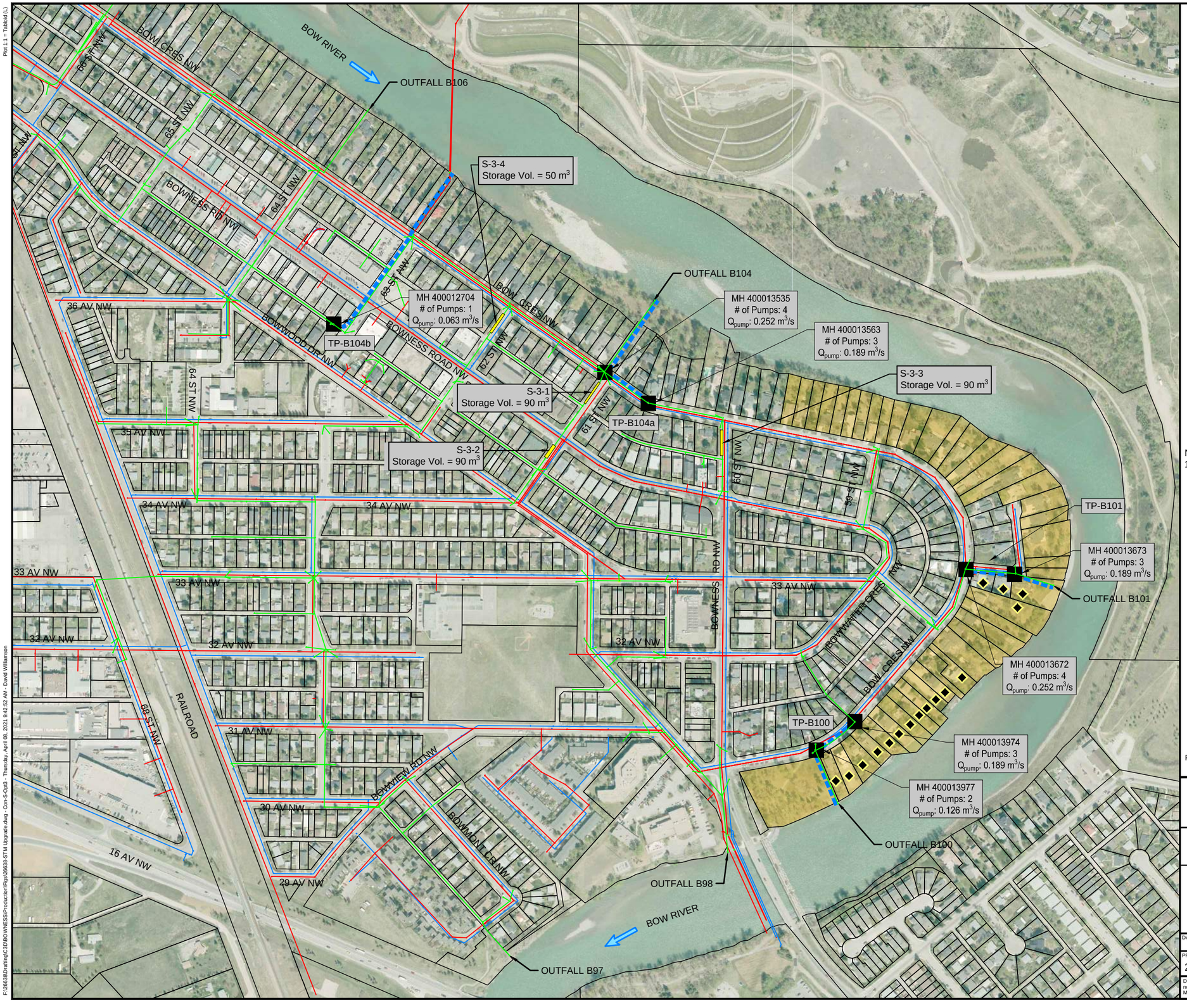
STORMWATER CONCEPT PLAN
NORTH AREA
OPTION 3

DATE:	TECHNICAL:	REVIEWER:	DRAWN:
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PROJECT:	REVISION:	FIGURE:
26638	A	27

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LEGEND

- Property Lines
- Existing Storm Network
- Existing Sanitary Network
- Existing Water Network
- Lots with Proposed Barrier
- Existing Manholes for Proposed Temporary Pumping
- TP-B100 — Proposed Temporary Pumping Location ID
- MH ###### / # of Pumps: 2 / Q_{pump}: 0.126 m^3/S — City of Calgary Manhole ID / Proposed Temporary Number of Pumps / Total Pump Capacity
- Proposed Temporary Pump Outlet Hose Alignment
- Proposed CB /w Sump (CB Lead connected to Storm Main)
- Proposed Underground Vault
- S-3-1 — Part ID

Notes:
1. The proposed barrier design has not been finalized.

1 : 7,500
75 0 75 150 metres
CANA83-3TM114

REFERENCE: 2018 DEM, 2013-2014 Bathymetry Contours, Existing Utilities, 24025S34_SID Image and Proposed Barrier Wall/Berm Provided by Klohn Crippen Berger.

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SOUTH AREA
OPTION 3

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26638	A	28

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Plot 11 = Tabloid (11)
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TABLE 20 Option 3 Proposed Underground Storage Details

Storage ID	Location	Volume (m^3)
S-3-1	61 Street NW between Bowness Road NW and Bowness Drive NW	90
S-3-2	61 Street NW between Bow Crescent NW and Bowness Road NW	90
S-3-3	60 Street NW between Bow Crescent NW and Bowness Road NW	90
S-3-4	62 Street NW between Bow Crescent NW and Bowness Road NW	50

8 PROPOSED CONDITIONS RESULTS

For each of the proposed mitigation options, the LOS and flood risk for each proposed mitigation option were compared to each other, as well as to existing conditions in order to assess differences between the mitigation options and to confirm that flooding was reduced or improved for each of the proposed mitigation options. The 1:2 year and 1:5 year, 4-hour design storm events were evaluated separately for Design Condition 1 (1:5 year river flood event, all outfall gates open) and Design Condition 2 (1:20 year river flood event, four outfall flood gates closed).

The HGL profiles for the proposed conditions models were evaluated using the design criteria described in Section 5.2.

Upon evaluation of Design Criteria 1, the proposed conditions HGLs (for Options 1 and 3) were equal to, or less than, the existing conditions HGLs for both all assessed river and stormwater flow combinations. As mentioned in Section 5.2, assessing the HGLs using additional combinations of urban storm and river flood return periods would be recommended at a later stage of the Project in order to confirm the upper limits of performance of the proposed barrier and mitigation measures. Option 2 was not specifically evaluated under Design Condition 1 as this option reflects existing conditions with the flood barrier; these conditions did not require engagement of the temporary pumps and no other storm infrastructure upgrades were proposed under this option.

All options meet Design Criteria 2. Under proposed conditions with 1:20 year river levels and four flood gates closed (Design Condition 2) the HGLs did not exceed the greater of ground elevations and the existing condition HGLs under Design Condition 1 for the 1:5 year, 4-hour design storm event.

The one exception is at the manhole immediately upstream of Outfall B104, which did not meet the second design criteria in all three options. This manhole is located in a rear yard that is not proposed to have a barrier and is able to drain downslope to the Bow River and is therefore not posing any risk to any dwellings.

8.1 Minor System Level of Service – Design Condition 1

Proposed conditions Option 1 (Barrier with Permanent Stormwater PS at B100, Temporary Pumping at B108, and Underground Storage) and Option 3 (Barrier with Temporary Stormwater Pumping and Underground Storage) were evaluated under Design Condition 1 (1:5 year river levels, all gates open). As mentioned, Option 2 (Barrier with Temporary Pumping Only) was not evaluated as it is equivalent to the existing conditions model under Design Condition 1 (i.e., no pumps, no storm upgrades). Option 1 results for the 1:2 year and 1:5 year, 4-hour design storm events with Design Condition 1 are shown in Figures 29 and 30, respectively. These figures outline the locations where the minor system meets the primary criteria (no surcharge to surface) and secondary criteria (HGL ≤2.5 m below grade and/or within the pipe).

While storm infrastructure upgrades were designed to satisfy the design criteria under Design Condition 2, the upgrades did improve major and minor storm system performance under Design Condition 1 as well. Therefore, the LOS analysis for Design Condition 1 demonstrates the improvements of the storm sewer upgrades and underground storage. In fact, there was a significant reduction in the number of surcharged MHs under Design Condition 1 for Options 1 and 3 compared to existing conditions. This reduction in MH surcharge would also result in reduced areas of surface flooding.

The results of the LOS for the mitigation options are displayed in Tables 21 and 22 as well as Figures 29 and 30 for Option 1, and Figures 31 and 32 for Option 3. The results are discussed in the following sections.

Easting (m)

-15000 -14375 -13750 -13125 -12500 -11875

Northing (m)

5662500 5661875 5661250 5660625 5660000

B109 B108A B108 B107 B106 B104 B101 B100 B98 B97

1 2 3 4 5 6 7 8 9

Study Area
Storm Sewer
Area of Interest
Outfall
Gated Outfall

Level of Surface - 1:2 Year Event

- Surcharged to Surface
- Surcharged with HWL 0.0 - 2.5 m BG
- Surcharged with HWL >2.5 m BG or Not Surcharged

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

Reference: Data obtained from AltaLIS © Government of Alberta and City of Calgary used under license. Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

1:12,500 metres
125 0 125 250
Calgary 3TM WGS 1984 W114

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City of Calgary
Bowness Flood Barrier Project

Storm Sewer LOS - Option 1
1:2-year, 4-hour Design Storm Event
(Design Condition 1 - Flood Gates Open)

Date:	Project:	Submitter:	Reviewer:
March 2021	26638	P. Bishop	A. Chan

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Figure 29

I:\City\Calgary\26638\Figures\Andtables\FLD\2019\Report\Final_Report\Figure-29-Storm_Sewer_LOS_Option_1_1_to_2_Year_4-Hour_Design_Storm_Event_Design_Condition_1_Flood_Gates_Open.mxd - Tabloid_L - 22-Mar-21, 04:10 PM - sylam - TID005

Easting (m)

-15000 -14375 -13750 -13125 -12500 -11875

Northing (m)

5662500 5661875 5661250 5660625 5660000

B109 B108A B108 B107 B106 B104 B101 B100 B98 B97

1 2 3 4 5 6 7 8 9

Study Area
Storm Sewer
Area of Interest
Outfall
Gated Outfall

Level of Surface - 1:5 Year Event

- Surcharged to Surface
- Surcharged with HWL 0.0 - 2.5 m BG
- Surcharged with HWL >2.5 m BG or Not Surcharged

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

Reference: Data obtained from AltaLIS © Government of Alberta and City of Calgary used under license. Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

1:12,500 metres
125 0 125 250
Calgary 3TM WGS 1984 W114

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

City of Calgary
Bowness Flood Barrier Project

Storm Sewer LOS - Option 1
1:5-year, 4-hour Design Storm Event
(Design Condition 1 - Flood Gates Open)

Date:	Project:	Submitter:	Reviewer:
March 2021	26638	P. Bishop	A. Chan

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Figure 30

I:\City\Calgary\26638\Figures\And\tables\FLD\2019\Report\Final_Report\Figure-30-Storm_Sewer_LOS_Option_1_1_in_5_Year_4-Hour_Design_Storm_Event_Design_Condition_1_Flood_Gates_Open.mxd - Tabloid_L - 22-Mar-21, 04:12 PM - sylam - TID005

Easting (m)

-15000 -14375 -13750 -13125 -12500 -11875

Northing (m)

5662500 5661875 5661250 5660625 5660000

B109 B108A B108 B107 B106 B104 B101 B100 B98 B97

1 2 3 4 5 6 7 8 9

Study Area
Storm Sewer
Area of Interest
Outfall
Gated Outfall

Level of Surface - 1:2 Year Event

- Surcharged to Surface
- Surcharged with HWL 0.0 - 2.5 m BG
- Surcharged with HWL >2.5 m BG or Not Surcharged

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

Reference: Data obtained from AltaLIS © Government of Alberta and City of Calgary used under license. Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

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125 0 125 250
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City of Calgary
Bowness Flood Barrier Project

Storm Sewer LOS - Option 3
1:2-year, 4-hour Design Storm Event
(Design Condition 1 - Flood Gates Open)

Date:	Project:	Submitter:	Reviewer:
March 2021	26638	P. Bishop	A. Chan

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Figure 31

I:\City\Calgary\26638\Figures\Andtables\FLD\2019\Report\Final_Report\Figure-31-Storm_Sewer_LOS_Option_3_1_to_2_Year_4-Hour_Design_Storm_Event_Design_Condition_1_Flood_Gates_Open.mxd - Tabloid_L - 22-Mar-21, 04:14 PM - sylam - TID005

Easting (m)

-15000 -14375 -13750 -13125 -12500 -11875

Northing (m)

5662500 5661875 5661250 5660625 5660000

B109 B108A B108 B107 B106 B104 B101 B100 B98 B97

1 2 3 4 5 6 7 8 9

Study Area
Storm Sewer
Area of Interest
Outfall
Gated Outfall

Level of Surface - 1:5 Year Event

- Surcharged to Surface
- Surcharged with HWL 0.0 - 2.5 m BG
- Surcharged with HWL >2.5 m BG or Not Surcharged

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

Reference: Data obtained from AltaLIS © Government of Alberta and City of Calgary used under license. Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

1:12,500 metres
125 0 125 250
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Bowness Flood Barrier Project

Storm Sewer LOS - Option 3
1:5-year, 4-hour Design Storm Event
(Design Condition 1 - Flood Gates Open)

Date:	Project:	Submitter:	Reviewer:
March 2021	26638	P. Bishop	A. Chan

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Figure 32

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TABLE 21 Level of Service Summary (Design Condition 1, 1:2 year, 4-hour Design Storm Event, No Pumping)

Outfall Catchment	# of MHs Surcharged to Surface			# of MHs Surcharged[1] with HWL 0.0 – 2.5 m BG			# of MHs Not Surcharged or Surcharged[1] with HWL > 2.5 m BG		
	Existing, Option 2[2]	Option 1	Option 3	Existing, Option 2[2]	Option 1	Option 3	Existing, Option 2[2]	Option 1	Option 3
B97	8	8	8	21	21	21	4	4	4
B98	5	5	5	16	16	16	1	1	1
B100	1	1	1	3	3	3	-	-	-
B101	5	-	5	6	10	6	-	1	-
B104	17	5	8	33	35	38	3	13	7
B106	2	2	2	16	16	16	-	-	-
B107	30	30	30	155	155	155	28	28	28
B108	-	-	-	6	6	6	3	3	3
B108A	-	-	-	7	7	7	-	-	-
B109	2	2	2	25	25	25	9	9	9
TOTAL	**70**	**53**	**61**	**288**	**294**	**294**	**48**	**59**	**51**

Notes:
HWL = High Water Line
BG = Below Ground
[1] Improvements in these columns may not be evident as values may be confounded by other categories.
[2] Option 2 displays the same results as the existing conditions as the solution includes no permanent infrastructure upgrades and relies solely on temporary pumps. Existing conditions LOS summary previously shown in Table 10.

TABLE 22 Level of Service Summary (Design Condition 1, 1:5 year, 4-hour Design Storm Event, No Pumping)

Outfall Catchment	# of MHs Surcharged to Surface			# of MHs Surcharged[1] with HWL 0.0 – 2.5 m BG			# of MHs Not Surcharged or Surcharged[1] with HWL > 2.5m BG		
	Existing, Option 2[2]	Option 1	Option 3	Existing, Option 2[2]	Option 1	Option 3	Existing, Option 2[2]	Option 1	Option 3
B97	10	10	10	22	22	22	1	1	1
B98	11	11	11	10	10	10	1	1	1
B100	1	1	1	3	3	3	-	-	-
B101	5	1	5	6	10	6	-	-	-
B104	21	14	16	30	33	34	2	6	3
B106	3	2	3	15	16	15	-	-	-
B107	62	60	62	139	141	139	12	12	12
B108	-	-	-	6	6	6	3	3	3
B108A	1	1	1	6	6	6	-	-	-
B109	7	7	7	25	25	25	4	4	4
TOTAL	**121**	**47**	**116**	**262**	**272**	**266**	**23**	**27**	**24**

Notes:
HWL = High Water Line
BG = Below Ground
[1] Improvements in these columns may not be evident as values may be confounded by other categories.
[2] Option 2 displays the same results as the existing conditions as the solution includes no permanent infrastructure upgrades and relies solely on temporary pumps. Existing conditions LOS summary previously shown in Table 11.

8.1.1 Option 1 Storm Sewer Network Level of Service Improvements

The results of Design Condition 1 demonstrate the reduction in HGL due to the proposed pumping (permanent and temporary) and improvements resulting from the sewer upgrades and underground storage. The interconnection of B104 does not worsen the LOS in B100/B101 due to the proposed storm sewer improvements in the B100/B101 catchments through to the B100 outfall. No evidence of changes in LOS was seen elsewhere since there were no permanent upgrades, including in the B108 catchment which employs temporary pumping alone.

For Option 1 under Design Condition 1, the combined storm sewer and storage upgrades will provide a 24% improvement in the number of overall surcharged MHs for the 1:2 year, 4-hour design storm (Table 21) and will provide a 61% improvement for the 1:5 year, 4-hour design storm (Table 22). For the 1:2 year, 4-hour design storm (Figure 29), LOS improvements to the minor system can be seen along Boxwood Drive NW (within Outfall Catchment B98), Bowbank Crescent NW (within Outfall Catchment B101), and along Bow Crescent NW and within the alleys between Bow Crescent NW and Bowness Road NW/Bowwater Crescent NW (within Outfall Catchment B104). For the 1:5 year, 4-hour design storm event (Figure 30), LOS improvements can be seen along Bow Crescent NW and in the alley between Bow Crescent NW and Bowness Road NW/ Bowwater Crescent NW (upstream and east of Outfalls B104 and B106). Other isolated LOS improvements were observed near the proposed locations for infrastructure improvements.

8.1.2 Option 3 Storm Sewer Network Level of Service Improvements

Under Design Condition 1, there was slight improvement in the B104 catchment due to the underground storage units (detailed in Section 7.2.3). For the overall Study Area, there was a 13% reduction in surcharging MHs for the 1:2 year, 4-hour design storm (Table 21) compared to existing conditions and a 4% reduction for the 1:5 year, 4-hour design storm (Table 22). No other improvements in the network were seen for Design Condition 1 as there were no other permanent infrastructure upgrades and no pumping.

For both the 1:2 year and 1:5 year, 4-hour design storms, the most significant improvements occurred near the intersection of 63 Street NW and Bowness Road NW with MHs improving from surcharged to surface (red) under existing to HGL below ground (yellow) and HGL significantly below ground (green) for a few nodes (see colour coding in Figures 31 and 32). For the 1:5 year, 4-hour design storm, the intersection of 61 Street NW and Bowwood Drive NW (Figure 32) also showed improvement. As with Option 1, other scattered nodes demonstrated HGL improvements without pumping due to the infrastructure improvements.

8.2 Maximum Depth of Ponding and Risk Mapping

The Areas of Interest identified under the existing conditions (Section 5.3) were revisited along with the general flood risk mapping assessment for each of the mitigation options. The barrier keeps river flood

waters from inundating the Study Area, most notably within the east (B100 and B101) and far northwest portions (B108 and B108A) of the Study Area (Figures 14 to 17).

Table 23 provides a comparison the resulting flooding for the Areas of Interest according to the design criteria.

For the 1:2 year, 4-hour design storm and Design Condition 1 (1:5 year river water level, gates open), all Areas of Interest have ponding depths less than 0.50 m along public road RoWs (Figures 33 and 45). The same is true for the 1:5 year, 4-hour design storm and Design Condition 1, except for two Areas of Interest (#1 and #2) which remained above 0.50 m (Figures 34 and 46). For the 1:5 year, 4-hour design storm under Design Condition 2 (1:20 year river water level, four gates closed), the combination of infrastructure upgrades and permanent pumping reduced surface water ponding within the public road RoWs for six Areas of Interest (#4 through #9) to below 0.50 m. Areas of Interest #2 and #3 demonstrate consistent flooding between 0.3 m and 0.5 m (with minor spots with simulated depths over 0.5 m) within their respective public RoW, however, these areas are largely unaffected by the proposed barrier and also have an acceptable level of risk per the design criteria (Section 5.3.2). Only Area of Interest #1, remained above 0.50 m. Area of Interest #1 is the Bowness Road NW underpass of the CP Rail crossing that exceeds a ponding depth of 0.5 m under existing conditions and under the mitigation options; it is unlikely that surface water ponding depths at this location can be mitigated without a targeted study for this location. This segment of Bowness Road NW under the CP Rail underpass is classified as an arterial road and should have a maximum depth of ponding of 0.3 m following City guidelines for maximum depth of overland flows on roads (The City 2011). While the depth of ponding at Area of Interest #1 is lower under the three mitigation options than existing, the depth of ponding under these scenarios still exceeds 0.3 m. Further investigation of this underpass to reduce flooding to below 0.3 m should be assessed under separate study.

For the 1:5 year, 4-hour design storm and Design Condition 2 (1:5 year river water level, gates open), the four Areas of Interest studied further for QVD exceedance (Table 23) saw improvements and moved from unacceptable to acceptable levels of flooding (Figures 40, 44, and 52). Furthermore, under Design Condition 2 (both design storm events), all exceedances of the QVD threshold (Section 5.3) improved to an acceptable limit with the introduction of the individual mitigation options.

TABLE 23 Flooding Assessment of Areas of Interest (All Options)

Areas of Interest	Location Description [Nearby Outfall]	Design Condition 1[1]				Design Condition 2[2]			
		1:2 year		1:5 year		1:2 year		1:5 year	
		Existing	Proposed	Existing	Proposed	Existing	Proposed	Existing	Proposed
Ponding in public RoWs exceeds a depth of 0.50 m									
1	Bowness Rd NW underpass of CP Rail Crossing								
2	81 St and 46 Ave NW (SE corner of intersection)								
3	69 St NW cul-de-sac north of 48 Ave NW [Outfall B109]								
4	North section of Bow Cres NW (from Y-intersection with 67 St NW to T-intersection at Bow Village Cres NW) [between Outfalls B108 and B108A]								
5	Bowbank Cres NW [Outfall B101]								
6	T-intersection of Bow Cres NW and 33 Ave NW								
7	South section of Bow Cres NW (from Bowness Rd NW to 260m east of Bowness Rd NW)								
8	Bow Cres Park [Outfall B100]								
9	Alley between Bow Cres NW and Bowwater Cres NW, approx. 80 m to 200 m east of Bowness Rd NW								
QVD criteria is exceeded									
1[3]	Bowness Rd NW underpass of CP Rail Crossing								
4[3]	North section of Bow Cres NW (from Y-intersection with 67 St NW to T-intersection at Bow Village Cres NW) [between Outfalls B108 and B108A]								
5[3]	Bowbank Cres NW [Outfall B101]								
7[3]	South section of Bow Cres NW (from Bowness Rd NW to 260m east of Bowness Rd NW)								

Notes:
[1] 1:5 year river level, gates open
[2] 1:20 year river level, gates closed
[3] Repeated locations

8.2.1 Option 1 Flood Risk Mapping

Design Condition 1

Under Design Condition 1 (both design storms), implementing Option 1 generated slight decreases in depths of ponding (approximately 10 cm) for some areas of the B101, B100, and B104 outfall catchments due to the storm sewer upgrades and underground storage.

Design Condition 2

Under Design Condition 2 (1:2 year, 4-hour design storm), the biggest reduction in depth of ponding was near Outfall B104 (approximately 30 cm). A reduction in depth of ponding also occurred within some alleys. The flooded area along Bow Crescent NW (Areas of Interest #6 and #7) and within the B100/B101 catchments cleared with the permanent PS. Additionally, improvements were seen in the B106 catchment even without a gated outfall due to the existing interconnection to the B104 catchments. At this interconnection, the B106 upstream invert is approximately 10 cm higher than the B104 upstream invert. Consequently, flow is preferential to B104 under small storms at this location. The HGL is lowered significantly due to pumping for certain areas on the RoW and within private properties at Bowwood Drive NW and 64 Street NW, especially along the river side.

Easting (m)

-15000 -14375 -13750 -13125 -12500 -11875

Northing (m)

5662500 5661875 5661250 5660625 5660000

B109 B108A B108 B107 B106 B104 B101 B100 B98 B97

1 2 3 4 5 6 7 8 9

Study Area
Design Condition 1 Riverine Flooding
Area of Interest
Outfall
Gated Outfall

Depth of Ponding (m)

Depth ≤ 0.05 m (Acceptable)
0.05 m < Depth ≤ 0.30 m (Acceptable)
0.30 m < Depth ≤ 0.50 m (Acceptable but not preferred)
Depth > 0.50 m (Not Acceptable)

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

Reference: Data obtained from AltaLIS © Government of Alberta and City of Calgary used under license. LiDAR acquired through the City of Calgary used under license. Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community.

1:12,500 metres
125 0 125 250
Calgary 3TM WGS 1984 W114

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City of Calgary
Bowness Flood Barrier Project

Maximum Depth of Ponding - Option 1
1:2-year, 4-hour Design Storm Event and 1:5-year Bow River Flood
(Design Condition 1 – Flood Gates Open)

Date:	Project:	Submitter:	Reviewer:
March 2021	26638	P. Bishop	A. Chan

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Figure 33

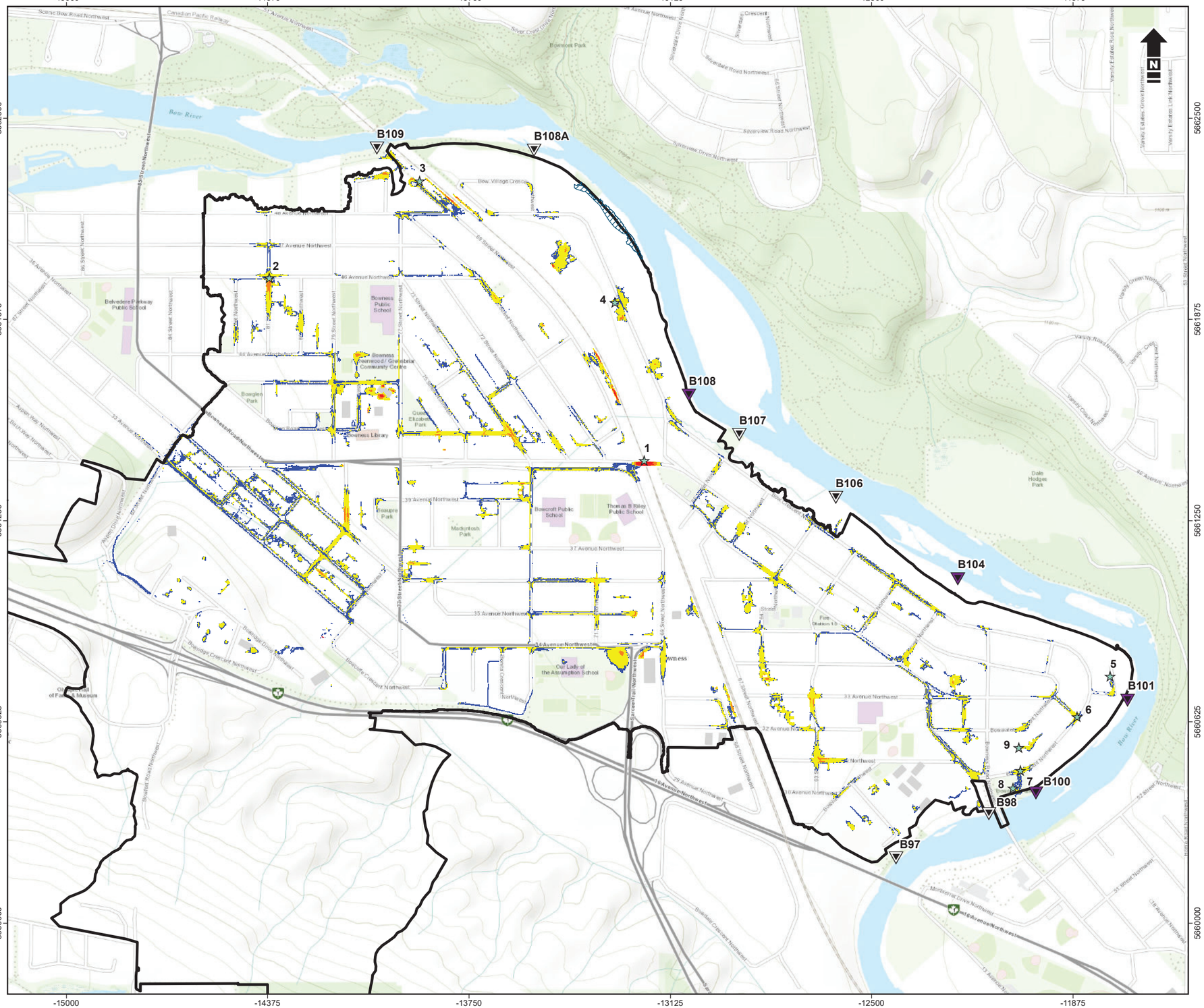
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Easting (m)

-15000 -14375 -13750 -13125 -12500 -11875

Northing (m)

5662500 5661875 5661250 5660625 5660000



Study Area
Design Condition 1 Riverine Flooding
Area of Interest
Outfall
Gated Outfall

Depth of Ponding (m)

- Depth ≤ 0.05 m (Acceptable)
- 0.05 m < Depth ≤ 0.30 m (Acceptable)
- 0.30 m < Depth ≤ 0.50 m (Acceptable but not preferred)
- Depth > 0.50 m (Not Acceptable)

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

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1:12,500 metres
125 0 125 250
Calgary 3TM WGS 1984 W114

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City of Calgary
Bowness Flood Barrier Project

Maximum Depth of Ponding - Option 1
1:5-year, 4-hour Design Storm Event and 1:5-year Bow River Flood
(Design Condition 1 – Flood Gates Open)

Date:	Project:	Submitter:	Reviewer:
March 2021	26638	P. Bishop	A. Chan

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Figure 34

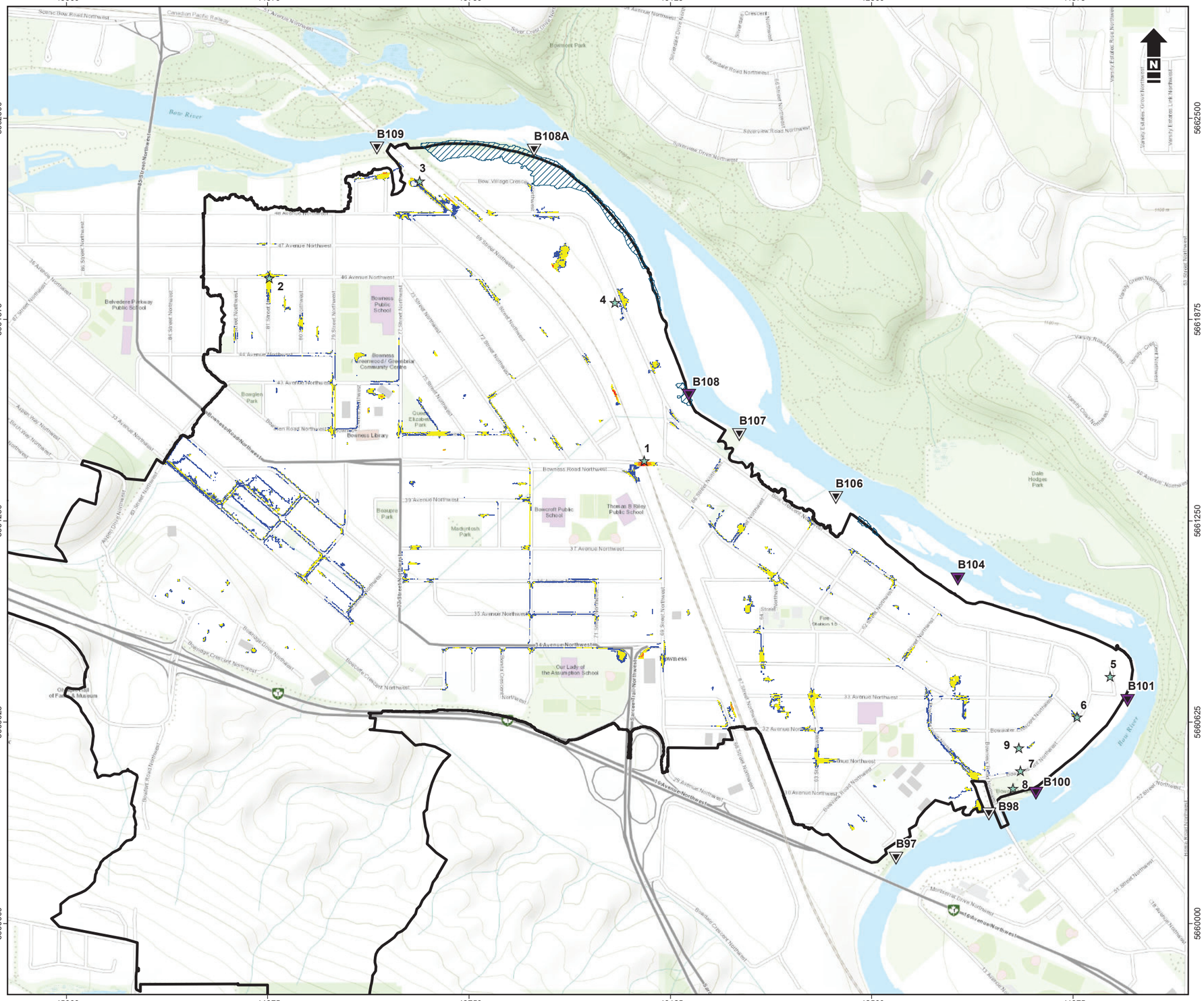
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Easting (m)

-15000 -14375 -13750 -13125 -12500 -11875

Northing (m)

5662500 5661875 5661250 5660625 5660000



- Study Area
- Design Condition 2 Riverine Flooding
- Area of Interest
- Outfall
- Gated Outfall

Depth of Ponding (m)

- Depth ≤ 0.05 m (Acceptable)
- 0.05 m < Depth ≤ 0.30 m (Acceptable)
- 0.30 m < Depth ≤ 0.50 m (Acceptable but not preferred)
- Depth > 0.50 m (Not Acceptable)

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

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1:12,500 metres
125 0 125 250
Calgary 3TM WGS 1984 W114

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Maximum Depth of Ponding - Option 1
1:2-year, 4-hour Design Storm Event and 1:20-year Bow River Flood
(Design Condition 2 – Flood Gates Closed)

Date:	Project:	Submitter:	Reviewer:
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Figure 35

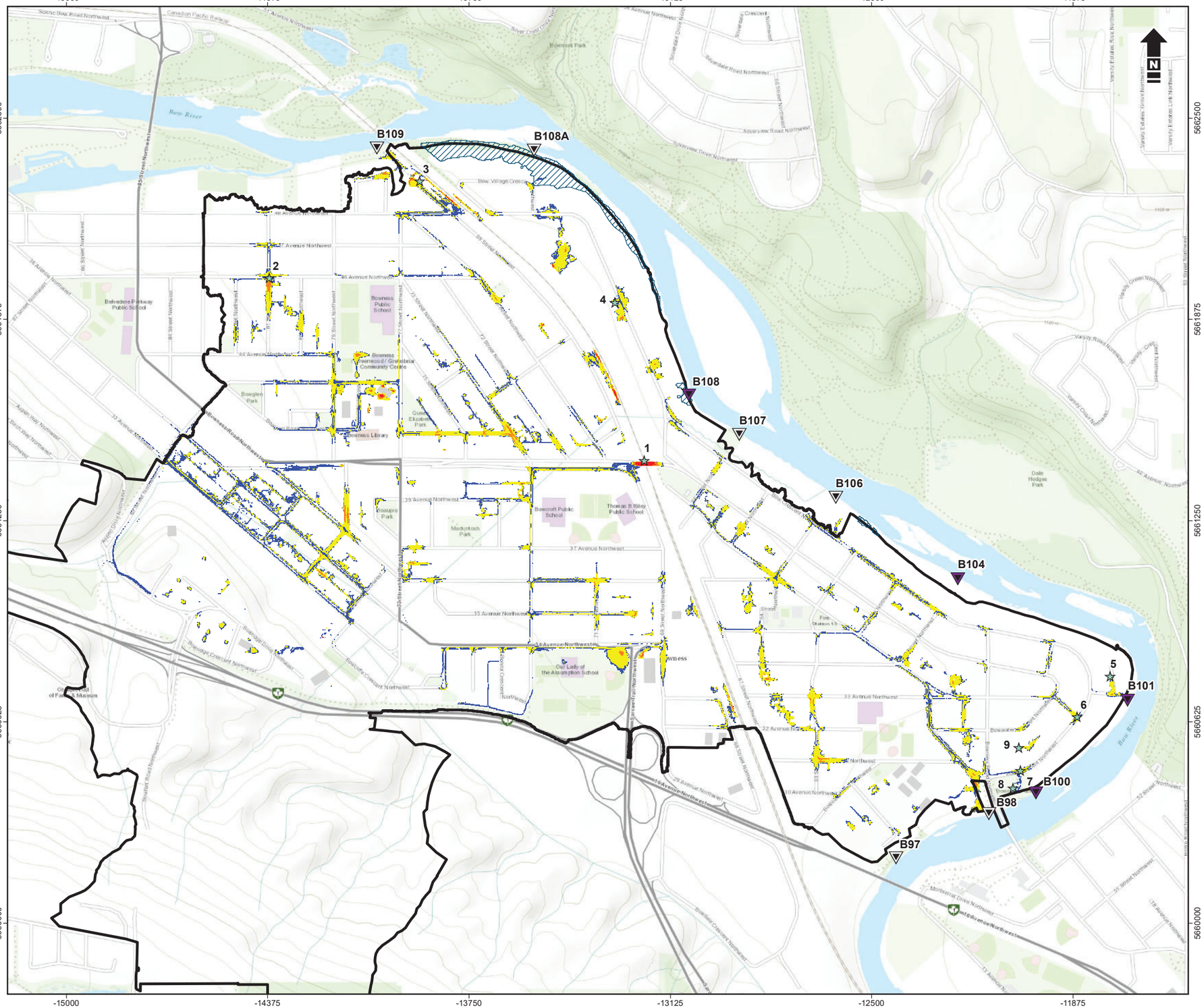
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Easting (m)

-15000 -14375 -13750 -13125 -12500 -11875

Northing (m)

5662500 5661875 5661250 5660625 5660000



- Study Area
- Design Condition 2 Riverine Flooding
- Area of Interest
- Outfall
- Gated Outfall

Depth of Ponding (m)

- Depth ≤ 0.05 m (Acceptable)
- 0.05 m < Depth ≤ 0.30 m (Acceptable)
- 0.30 m < Depth ≤ 0.50 m (Acceptable but not preferred)
- Depth > 0.50 m (Not Acceptable)

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

Reference: Data obtained from AltaLIS © Government of Alberta and City of Calgary used under license. LiDAR acquired through the City of Calgary used under license. Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community.

1:12,500 metres
125 0 125 250
Calgary 3TM WGS 1984 W114

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City of Calgary
Bowness Flood Barrier Project

Maximum Depth of Ponding - Option 1
1:5-year, 4-hour Design Storm Event and 1:20-year Bow River Flood
(Design Condition 2 – Flood Gates Closed)

Date:	Project:	Submitter:	Reviewer:
March 2021	26638	P. Bishop	A. Chan

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Figure 36

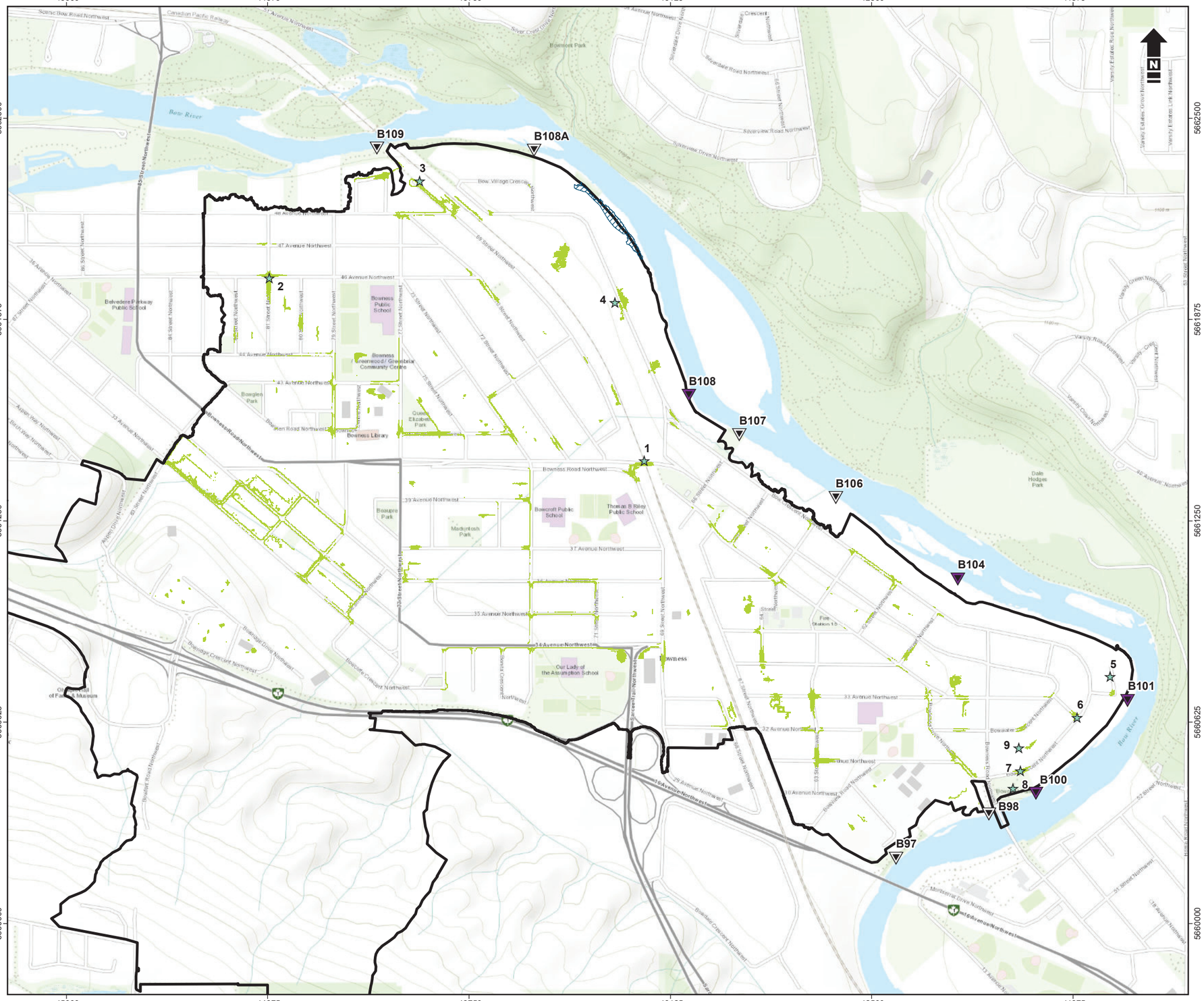
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Easting (m)

-15000 -14375 -13750 -13125 -12500 -11875

Northing (m)

5662500 5661875 5661250 5660625 5660000



- Study Area
- Design Condition 1 Riverine Flooding
- Area of Interest
- Outfall
- Gated Outfall

Flood Risk

- Acceptable
- Not Acceptable

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

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1:12,500 metres
125 0 125 250
Calgary 3TM WGS 1984 W114

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City of Calgary
Bowness Flood Barrier Project

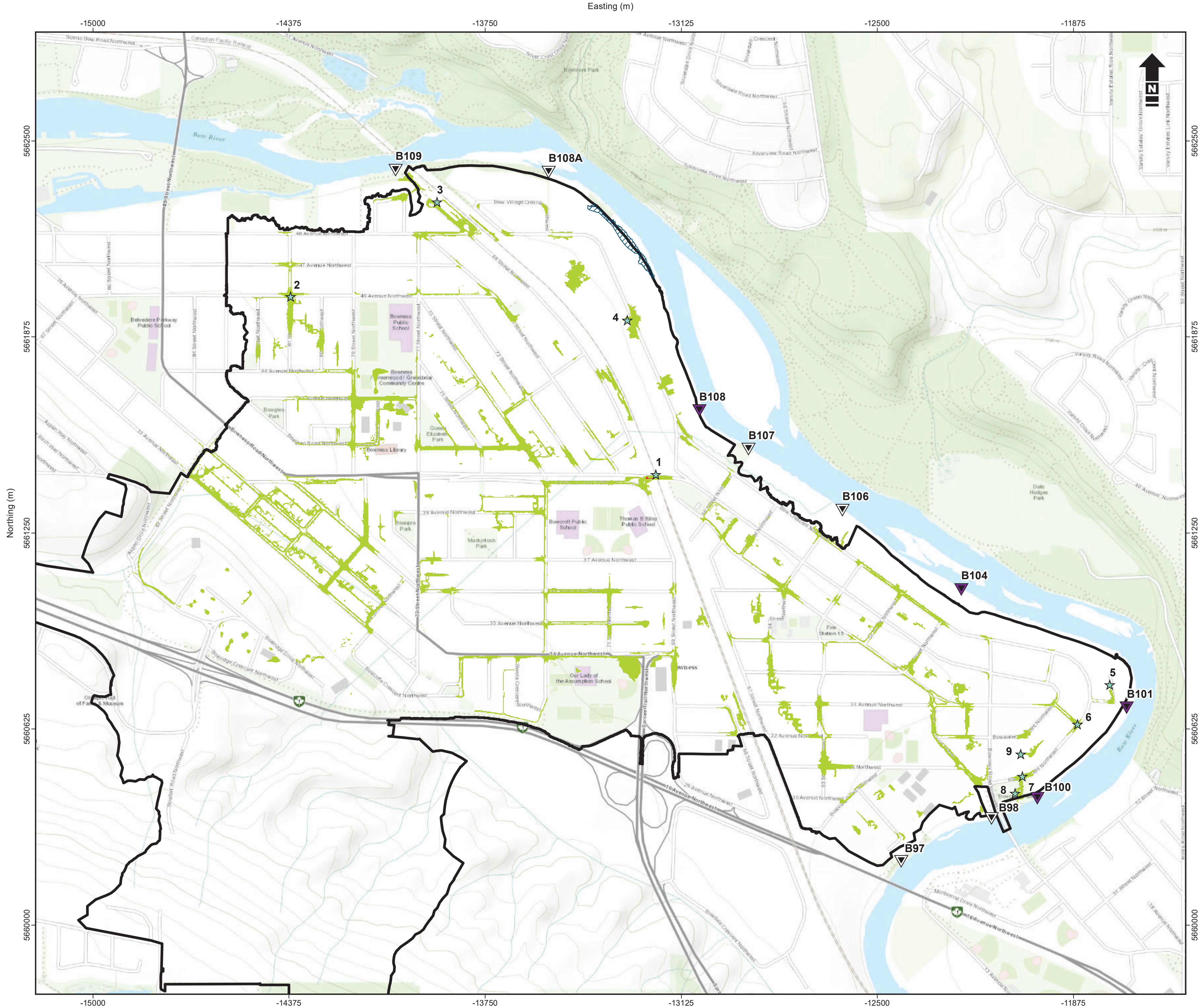
Flood Risk Mapping – Option 1
1:2-year, 4-hour Design Storm Event and 1:5-year Bow River Flood
(Design Condition 1 – Flood Gates Open)

Date:	Project:	Submitter:	Reviewer:
March 2021	26638	P. Bishop	A. Chan

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Figure 37

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Study Area
Design Condition 1 Riverine Flooding
Area of Interest
Outfall
Gated Outfall

Flood Risk

Acceptable
Not Acceptable

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

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1:12,500 metres
125 0 125 250
Calgary 3TM WGS 1984 W114

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City of Calgary
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Flood Risk Mapping – Option 1
1:5-year, 4-hour Design Storm Event and 1:5-year Bow River Flood
(Design Condition 1 – Flood Gates Open)

Date:	Project:	Submitter:	Reviewer:
March 2021	26638	P. Bishop	A. Chan

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Figure 38

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Easting (m)

-15000 -14375 -13750 -13125 -12500 -11875

Northing (m)

5662500 5661875 5661250 5660625 5660000

B109 B108A B107 B108 B106 B104 B101 B100 B98 B97

1 2 3 4 5 6 7 8 9

Study Area
Design Condition 2 Riverine Flooding
Area of Interest
Outfall
Gated Outfall

Flood Risk
Acceptable
Not Acceptable

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

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1:12,500
125 0 125 250 metres
Calgary 3TM WGS 1984 W114

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City of Calgary
Bowness Flood Barrier Project

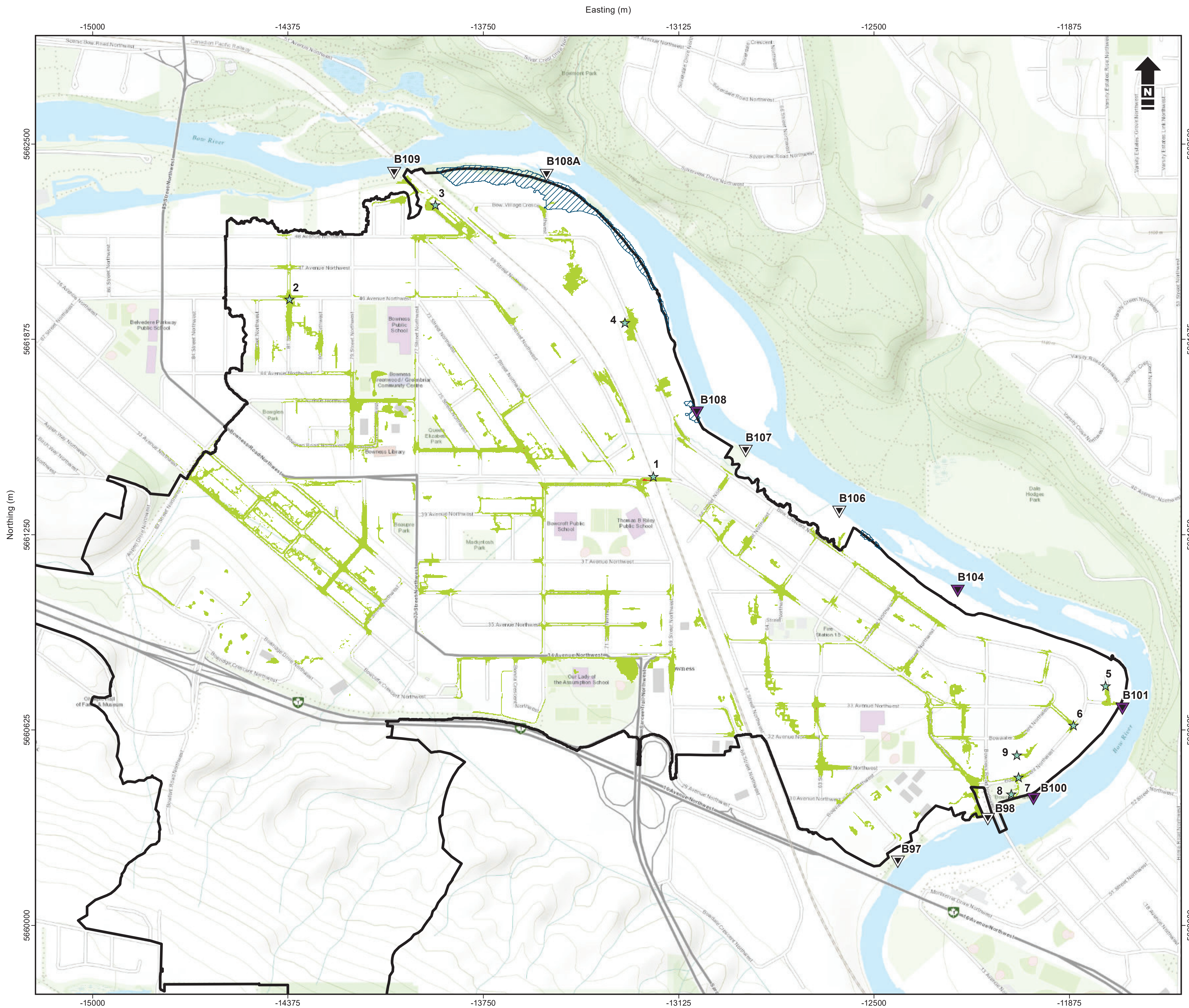
Flood Risk Mapping – Option 1
1:2-year, 4-hour Design Storm Event and 1:20-year Bow River Flood
(Design Condition 2 – Flood Gates Closed)

Date:	Project:	Submitter:	Reviewer:
March 2021	26638	P. Bishop	A. Chan

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Figure 39

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Study Area
Design Condition 2 Riverine Flooding
Area of Interest
Outfall
Gated Outfall

Flood Risk

Acceptable
Not Acceptable

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

1:12,500 metres
125 0 125 250
Calgary 3TM WGS 1984 W114

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Flood Risk Mapping – Option 1
1:5-year, 4-hour Design Storm Event and 1:20-year Bow River Flood
(Design Condition 2 – Flood Gates Closed)

Date:	Project:	Submitter:	Reviewer:
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Figure 40

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8.2.2 Option 2 Flood Risk Mapping

Design Condition 1

There are no permanent infrastructure improvements proposed for Option 2 under Design Condition 1 aside from the barrier; therefore, surface flooding and minor system LOS will be the same as existing conditions. Therefore, the maximum depth of ponding and flood risk maps would match those of the existing conditions (Figures 18 to 21).

Two exceptions were noted where the barrier would impact flooding depths:

1. Back-of-lot riverine flooding for six properties would be improved due to the barrier along Bow Crescent NW (northwest of the B108 outfall). The reduction in riverine flooding at this location would not impact the minor system.

2. Further examination is warranted at the John Hextall Park near the B100 outfall. Although both design criteria are met, additional interception or underground storage may be needed to prevent existing flooding from the traplow on Bow Crescent NW from flowing into John Hextall Park.

Design Condition 2

Under Design Condition 2, the maximum depth of ponding (Figures 41 and 42) and flood risk (Figures 43 and 44) along the river side reduces significantly for large expanses of areas previously modelled as having high depth and risk. The temporary pumps would relieve urban flooding within the Study Area at key locations. Coupled with strategic placements of the temporary pumps, a decrease in flooding is seen along Bowness Road NW and Bow Crescent NW between 60 Street NW and 62 Street NW.

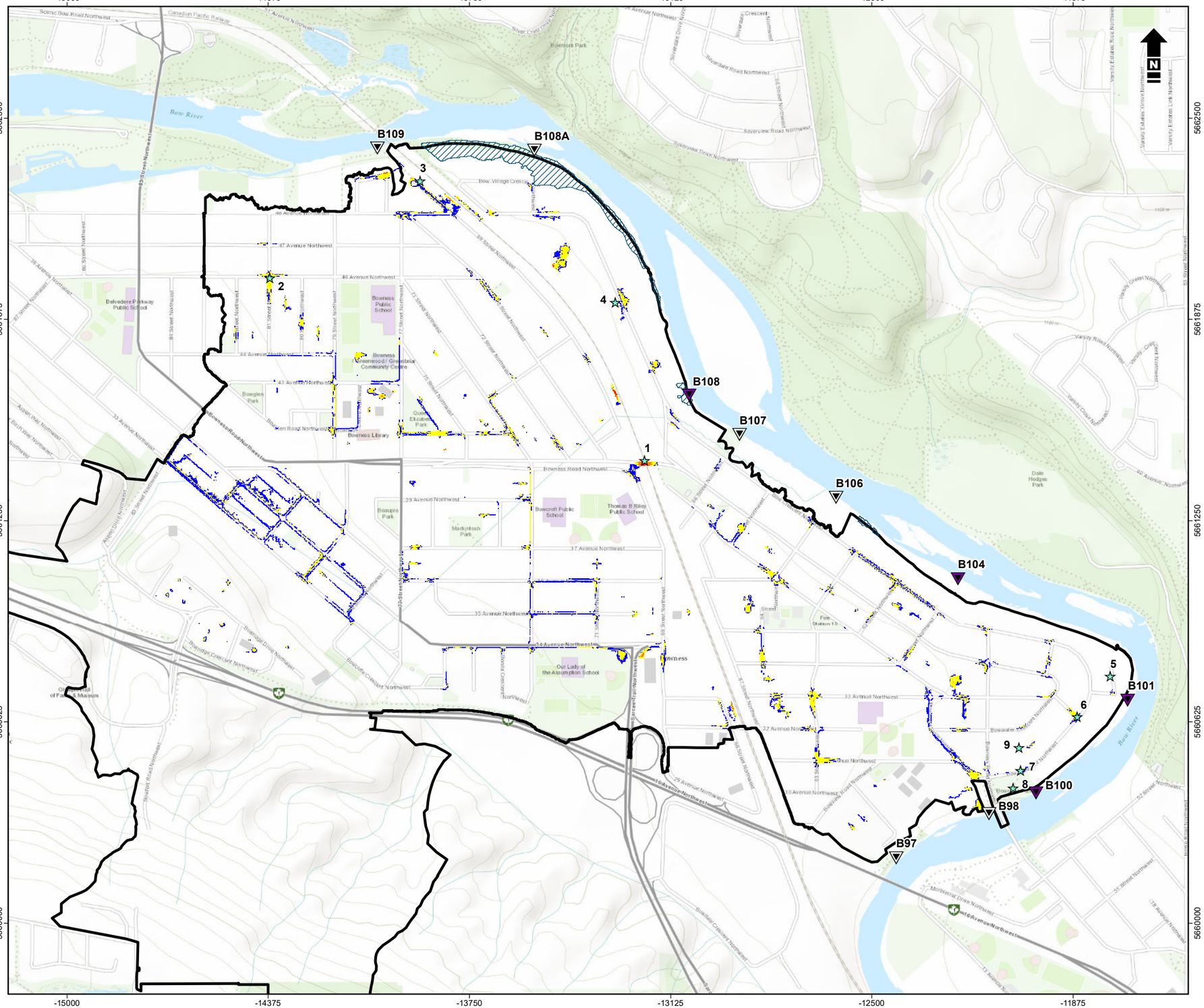
Under Design Condition 2, two areas experienced significant flooding improvements. The first location at Areas of Interest #6 and #7) for which there were widespread depths of ponding that exceeded 0.5 m along the road (without mitigations) reduced to less than 0.05 m in depth (Figures 41 and 42) and eliminating areas previously deemed as unacceptable areas of risk (under the QVD criteria; Figures 43 and 44). Similarly, previous areas of high-risk flooding were eliminated along the road surface at Area of Interest #4).

Easting (m)

-15000 -14375 -13750 -13125 -12500 -11875

Northing (m)

5662500 5661875 5661250 5660625 5660000



Study Area
Design Condition 2 Riverine Flooding
Area of Interest
Outfall
Gated Outfall

Depth of Ponding (m)

- Depth ≤ 0.05 m (Acceptable)
- 0.05 m < Depth ≤ 0.30 m (Acceptable)
- 0.30 m < Depth ≤ 0.50 m (Acceptable but not preferred)
- Depth > 0.50 m (Not Acceptable)

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

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1:12,500
metres
125 0 125 250
Calgary 3TM WGS 1984 W114

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Bowness Flood Barrier Project

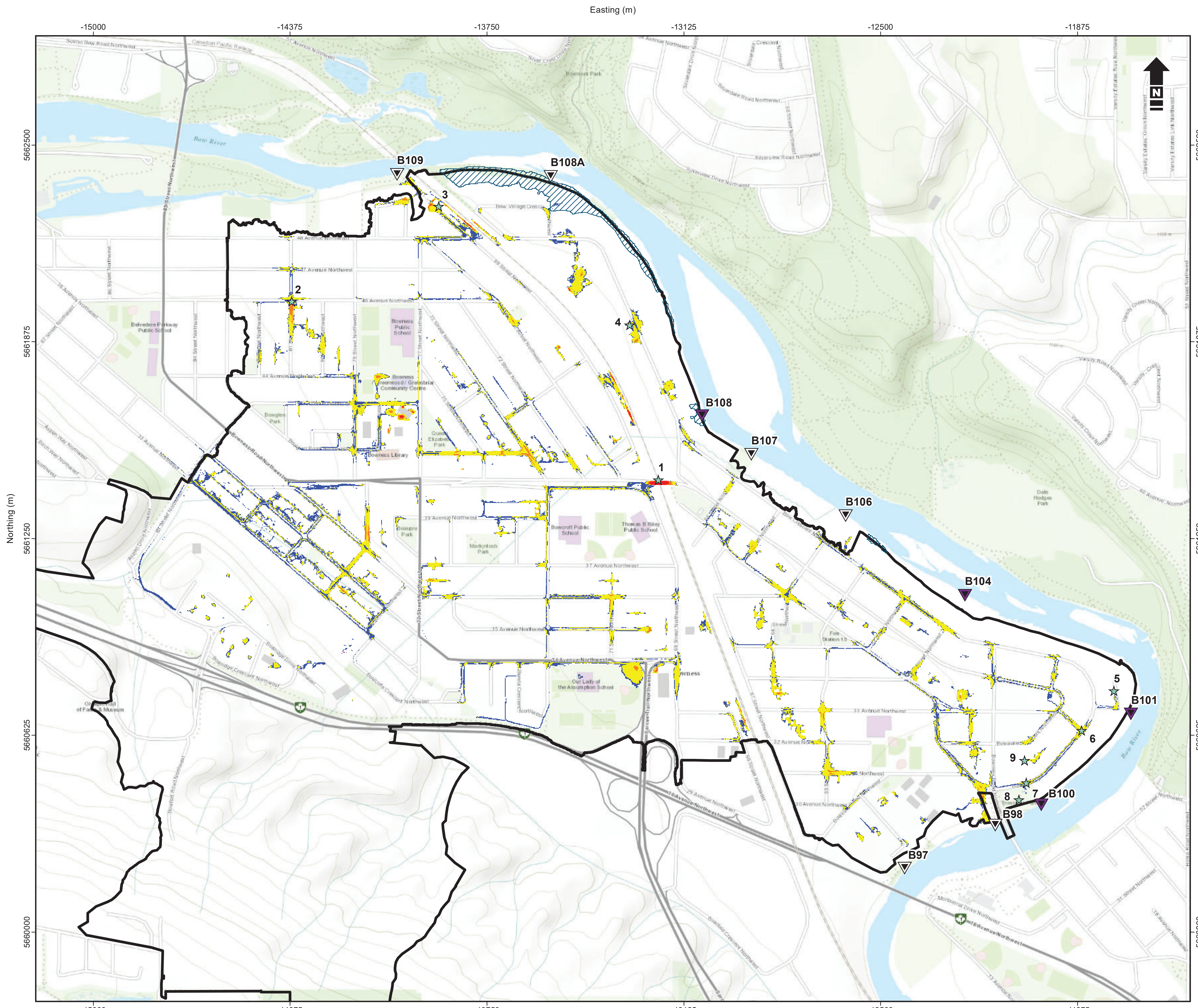
Maximum Depth of Ponding - Option 2
1:2-year, 4-hour Design Storm Event and 1:20-year Bow River Flood
(Design Condition 2 – Flood Gates Closed)

Date:	Project:	Submitter:	Reviewer:
March 2021	26638	P. Bishop	A. Chan

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Figure 41

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Study Area
Design Condition 2 Riverine Flooding
Area of Interest
Outfall
Gated Outfall

Depth of Ponding (m)

Depth ≤ 0.05 m (Acceptable)
0.05 m < Depth ≤ 0.30 m (Acceptable)
0.30 m < Depth ≤ 0.50 m (Acceptable but not preferred)
Depth > 0.50 m (Not Acceptable)

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

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1:12,500 metres
125 0 125 250
Calgary 3TM WGS 1984 W114

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City of Calgary
Bowness Flood Barrier Project

Maximum Depth of Ponding - Option 2
1:5-year, 4-hour Design Storm Event and 1:20-year Bow River Flood
(Design Condition 2 – Flood Gates Closed)

Date:	Project:	Submitter:	Reviewer:
March 2021	26638	P. Bishop	A. Chan

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Figure 42

I:\CityOfCalgary\26638\FiguresAndTables\FLD\2018\Report\Final_Report\Figure-x-x-Maximum Depth_of_Ponding_Option.mxd - Tabloid_L - 22-Mar-21, 07:25 PM - sylam - TID005

Easting (m)

-15000 -14375 -13750 -13125 -12500 -11875

Northing (m)

5662500 5661875 5661250 5660625 5660000

B109 B108A B108 B107 B106 B104 B101 B100 B98 B97

1 2 3 4 5 6 7 8 9

- Study Area
- Design Condition 2 Riverine Flooding
- Area of Interest
- Outfall
- Gated Outfall

Flood Risk

- Acceptable
- Not Acceptable

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

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1:12,500 metres

125 0 125 250

Calgary 3TM WGS 1984 W114

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City of Calgary
Bowness Flood Barrier Project

Flood Risk Mapping – Option 2
1:2-year, 4-hour Design Storm Event and 1:20-year Bow River Flood
(Design Condition 2 – Flood Gates Closed)

Date:	Project:	Submitter:	Reviewer:
March 2021	26638	P. Bishop	A. Chan

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Figure 43

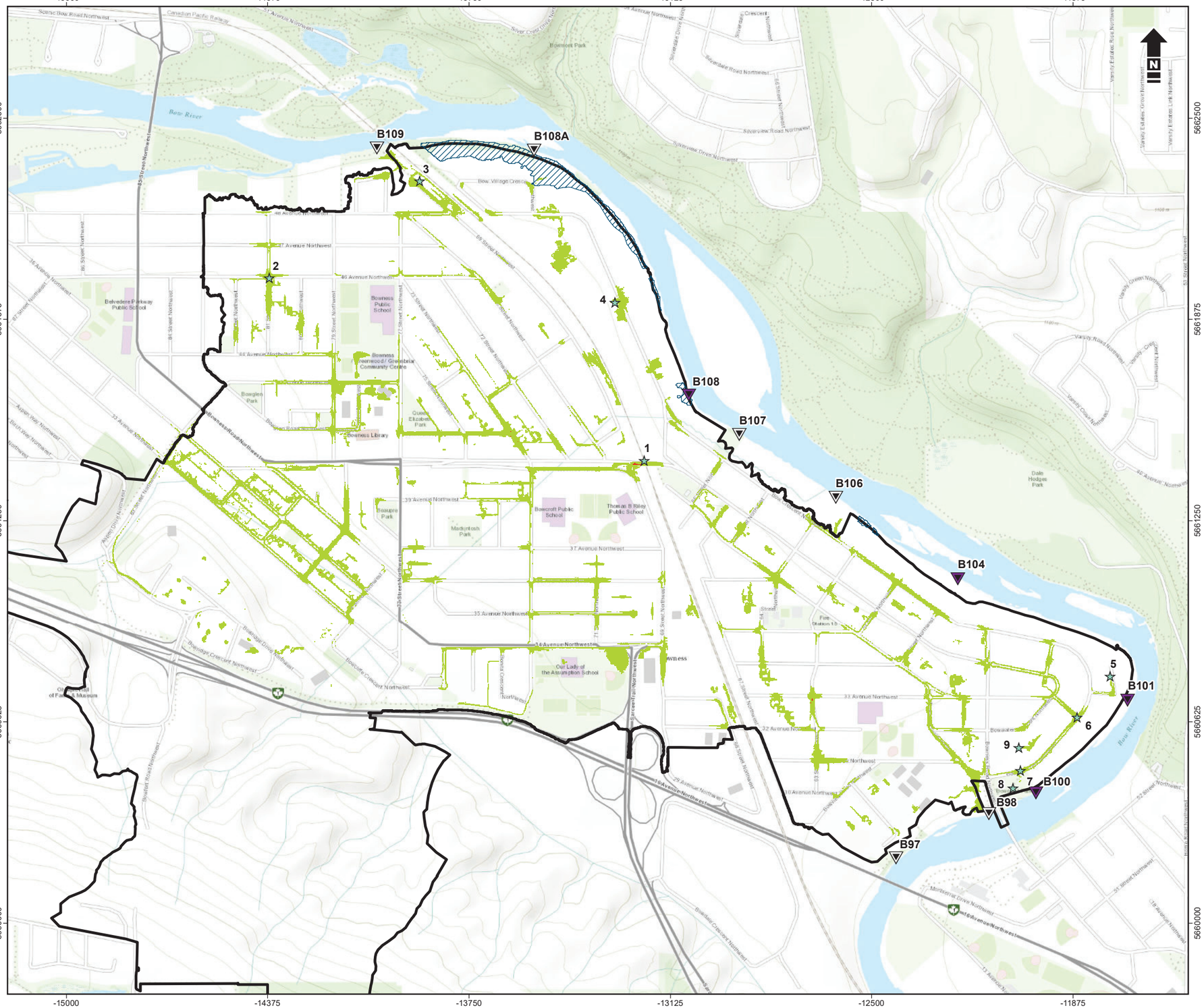
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Easting (m)

-15000 -14375 -13750 -13125 -12500 -11875

Northing (m)

5662500 5661875 5661250 5660625 5660000



Study Area
Design Condition 2 Riverine Flooding
Area of Interest
Outfall
Gated Outfall

Flood Risk

Acceptable
Not Acceptable

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

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1:12,500 metres
125 0 125 250
Calgary 3TM WGS 1984 W114

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City of Calgary
Bowness Flood Barrier Project

Flood Risk Mapping – Option 2
1:5-year, 4-hour Design Storm Event and 1:20-year Bow River Flood
(Design Condition 2 – Flood Gates Closed)

Date:	Project:	Submitter:	Reviewer:
March 2021	26638	P. Bishop	A. Chan

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Figure 44

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8.2.3 Option 3 Flood Risk Mapping

Design Condition 1

The addition of underground storage units resulted in a slight decrease in the maximum depth of ponding near storage B104 (Figures 45 and 46). Flood risk were comparable to existing conditions (Figures 49 and 50). There were no flood improvements elsewhere as there were no further infrastructure upgrades aside from the barrier.

Two exceptions were noted and are described in Section 8.2.2 (back-of-lot riverine flooding Bow Crescent NW and John Hextall Park). Recommendations for these two locations are the same between Options 2 and 3 since there are no differences between these two options at this location.

Design Condition 2

Similar to Option 2, little improvements were seen apart for the area around B104 which improved due to different pumping rates and the storage additions. In the southern portion of the Study Area, Areas of Interest #5 through #9 were improved from the previous widespread depths of ponding that exceeded 0.5 m along the road (without mitigations) reduced to less than 0.05 m in depth (Figures 47 and 48). Similarly, Area of Interest #4 reduced significantly in flood extent and depth due to the barrier and proposed pumping solutions. Flood risks in these same areas improve significantly (Figures 51 and 52).

8.2.4 Maximum Ponding Depths and Flood Risk Mapping Summary

Table 23 summarizes the flood risk assessment for each existing conditions and proposed conditions design scenarios at each Area of Interest. Similar results were observed for all three mitigation options. All options provided significant improvement to flood risk within the Study Area.

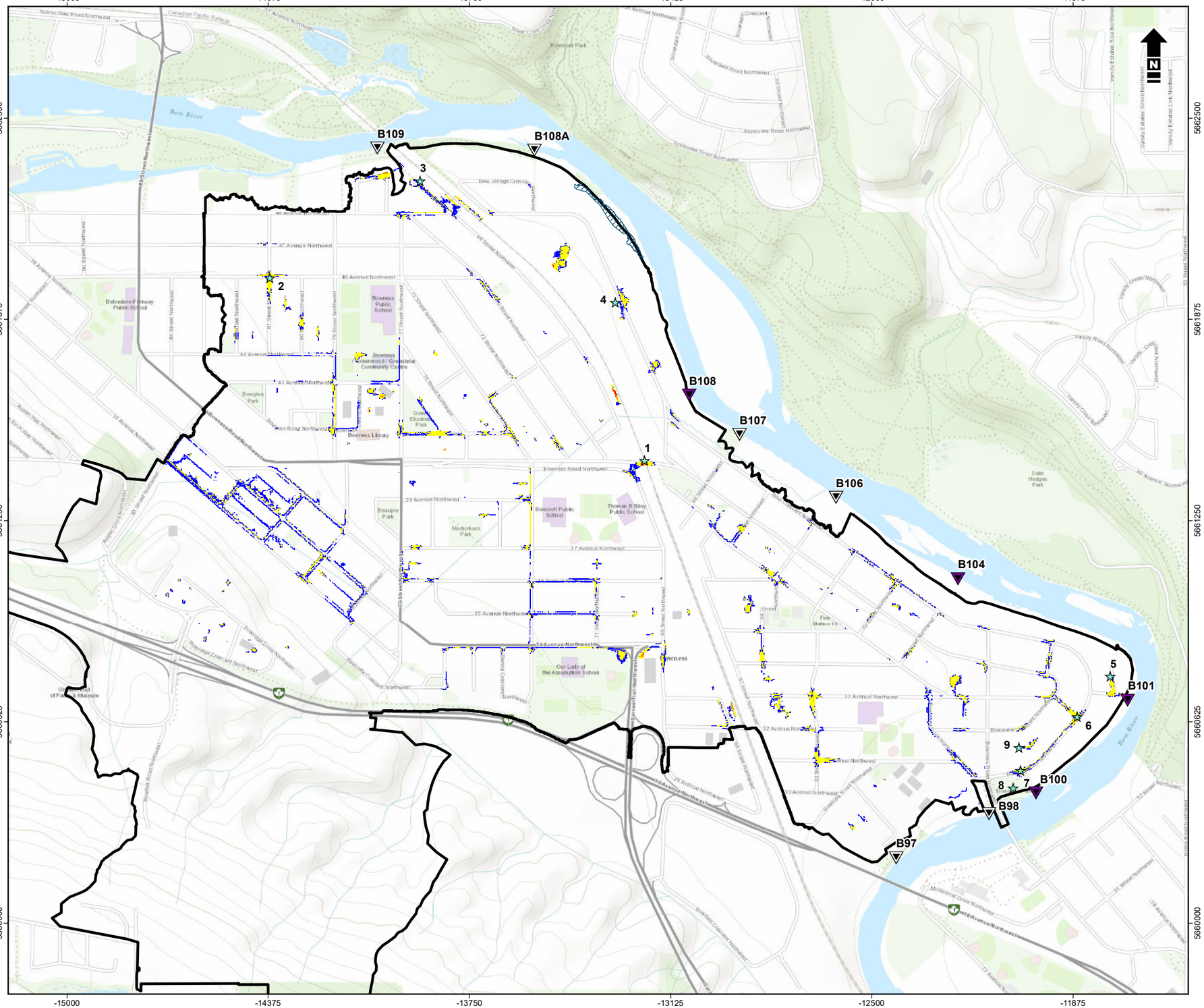
Under Design Condition 2 (both design storm events), ponding depths within public road RoWs were comparable for all three proposed conditions model runs. For the 1:5 year, 4-hour design storm event, Area of Interest #6 saw the greatest improvements in maximum ponding depths. Under Design Condition 1 and Design Condition 2, Area of Interest #4 experiences moderate surface ponding depths.

Easting (m)

-15000 -14375 -13750 -13125 -12500 -11875

Northing (m)

5662500 5661875 5661250 5660625 5660000



Study Area
Design Condition 1 Riverine Flooding
Area of Interest
Outfall
Gated Outfall

Depth of Ponding (m)

Depth ≤ 0.05 m (Acceptable)
0.05 m < Depth ≤ 0.30 m (Acceptable)
0.30 m < Depth ≤ 0.50 m (Acceptable but not preferred)
Depth > 0.50 m (Not Acceptable)

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

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1:12,500
metres
125 0 125 250
Calgary 3TM WGS 1984 W114

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Bowness Flood Barrier Project

Maximum Depth of Ponding - Option 3
1:2-year, 4-hour Design Storm Event and 1:5-year Bow River Flood
(Design Condition 1 – Flood Gates Open)

Date:	Project:	Submitter:	Reviewer:
March 2021	26638	P. Bishop	A. Chan

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Figure 45

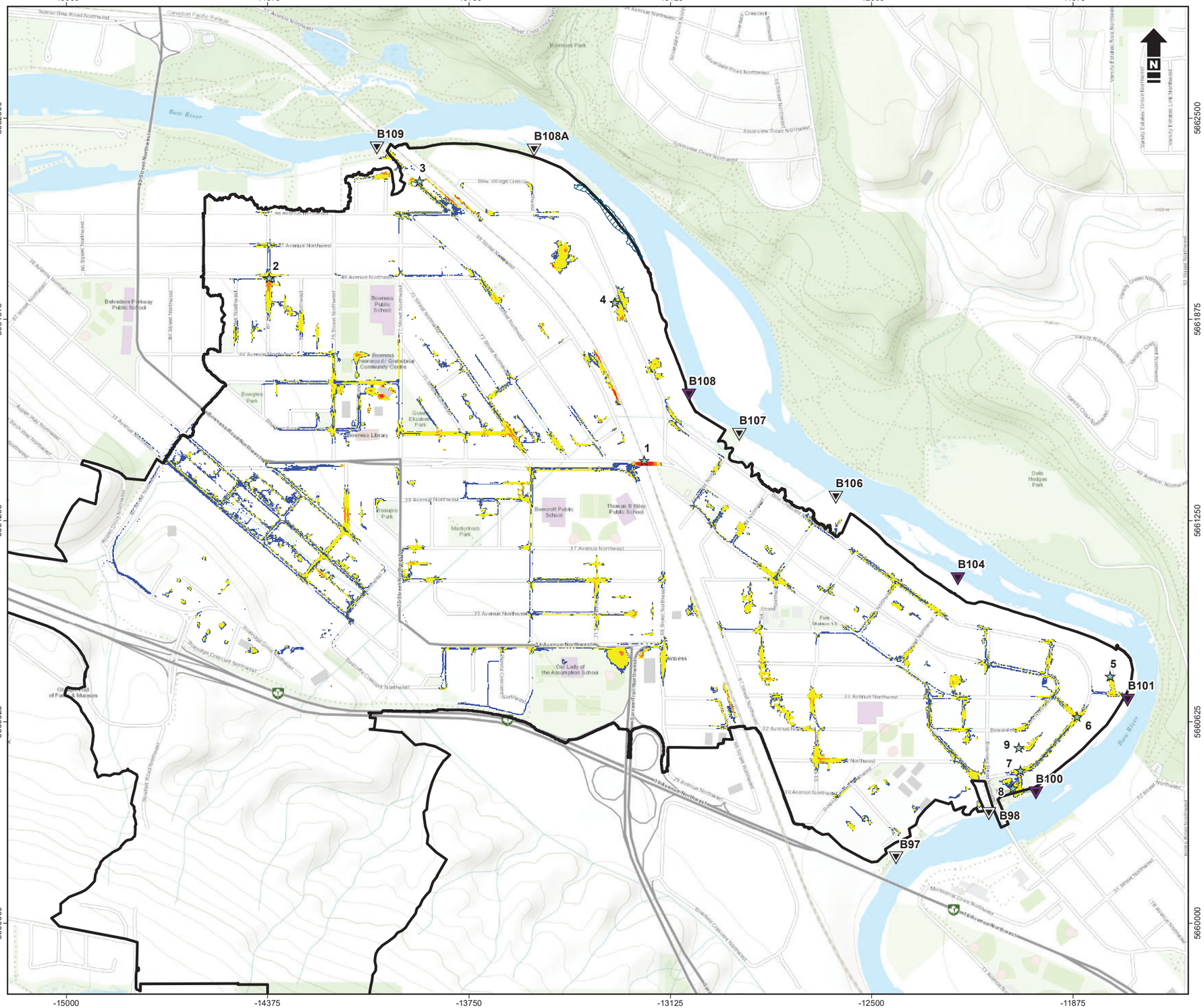
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Easting (m)

-15000 -14375 -13750 -13125 -12500 -11875

Northing (m)

5662500 5661875 5661250 5660625 5660000



Study Area
Design Condition 1 Riverine Flooding
Area of Interest
Outfall
Gated Outfall

Depth of Ponding (m)

Depth ≤ 0.05 m (Acceptable)
0.05 m < Depth ≤ 0.30 m (Acceptable)
0.30 m < Depth ≤ 0.50 m (Acceptable but not preferred)
Depth > 0.50 m (Not Acceptable)

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

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1:12,500
metres
125 0 125 250
Calgary 3TM WGS 1984 W114

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Maximum Depth of Ponding - Option 3
1:5-year, 4-hour Design Storm Event and 1:5-year Bow River Flood
(Design Condition 1 – Flood Gates Open)

Date:	Project:	Submitter:	Reviewer:
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Figure 46

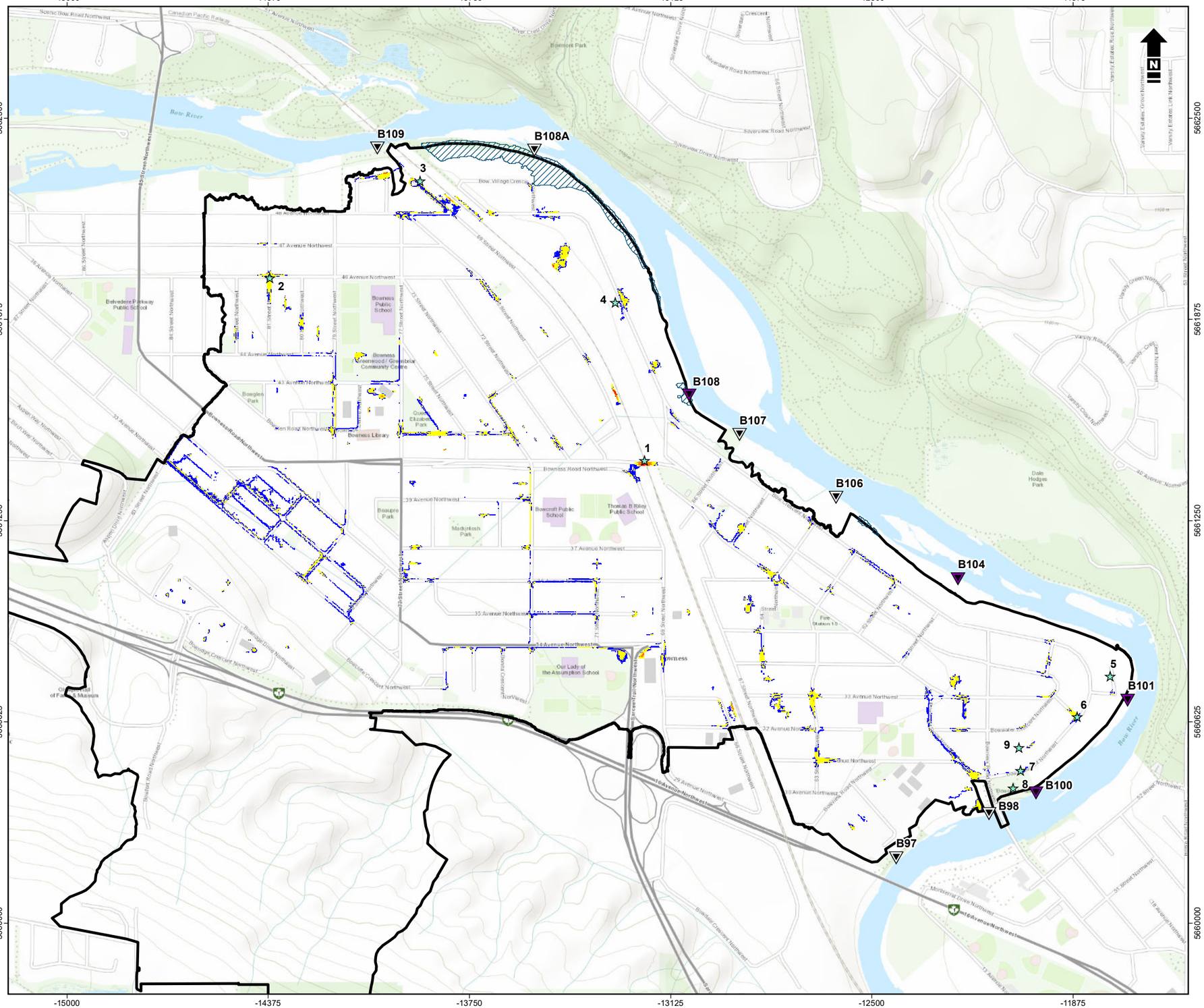
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Easting (m)

-15000 -14375 -13750 -13125 -12500 -11875

Northing (m)

5662500 5661875 5661250 5660625 5660000



Study Area
Design Condition 2 Riverine Flooding
Area of Interest
Outfall
Gated Outfall

Depth of Ponding (m)

- Depth ≤ 0.05 m (Acceptable)
- 0.05 m < Depth ≤ 0.30 m (Acceptable)
- 0.30 m < Depth ≤ 0.50 m (Acceptable but not preferred)
- Depth > 0.50 m (Not Acceptable)

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

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1:12,500
metres
125 0 125 250
Calgary 3TM WGS 1984 W114

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

City of Calgary
Bowness Flood Barrier Project

Maximum Depth of Ponding - Option 3
1:2-year, 4-hour Design Storm Event and 1:20-year Bow River Flood
(Design Condition 2 – Flood Gates Closed)

Date:	Project:	Submitter:	Reviewer:
March 2021	26638	P. Bishop	A. Chan

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Figure 47

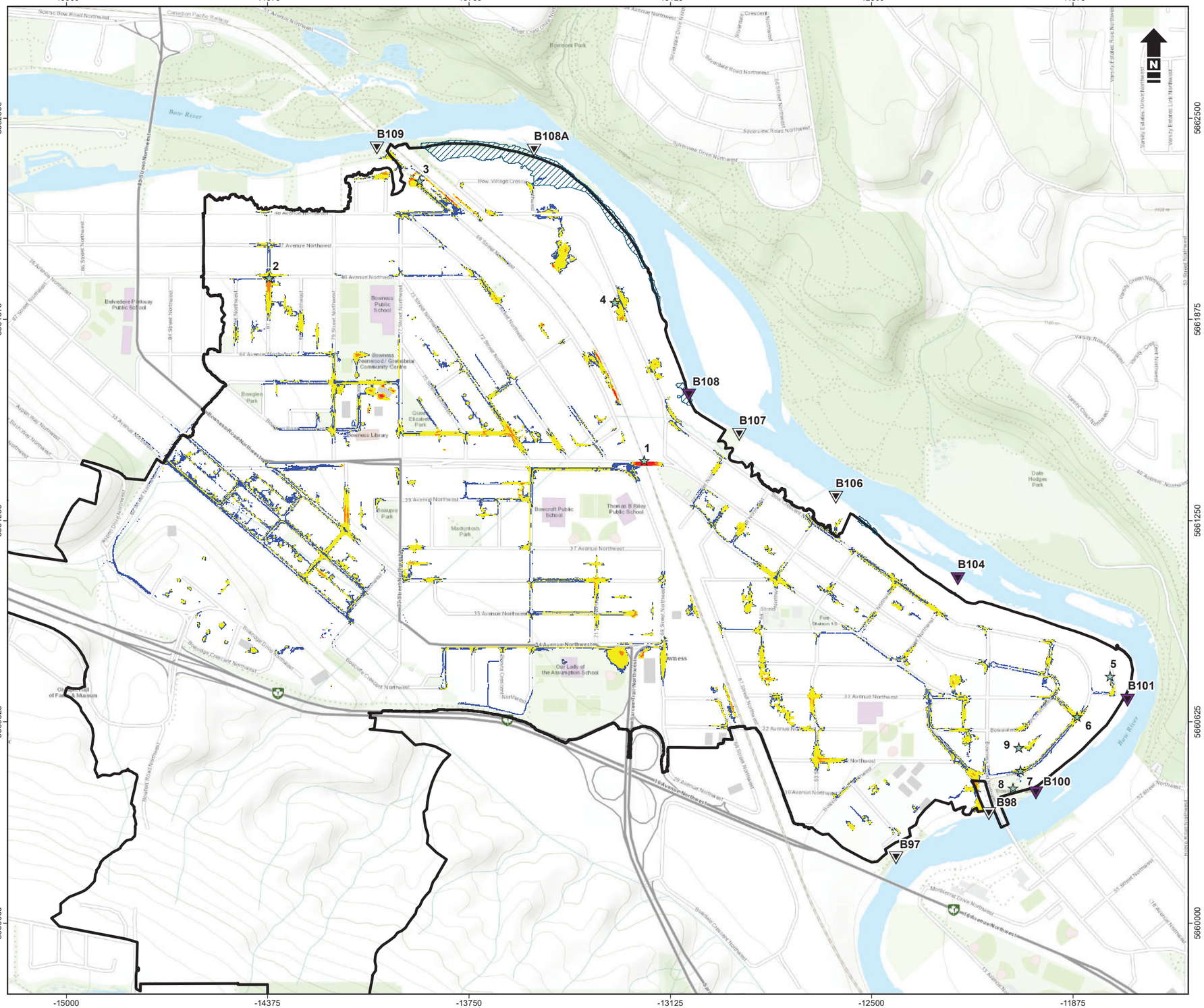
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Easting (m)

-15000 -14375 -13750 -13125 -12500 -11875

Northing (m)

5662500 5661875 5661250 5660625 5660000



Study Area
Design Condition 2 Riverine Flooding
Area of Interest
Outfall
Gated Outfall

Depth of Ponding (m)

Depth ≤ 0.05 m (Acceptable)
0.05 m < Depth ≤ 0.30 m (Acceptable)
0.30 m < Depth ≤ 0.50 m (Acceptable but not preferred)
Depth > 0.50 m (Not Acceptable)

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

Reference: Data obtained from AltaLIS © Government of Alberta and City of Calgary used under license. LiDAR acquired through the City of Calgary used under license. Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community.

1:12,500 metres
125 0 125 250
Calgary 3TM WGS 1984 W114

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

City of Calgary
Bowness Flood Barrier Project

Maximum Depth of Ponding - Option 3
1:5-year, 4-hour Design Storm Event and 1:20-year Bow River Flood
(Design Condition 2 – Flood Gates Closed)

Date:	Project:	Submitter:	Reviewer:
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Figure 48

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Easting (m)

-15000 -14375 -13750 -13125 -12500 -11875

Northing (m)

5662500 5661875 5661250 5660625 5660000

B109 B108A B108 B107 B106 B104 B101 B100 B98 B97

1 2 3 4 5 6 7 8 9

Bow River

Study Area
Design Condition 1 Riverine Flooding
Area of Interest
Outfall
Gated Outfall

Flood Risk
Acceptable
Not Acceptable

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

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1:12,500 metres
125 0 125 250
Calgary 3TM WGS 1984 W114

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

City of Calgary
Bowness Flood Barrier Project

Flood Risk Mapping – Option 3
1:2-year, 4-hour Design Storm Event and 1:5-year Bow River Flood
(Design Condition 1 – Flood Gates Open)

Date:	Project:	Submitter:	Reviewer:
March 2021	26638	P. Bishop	A. Chan

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Figure 49

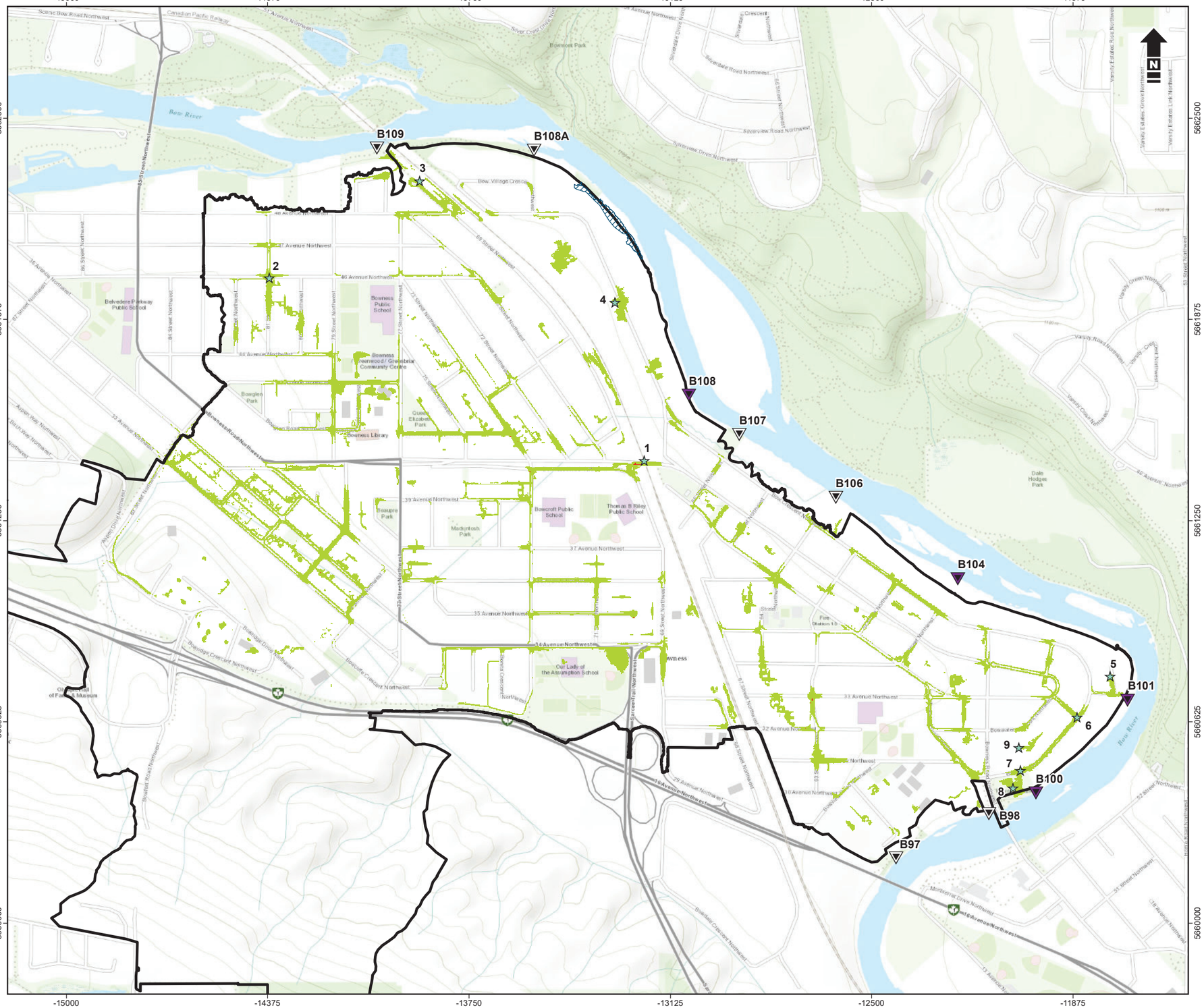
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Easting (m)

-15000 -14375 -13750 -13125 -12500 -11875

Northing (m)

5662500 5661875 5661250 5660625 5660000



- Study Area
- Design Condition 1 Riverine Flooding
- Area of Interest
- Outfall
- Gated Outfall

Flood Risk

- Acceptable
- Not Acceptable

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

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1:12,500 metres

125 0 125 250

Calgary 3TM WGS 1984 W114

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City of Calgary
Bowness Flood Barrier Project

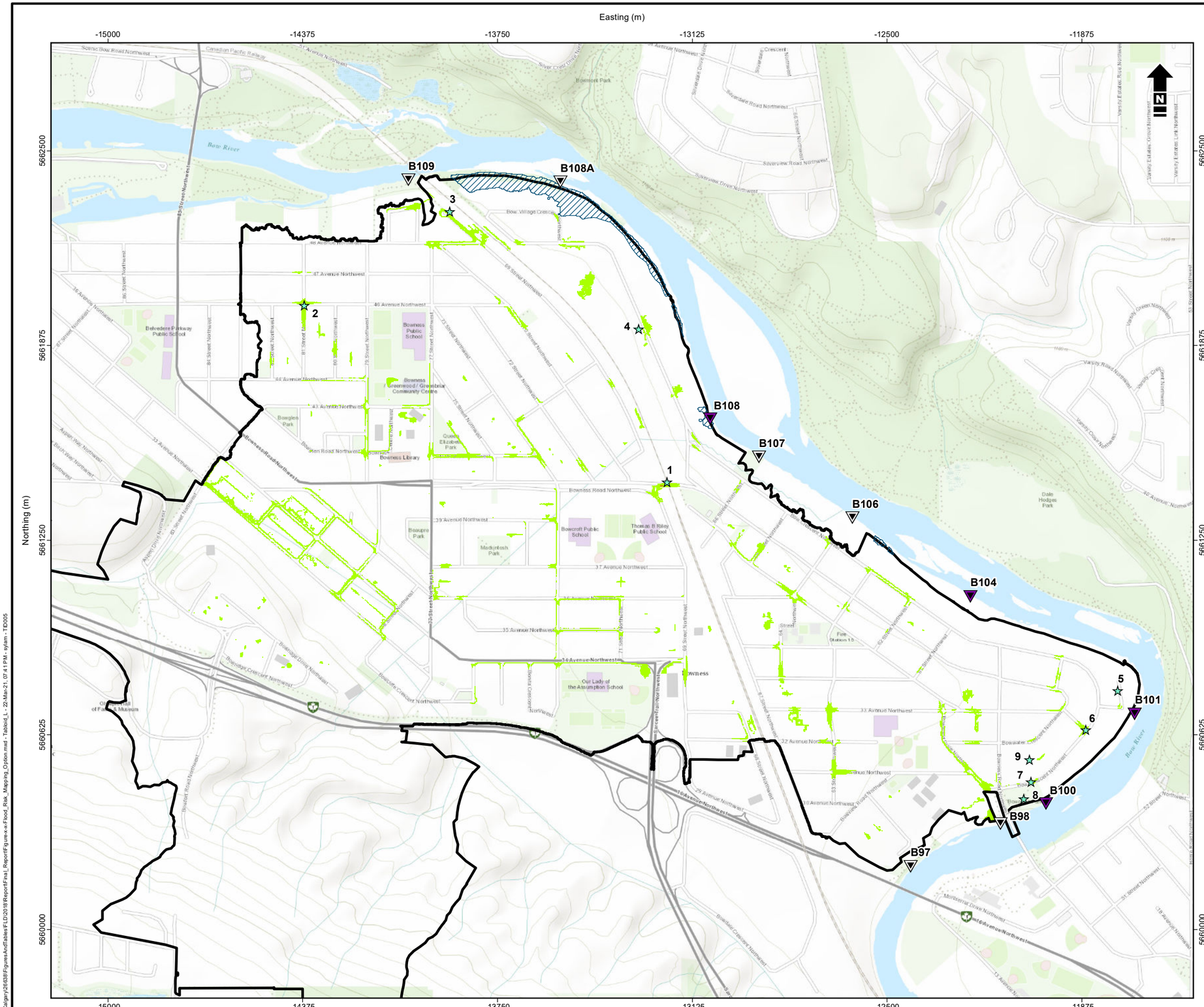
Flood Risk Mapping – Option 3
1:5-year, 4-hour Design Storm Event and 1:5-year Bow River Flood
(Design Condition 1 – Flood Gates Open)

Date:	Project:	Submitter:	Reviewer:
March 2021	26638	P. Bishop	A. Chan

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Figure 50

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Study Area
Design Condition 2 Riverine Flooding
Area of Interest
Outfall
Gated Outfall

Flood Risk
Acceptable
Not Acceptable

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

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1:12,500 metres
125 0 125 250
Calgary 3TM WGS 1984 W114

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

City of Calgary
Bowness Flood Barrier Project

Flood Risk Mapping – Option 3
1:2-year, 4-hour Design Storm Event and 1:20-year Bow River Flood
(Design Condition 2 – Flood Gates Closed)

Date:	Project:	Submitter:	Reviewer:
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Figure 51

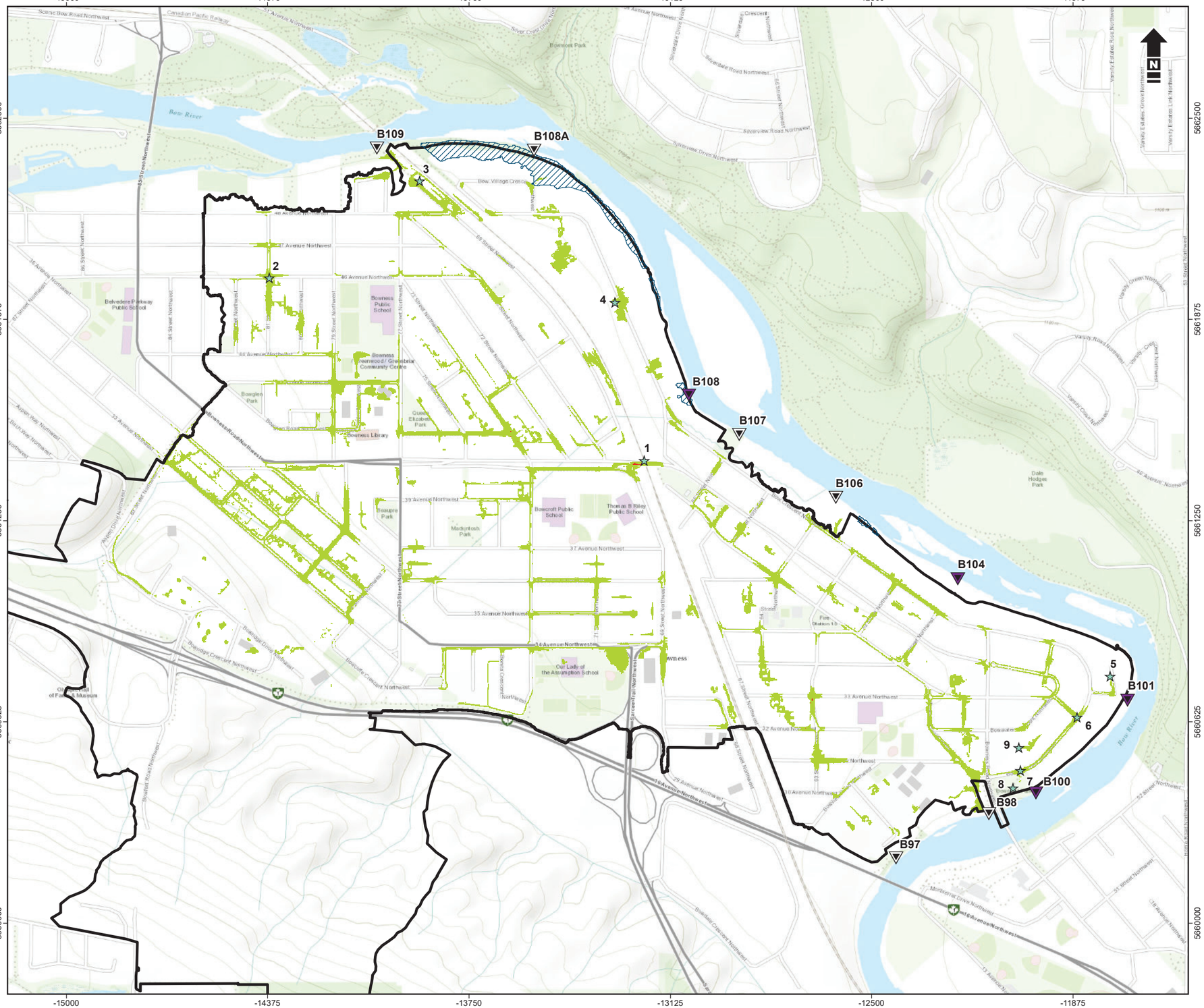
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Easting (m)

-15000 -14375 -13750 -13125 -12500 -11875

Northing (m)

5662500 5661875 5661250 5660625 5660000



Study Area
Design Condition 2 Riverine Flooding
Area of Interest
Outfall
Gated Outfall

Flood Risk
Acceptable
Not Acceptable

Note:
In Design Condition #1, flood gates on all gated outfalls are open.
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1:12,500 metres
125 0 125 250
Calgary 3TM WGS 1984 W114

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

City of Calgary
Bowness Flood Barrier Project

Flood Risk Mapping – Option 3
1:5-year, 4-hour Design Storm Event and 1:20-year Bow River Flood
(Design Condition 2 – Flood Gates Closed)

Date:	Project:	Submitter:	Reviewer:
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Figure 52

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9 EVALUATION OF MITIGATION OPTIONS

9.1 Evaluation Criteria

A high-level subjective evaluation with relative weighting (Table 24) has been completed for each mitigation option. Each option was evaluated using the following categories and rankings that uses a simple rating system of 1 to 3, with a rating of 1 representing less preferred outcomes and a rating of 3 representing better or more preferred outcomes. Categories were grouped into four overall evaluation criteria categories: Technical; Environmental Impacts; Life Cycle; and Social Impacts. After the individual ratings within each category were rated, the sum of the categories ratings was factored by a relative weighting representing their relative perceived importance such that the sum total of all categories yielded an evaluation score out of 100. The weighting and criteria were discussed and confirmed with the City.

9.1.1 Technical (30 points out of 100)

- **Flood Risk Improvement**: the benefit of the mitigation option was based on the improvement in flood risk severity (lowering the risk in flooded areas). Flood risk mapping results for each mitigation option were compared to results for existing conditions (no barrier, no mitigation measures) for the assessed design storms and Bow River flood levels. For this category, all options were designed to provide acceptable flood improvement and therefore all three options were rated the same with a score of 1.

  - 1 - Acceptable: Ponding depth on public roads ≤0.50 m (apart from three existing ponding locations); QVD criteria met.
  - 0 - Not acceptable: Ponding depth on public roads >0.50 m, QVD criteria exceeded.

- **Improved Storm Sewer LOS:** the improvement in the storm sewer network was assessed by the number of total surcharged MHs. The LOS improvement was assessed under Design Condition 1. While both the 1:2 year and 1:5 year, 4-hour design storms were considered, the 1:5 year, 4-hour design storm was used for this evaluation criteria. At the direction of the City, larger urban storms, and different combinations of urban storms and river flood events have not been assessed.

  - 3 - High: significant improvement in number of surcharged MHs (≥50% reduction).
  - 2 - Medium: moderate improvement in number of surcharged MHs (between 10% and 50%).
  - 1 - Low: negligible or little improvement in number of surcharged MHs (≤10% reduction).

- **Detailed Design Considerations:** the relative level of additional assessments required as part of the detailed design. The assessments in this study only considered the combinations of river water levels and urban design storms identified as Design Condition 1 (1:5 year river level, 1:2 year and 1:5 year, 4-hour design storms, gates open) and Design Condition 2 (1:20 year river level, 1:2 year and 1:5 year, 4-hour design storms, gates closed).

- 3 - Low: completed assessments provide sufficient evidence that the option will function as intended.
- 2 - Medium: Some additional assessments will be required to confirm the function of the design.
- 1 - High: Additional assessments over a comprehensive range of conditions are required to ensure the option will function as intended.

- **Deployment Response Time/Activation Time:** the relative response time expected between when a 1:20 year flood event is expected that would trigger the need to close outfall flood gates and deploy pumping mitigations (permanent or temporary). Response time considers the effort and coordination required during a flood event. For example, deploying temporary pumps would require extensive coordination by the City.

  - 3 - High: near-immediate response and limited required coordination.
  - 2 - Medium: generally rapid response, but some potential for delays and need for coordination.
  - 1 - Low: some potential for delays, relies on coordinated efforts.

9.1.2 Environmental (20 points out of 100)

- **Environmental Impacts - Construction**: minimizes impact to the environment resulting from the proposed construction and implementation of the mitigation option.

  - 3 - Low: low impact to the environment, positive impacts.
  - 2 - Medium: moderate impact to the environment, neutral.
  - 1 - High: high impact to the environment, negative impacts.

- **Environmental Impacts - Operations**: considers potential risks to the environment resulting from operation and maintenance of the mitigation option. Examples include potential risks of spill of diesel fuel to operate temporary portable pumps.

  - 3 - Low: low impact to the environment, positive impacts.
  - 2 - Medium: moderate impact to the environment, neutral.
  - 1 - High: high impact to the environment, negative impacts.

9.1.3 Life Cycle Assessment (30 points out of 100)

- **Capital Costs**: the estimated capital costs required to construct and implement the mitigation option. Note that these costs do not include lifecycle, flood damage assessment, operation, or maintenance costs. Other costs such as possible land acquisition costs were not considered.

  - 3 - Low: less than $2,500,000.
  - 2 - Medium: between $2,500,000 and $10,000,000.
  - 1 - High: greater than $10,000,000.

- **Annual Operations and Maintenance (O&M) and Pump Rental Costs**: the estimated annual operation and maintenance costs required as a result of the implemented mitigation option. Other costs pertaining to logistics (such as City coordination of maintenance crews) have not been considered. Deployment of City maintenance crews to undertake temporary pumping has been considered. Multi-year rental contracts for temporary pumps are included in annual O&M costs. O&M and rental costs are based on an estimated 50 year life cycle analysis.

  - 3 - Low: less than $1,000,000.
  - 2 - Medium: between $1,000,000 and $5,000,000.
  - 1 - High: greater than $5,000,000.

9.1.4 Social (20 points out of 100)

- **Social Impacts - Construction**: social impact was determined by assessing the short-term disruptions to residents caused by construction or implementation of the mitigation option measures. Social impacts consider the likelihood of public acceptance of the mitigation option, as well as the opinions of stakeholders. For example, temporary pumping was assessed to have a rating of "Low" and permanent pumping was assessed to have a rating of "High."

  - 3 - Low: low disruptions, low chance of disagreement.
  - 2 - Medium: moderate disruptions, split views on approvals.
  - 1 - High: high disruptions, high chance of disagreement.

- **Social Impacts - Operation**: social impact was determined by assessing the short-term and long-term disruptions to residents caused by operation and maintenance of the mitigation option measures. Social impacts consider the likelihood of public acceptance of the mitigation option.

  - 3 - Low: low disruptions, low chance of disagreement.
  - 2 - Medium: moderate disruptions, split views on approvals.
  - 1 - High: high disruptions, high chance of disagreement.

9.2 Evaluation of Options

Each option was evaluated relative to existing conditions or relative to the other options. The ratings for each option and the totals per category are listed in Table 24. The highest total suggests the preferred option to proceed to detailed design.

TABLE 24 Proposed Conditions Mitigation Option Evaluation

Evaluation Criteria (Weighting)	Option 1 – Barrier with Permanent Pumping and Minor Temporary Pumping	Option 2 – Barrier with Temporary Pumping Only	Option 3 – Barrier with Temporary Pumping and U/G Storage
Technical (30 Points out of 100)			
Flood Risk Improvement	1 - Acceptable	1 - Acceptable	1 - Acceptable
Storm Sewer LOS Improvement	3 - High	1 - Low	1 - Low
Detailed Design Considerations	1 - High	3 - Low	2 - Medium
Deployment Response Time / Activation Time	2 - Medium	1 - Low	1 - Low
Subtotal Technical	**7/10**	**6/10**	**5/10**
Environmental Impacts (20 Points out of 100)			
Through Construction	2 - Medium	3 - Low	3 - Low
Through Operations	3 - Low	2 - Medium	2 - Medium
Subtotal Environmental	**5/6**	**5/6**	**5/6**
Life Cycle (30 Points out of 100)			
Capital Costs	1 - High	3 - Low	2 - Medium
Annual O&M / Pump Rental Costs	2 - Medium	1 - High	1 - High
Subtotal Life Cycle	**3/6**	**4/6**	**3/6**
Social Impacts (20 Points out of 100)			
Through Construction	1 - High	3 - Low	2 - Medium
Through O&M	3 - Low	3 - Low	3 - Low
Subtotal Social	**4/6**	**6/6**	**5/6**
Weighted Total	**66/100**	**75/100**	**63/100**

Notes:
LOS – level of service
O&M – operations and maintenance
U/G – underground

Additional comments to Table 24 have been provided for each of the options:

Option 1:

- Negative to neutral social impact – Construction due to large number of underground upgrades, high but short-term disruption; permanent pumping station is a moderate, medium-term disruption, permanent pumping station (B100) would be located within a City-owned greenspace/park, greenspace to be used as a staging/laydown area, reduction in park footprint due to permanent pumping station and maintenance access.
- Storm sewer construction at multiple locations and high potential for conflicts with existing utility piping and service connection crossings.
- Regulatory permitting and approvals required for upgrades to Outfalls B100 & B104.
- High capital construction cost to implement permanent pumping station.
- Low O&M costs for B108 temporary pumping station.

Option 2:

- Temporary pumping only required under Design Condition 2 (1:20 year river flood).
- This design is the most flexible and would only be deployed based on need during flood events.
- Potential land acquisition required for easements access to pump stormwater to the Bow River.
- Low social impact – O&M due to short-term disruption during temporary pumping (as required).
- Low cost to implement, no permanent infrastructure constructed
- Multi-year rental contracts required to reserve temporary pumps and City crews required to deploy and operate.

Option 3:

- Temporary pumping only required under Design Condition 2 (1:20 year river flood).
- Potential land acquisition required for easements access to pump stormwater to the Bow River.
- Medium social impact – Construction due to high, short-term disruption from underground storage construction.
- Low social impact – O&M due to short-term disruption during temporary pumping (as required).
- Low cost to implement (with potential disruptions), but multi-year rental contracts required to reserve temporary pumps and City crews required to deploy and operate.

9.3 Evaluation Summary

The evaluation presented above indicates that Option 2 is the highest ranked option. Following detailed design and the associated assessments, each of the options will meet the objective for flood risk. The biggest differences between these options are the overall operational approach and the costs.

- Option 1 has a high capital cost and a higher lifecycle cost; however, the proposed infrastructure would require minimal hands-on deployment during a flood situation. Nonetheless, the frequency of use (perhaps for a 1:200 year flood event) is of concern as this may yield a low return on investment.

- Option 2 requires no new infrastructure and has a moderate lifecycle cost. This option requires deployment of 30 temporary pumps in a flood situation with associated staff and equipment mobilization considerations. A sensitivity analyses that was conducted by varying the criteria weightings (i.e., varying each of the evaluation criteria components upwards and downwards by 30 points), revealed that Option 2 was still the highest ranked among the three options.

- Option 3 requires the construction of new underground storage; however, 28 temporary pumps would be required. The staff and equipment mobilization considerations would be similar to Option 2.

10 CONCLUSION

The Project investigated stormwater strategies for the Bowness neighbourhood to ensure that implementation of the proposed Bowness Flood Barrier (intended to reduce riverine flooding) would not result in more frequent urban flooding (i.e., flooding due to rainfall runoff). A three-way model (1D urban, 2D overland, and 1D river) was built to assess drainage and flooding within the Study Area and establish a baseline for existing conditions (no barrier, no mitigation measures). The existing conditions model results were compared to model results for the proposed mitigation options to quantify improvements and selected a preferred mitigation option.

Under existing conditions, the modelled minor systems within the Study Area provide less than a 1:2 year, 4-hour LOS. Under existing conditions, Design Condition 1 (1:5 year, 4-hour storm event, 1:5 year river flood event, all outfall gates open), surface water ponding (overland flooding) within the public road RoWs exceeds 0.50 m at two Areas of Interest within the Study Area: Location ID 1 - Bowness Road NW underpass of CP Rail, and Location ID 2 - SE corner of the intersection of 81 Street and 46 Avenue NW. Larger, less frequent urban storm events will likely result in the inundation of more low-lying areas within the Study Area and produce deeper depths of ponding within public road RoWs, and should be modelled in future design phases. Furthermore, existing condition results under Design Condition 2 (1:20 year river flood event, four outfall flood gates closed) revealed significantly higher HGLs, with more surcharge within the minor system and more surcharging to surface at existing CBs and MHs. Larger urban storms and/or river flood levels will further stress the storm sewer network and exacerbate surcharging to surface. The low LOS performance of the existing storm sewer network within the Study Area is similar to that of other older communities in Calgary. It is recommended that the performance of the stormwater systems of the Bowness community be evaluated under the City's CDI program to evaluate and propose prioritized drainage improvements beyond the stormwater infrastructure upgrades recommended to mitigate impacts resulting from the implementation of the proposed barrier.

Proposed mitigations to facilitate back-of-lot drainage toward the Bow River (with the barrier in place) may include surface culverts. Some properties may be outfitted with CBs within their rear yard – back-of-lot drainage would be directed into the CB and collected flows would either be pumped or flow by gravity into the existing storm sewer along Bow Crescent NW. Portable diesel-powered pumps can also be deployed to dewater backyard areas upland of the barrier during extreme events. Stormwater would be pumped over top of the barrier and be directed into the Bow River. Back-of-lot drainage will be assessed during detailed design of the barrier on a lot-by-lot basis.

Stormwater system improvements will be required to mitigate any potential increase in overland flooding resulting from outfall flood gates being closed during a 1:20 year river flood event. These stormwater mitigations will provide protection to the community of Bowness - the proposed barrier would provide protection from riverine flooding and the proposed mitigation options would address urban flooding effects on the major and minor system.

The following three mitigation options, which include stormwater pumping solutions (permanent and/or temporary), temporary underground storage, storm sewer diversions, and/or storm sewer upgrades, were identified and evaluated as part of this Project:

- Option 1: Barrier with Permanent Stormwater Pumping Station at B100, Temporary Pumping at B108 and Underground Storage.
- Option 2: Barrier with Temporary Pumping Only.
- Option 3: Barrier with Temporary Pumping and Underground Storage.

In all three options, the areas of unacceptable flooding were nearly eliminated. Ponding in public RoWs exceeding 0.50 m was eliminated at all but three Areas of Interest (#1 to #3); these areas have an acceptable risk tolerance as per the design criteria and deemed acceptable. The City should investigate individual storm drainage mitigation in these areas as part of a future Bowness CDI project if flood depth improvement is desired at these areas. Upon comparison of the maximum ponding depth and flood risk mapping assessment, each option produced comparable reductions to overall risks (acceptable and unacceptable) under Design Condition 2 and the 1:5 year, 4-hour design storm events.

11 RECOMMENDATIONS

Matrix recommends that *Option 2 – Barrier with Temporary Pumping Only* be considered by the City for advancement to the next phase of design, should the proposed Bowness Flood Barrier Project be advanced for detailed design.

Given the current analysis and Project objective, Matrix has provided recommendations for future design on the following:

- The automation of motor-operated lifts at existing outfalls currently equipped with flood gates should be investigated to improve response time and safety of City crews (excluding flood gate B104 which is located in the Bow Crescent NW RoW).

- Once the barrier and back-of-lot drainage is in place restrictions should be placed on future developments for riverfront properties along and adjacent to the barrier to avoid disrupting the designed drainage pattern. Should future development be required, adequate and complimentary drainage should be proven in a formal document stamped by a qualified and licensed engineer. Back-of-lot drainage details for each lot will be assessed during detailed design of the barrier.

Whether the Bowness Flood Barrier Project proceeds, Matrix also recommends that the performance of the stormwater systems of the Bowness community be evaluated under the City's CDI program to evaluate and propose prioritized drainage improvements for problem locations within the broader Bowness community that are not caused by the proposed barrier (which is beyond the scope of this current study). The modelling and assessment work carried out for this study would be used as the basis for a future CDI study. Additional recommendations may be generated from a future CDI study that addresses stormwater management criteria or upgrades that should be implemented to protect the Bowness community as future planning and development of the community advances.

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APPENDIX A
Hydraulic Grade Line Plots

APPENDIX A1
Existing Conditions

Easting (m)

-15000 -14375 -13750 -13125 -12500 -11875

Northing (m)

5662500 5661875 5661250 5660625 5660000

B109 B108A B108 B107 B106 B104 B101 B100 B98 B97

Bow River

Study Area
Proposed Flood Barrier Alignment (Option A)
Proposed Flood Barrier Alignment (Option B)
Hydraulic Grade Line
Storm Sewer
Modelled Storm Manhole/Catchbasin
Gated
Gated Outfall (Existing)

Note:
B106 outfall is not gated under the Proposed Options.
In Design Condition #1, flood gates on all gated outfalls are open.
In Design Condition #2, flood gates on all gated outfalls are closed.

Reference: Data obtained from AltaLIS © Government of Alberta and City of Calgary used under license. Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community.

1:12,500 metres
125 0 125 250
Calgary 3TM WGS 1984 W114

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City of Calgary
Bowness Flood Barrier Project

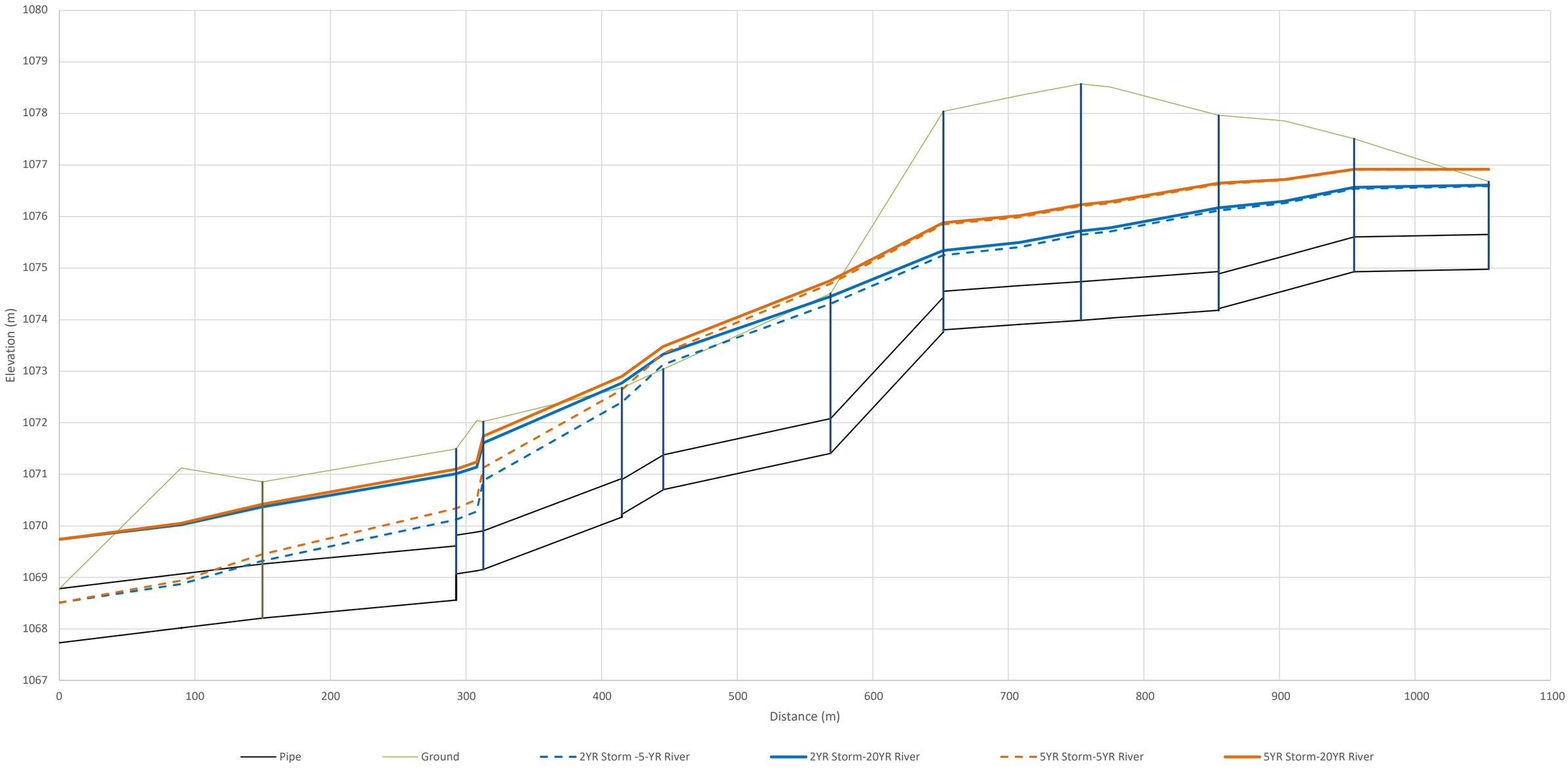
Hydraulic Grade Lines | Overview

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Figure A1-1

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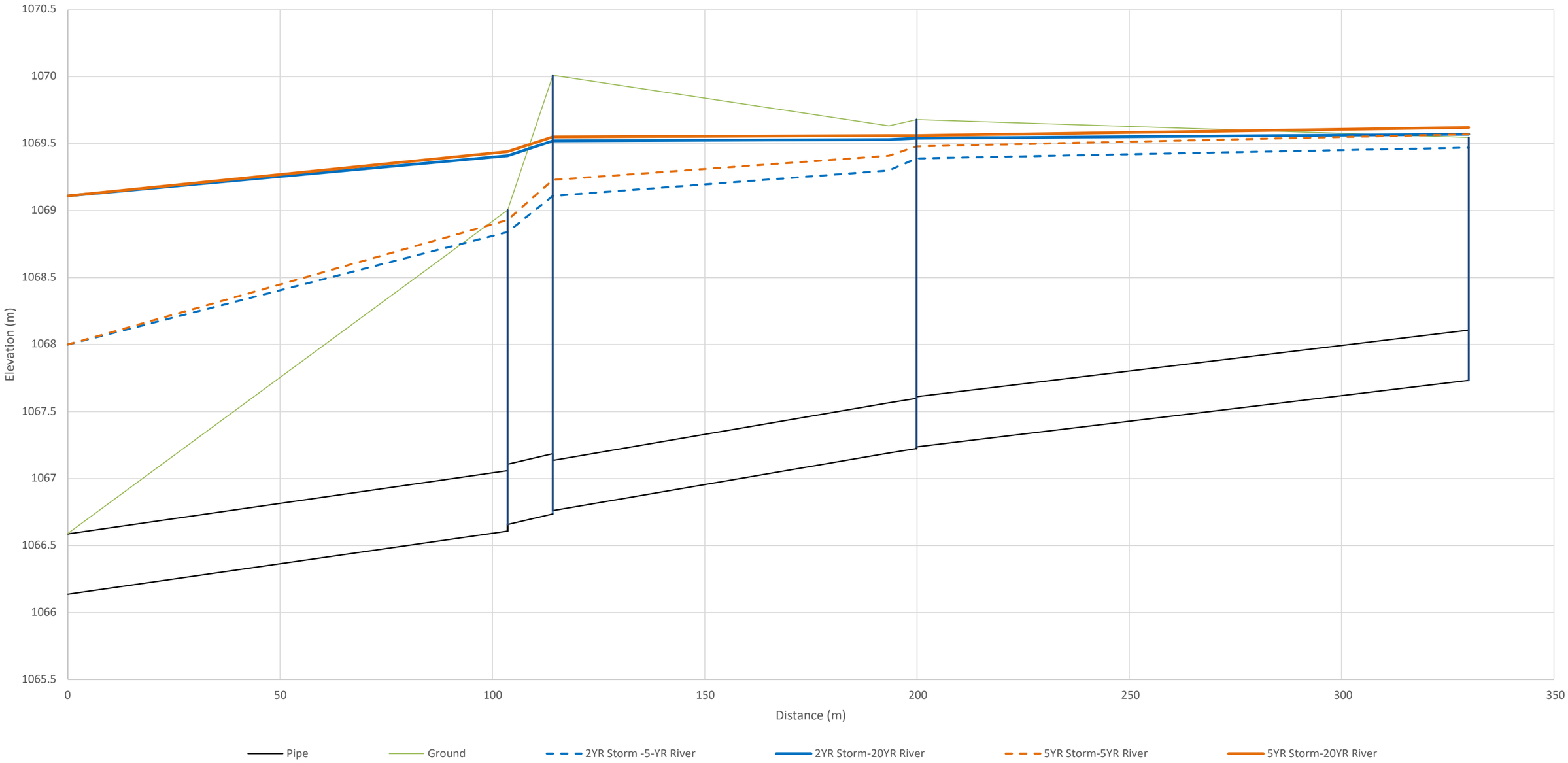
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Existing Conditions

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Figure A1-2



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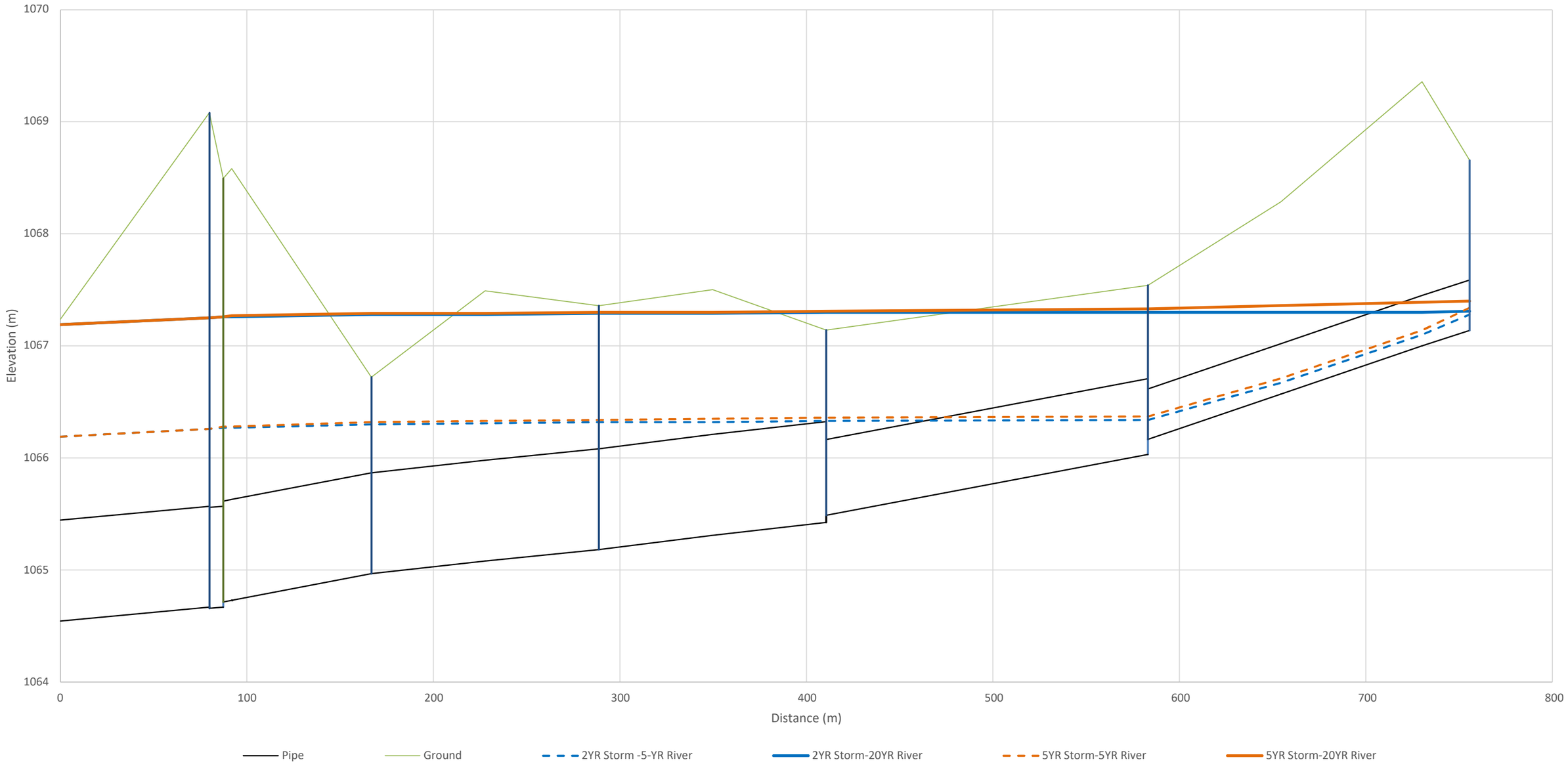
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HGL | B108A
Existing Conditions

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Figure A1-3



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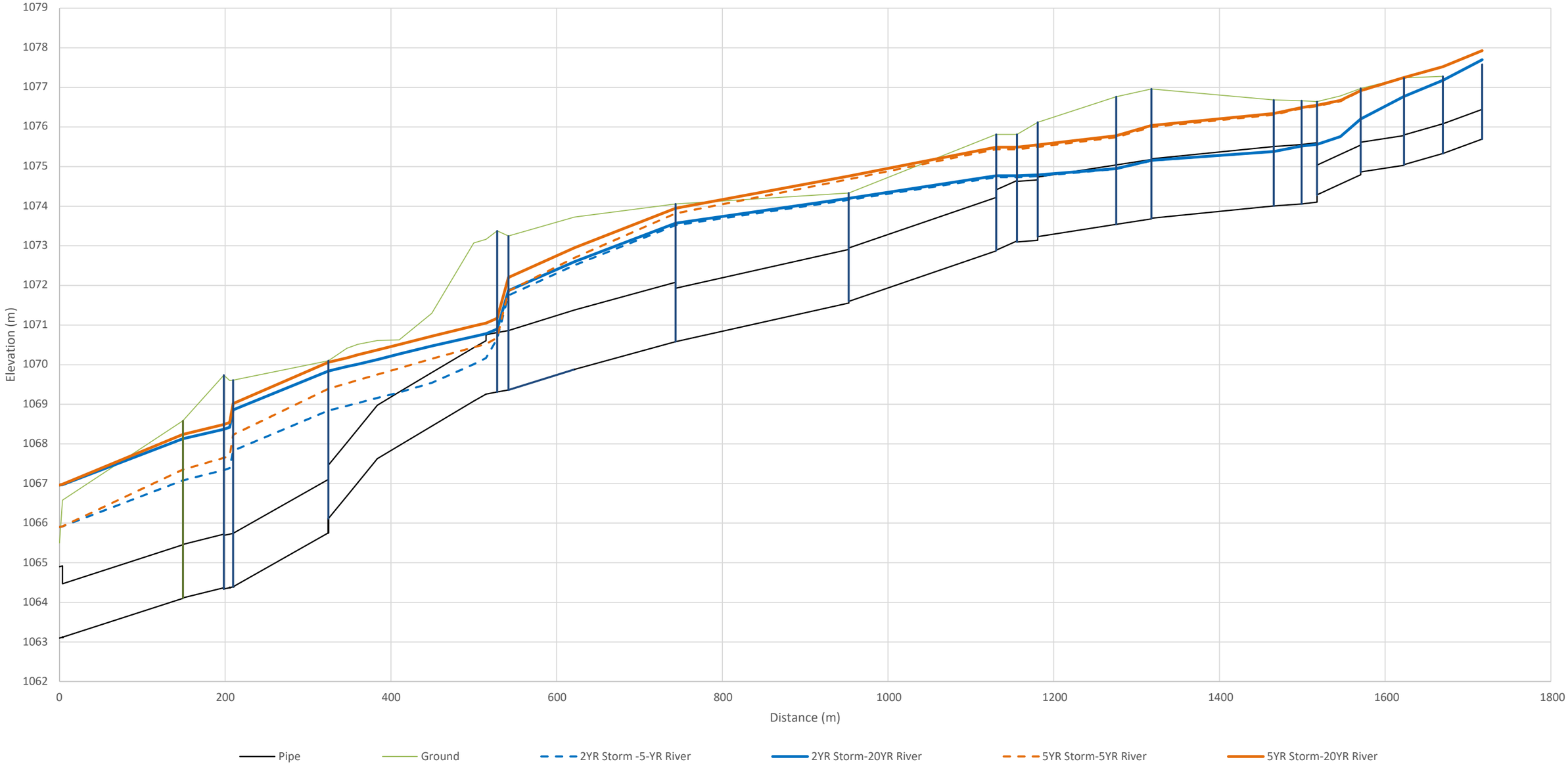
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Bowness Flood Barrier Project

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Existing Conditions

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Figure A1-4



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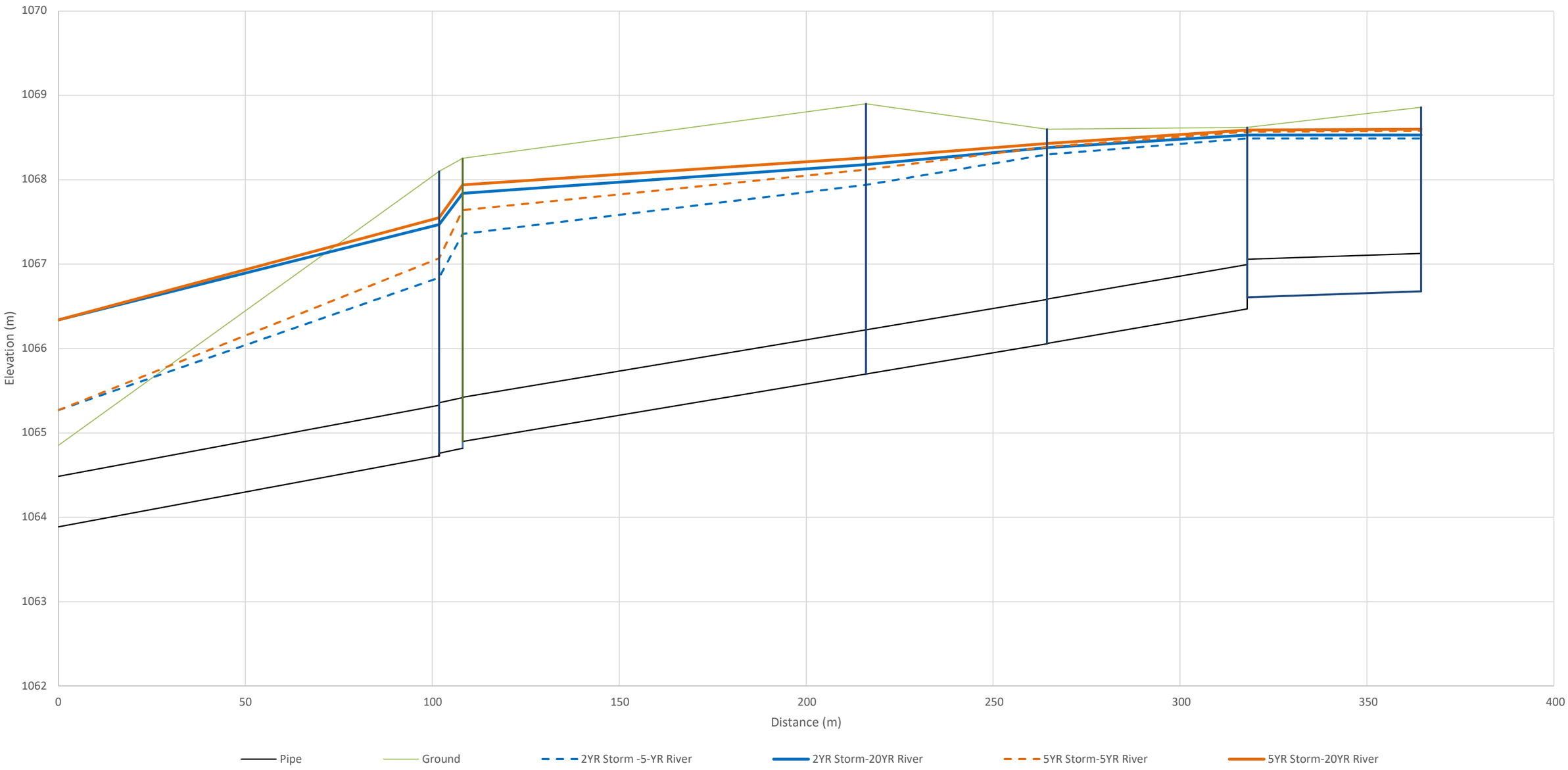
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Figure A1-5



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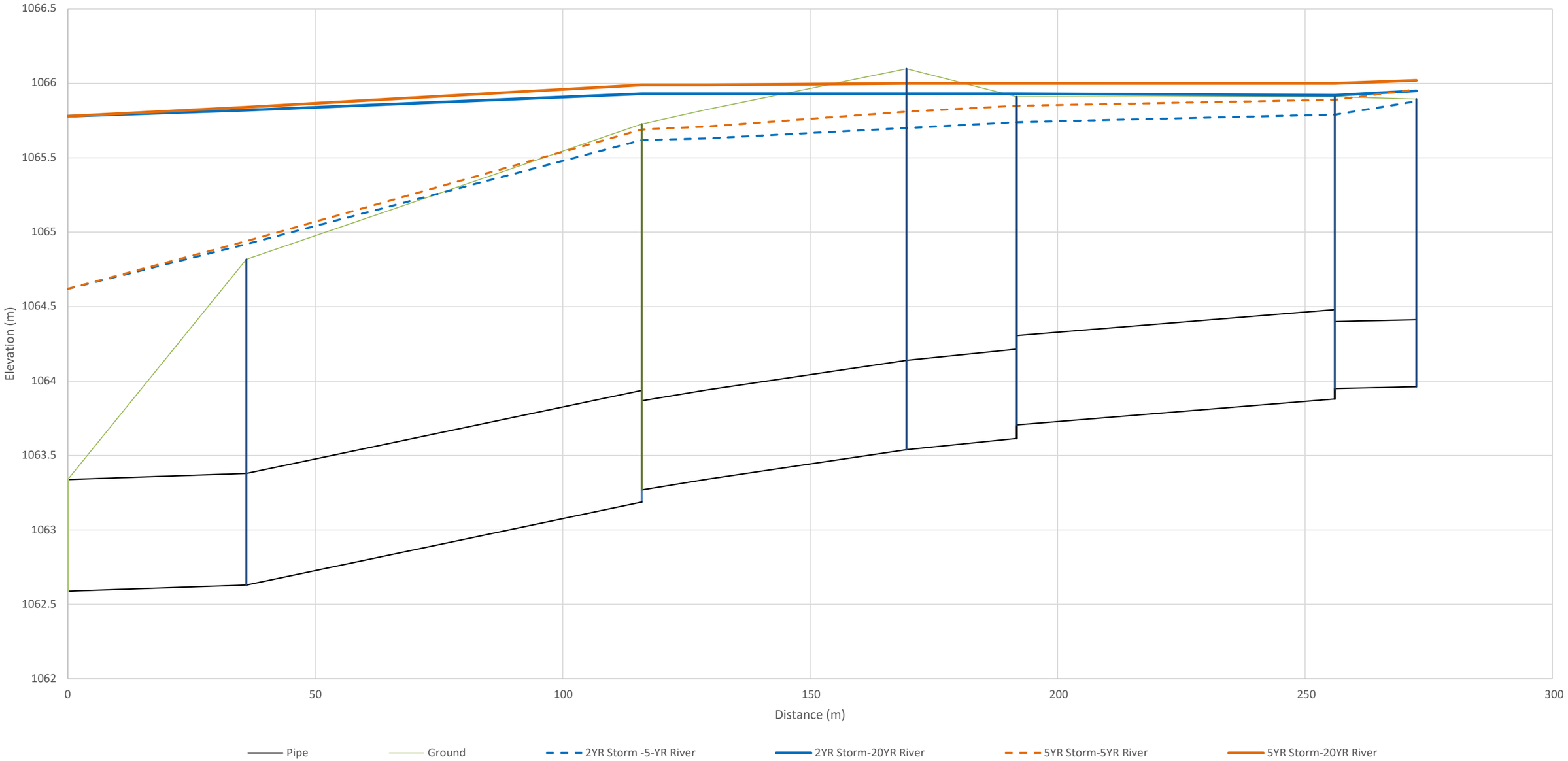
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Figure A1-6



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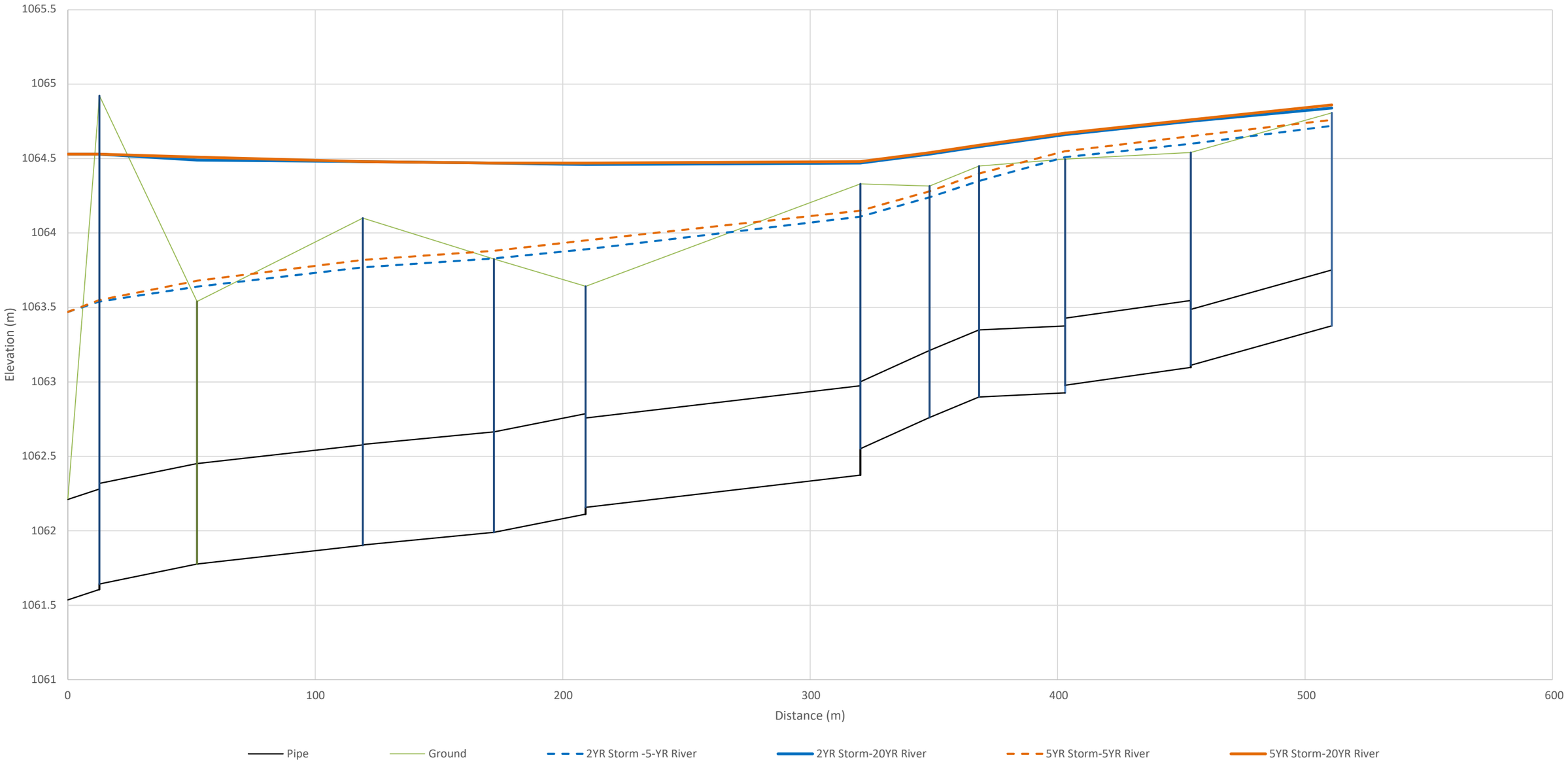
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Figure A1-7



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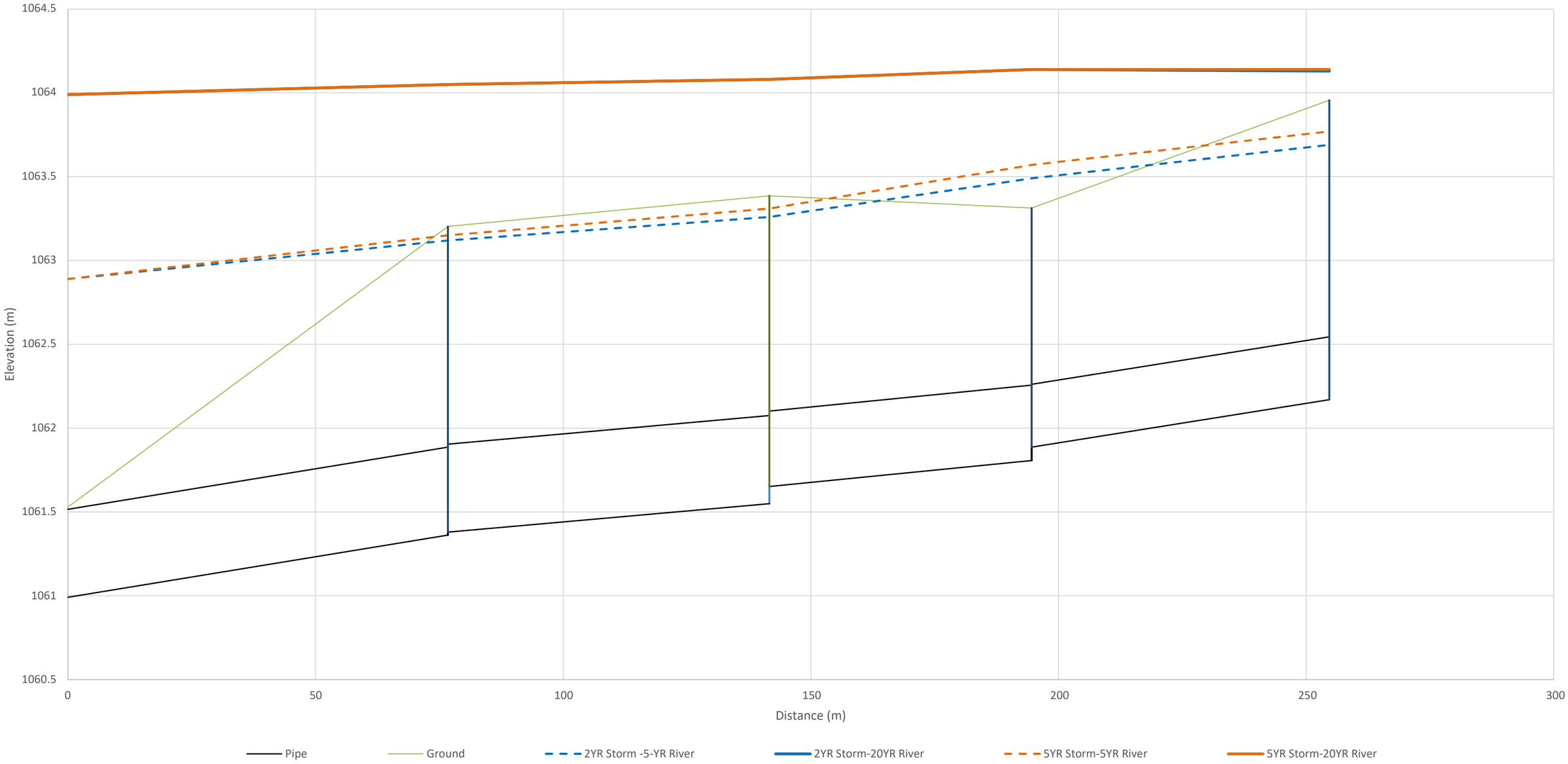
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HGL | B101
Existing Conditions

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Figure A1-8



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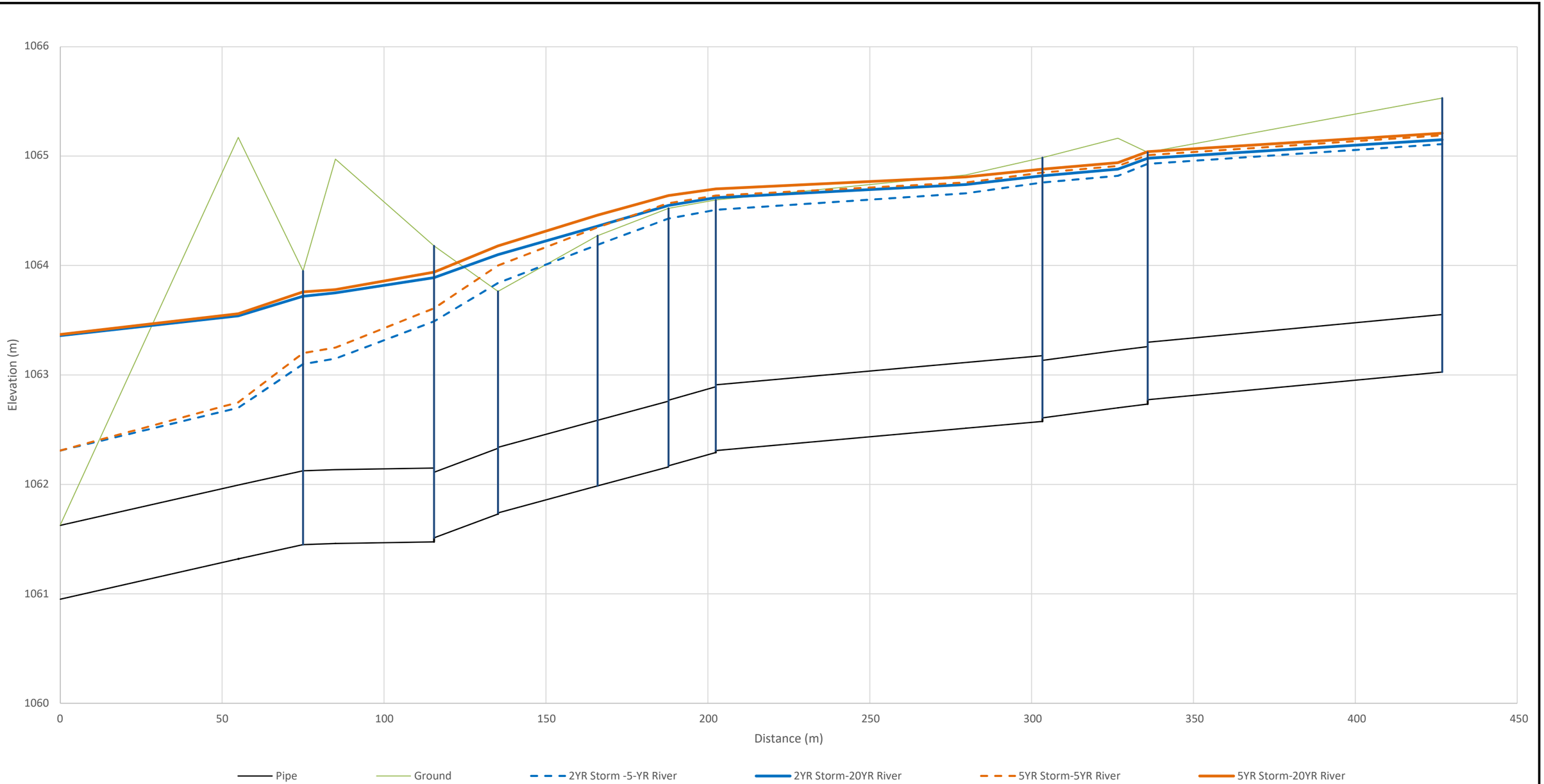
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Figure A1-9



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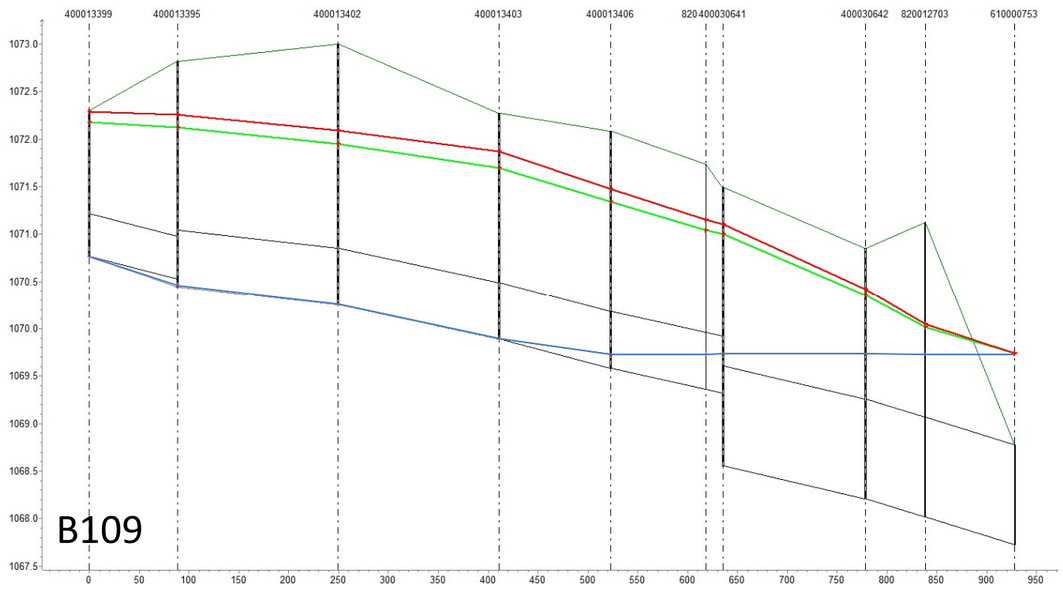
HGL | B98
Existing Conditions

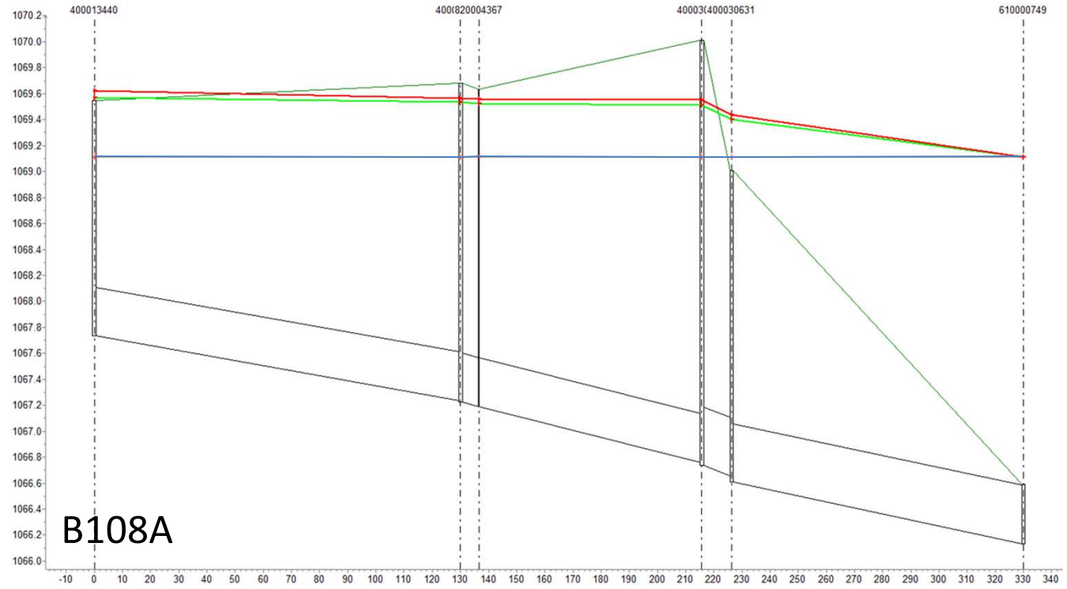
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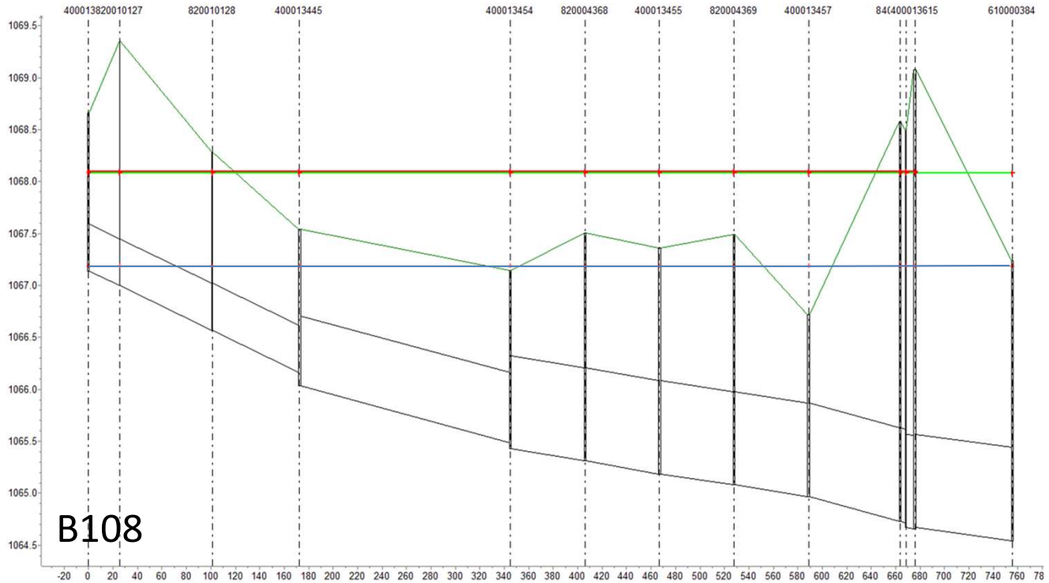
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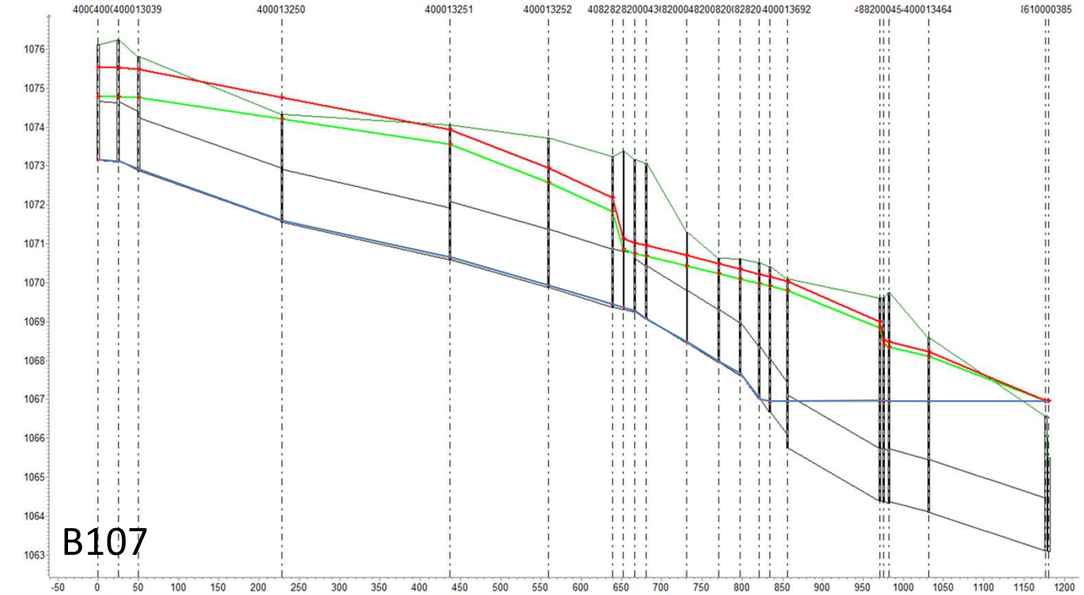
Figure A1-10

APPENDIX A2
Existing Conditions: Comparison of 1:20 year River Water Level to Design Condition 2









Legend

- No Urban, 20-year River, Gates Open
- 2-year Urban, 20-year River, Gates Closed, Design Condition #2
- 5-year Urban, 20-year River, Gates Closed, Design Condition #2

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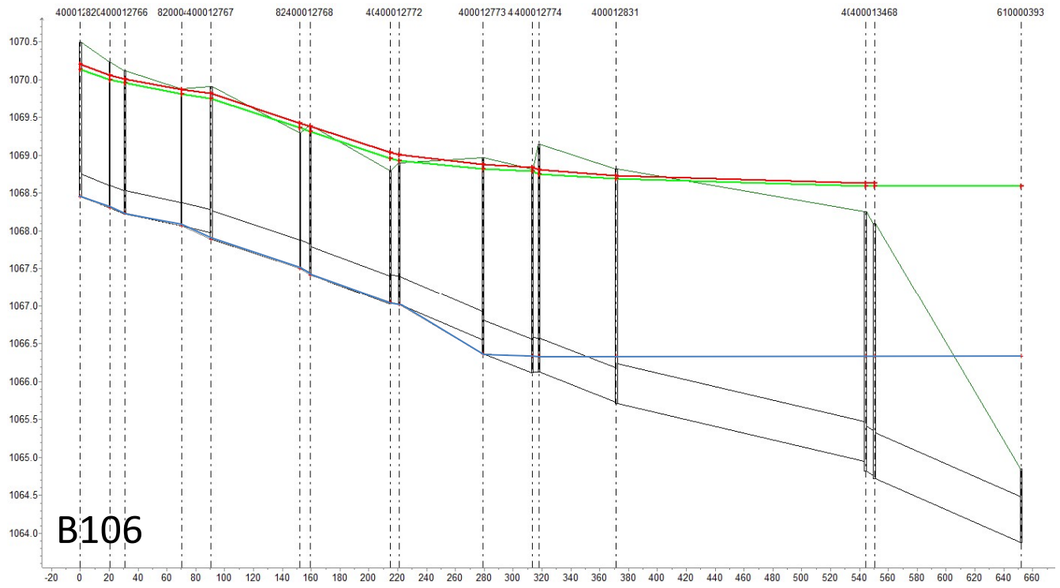
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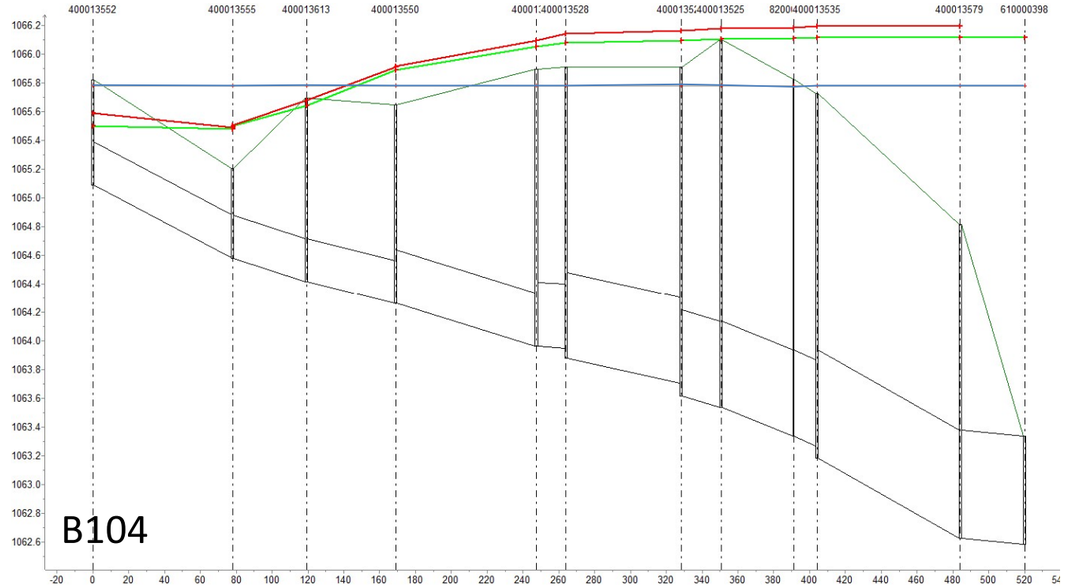
Comparison of 1:20 year Bow River Water Levels with Design Condition 2

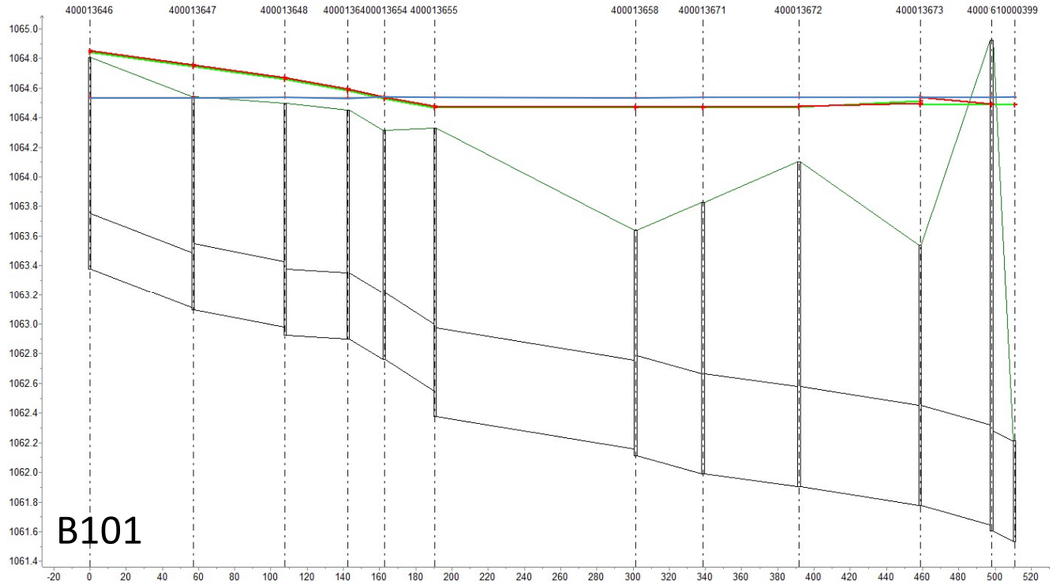
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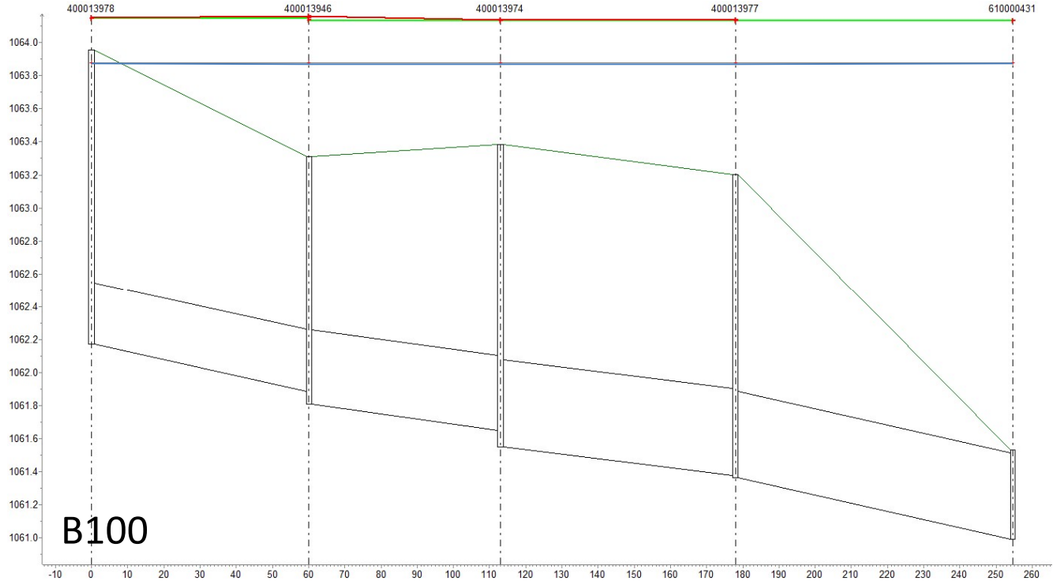
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Figure A2-1









Legend

- No Urban, 20-year River, Gates Open
- 2-year Urban, 20-year River, Gates Closed, Design Condition #2
- 5-year Urban, 20-year River, Gates Closed, Design Condition #2

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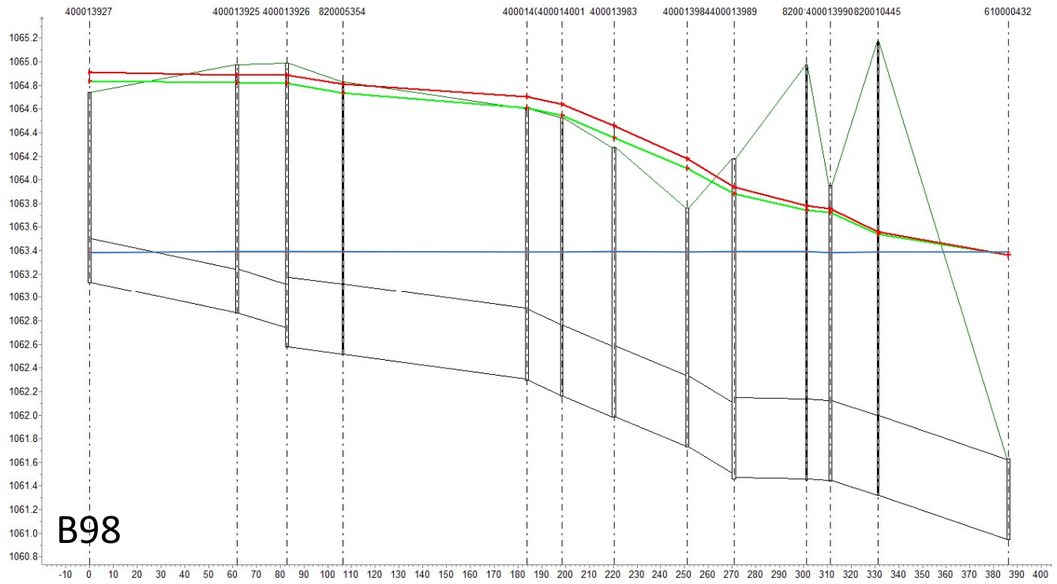
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Bowness Flood Barrier Project

Comparison of 1:20 year Bow River Water Levels with Design Condition 2

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Figure A2-2



Legend

- No Urban, 20-year River, Gates Open
- 2-year Urban, 20-year River, Gates Closed, Design Condition #2
- 5-year Urban, 20-year River, Gates Closed, Design Condition #2

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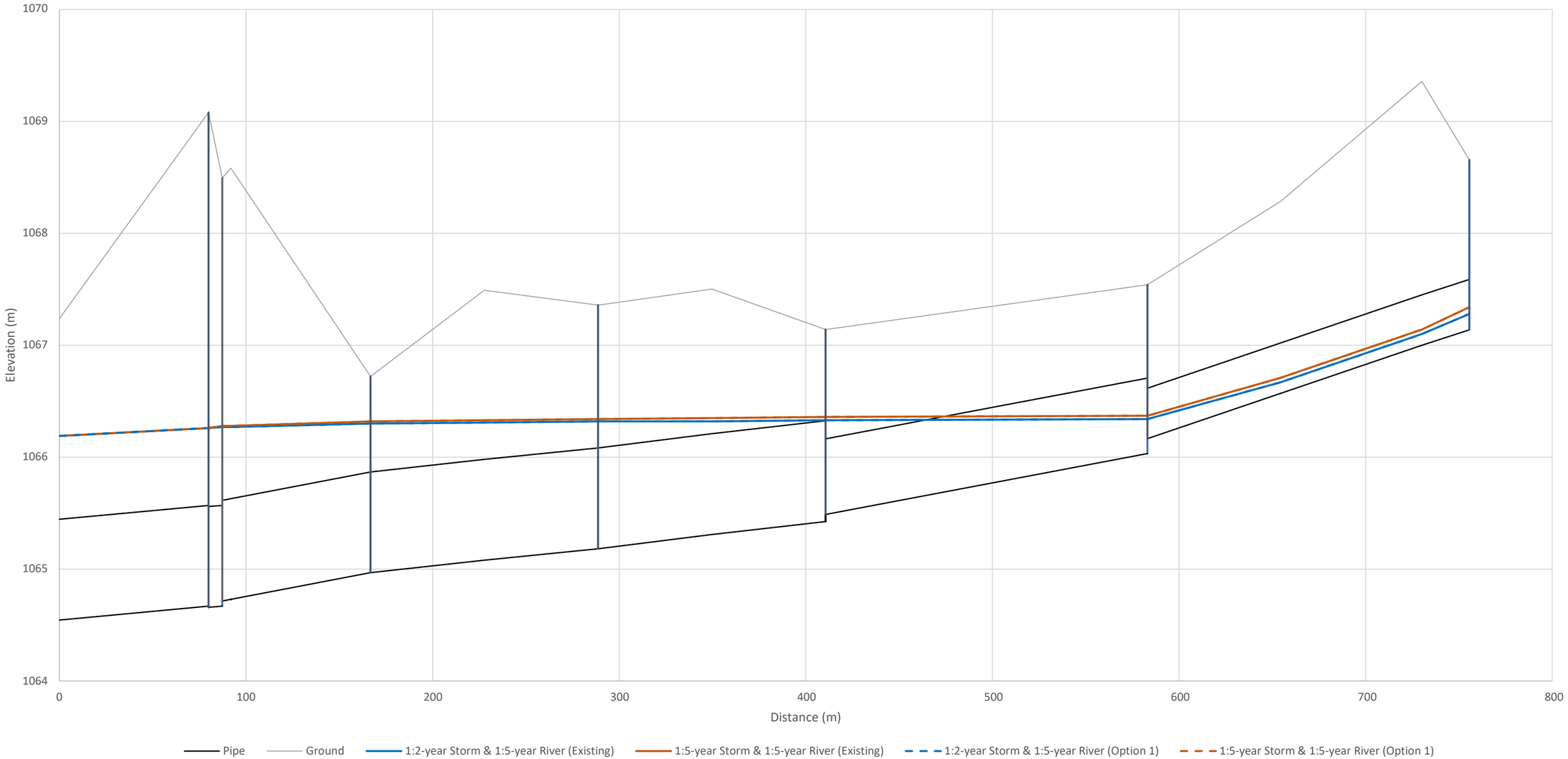
Comparison of 1:20 year Bow River Water Levels with Design Condition 2

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Figure A2-3

APPENDIX A3
Proposed Conditions: Option 1



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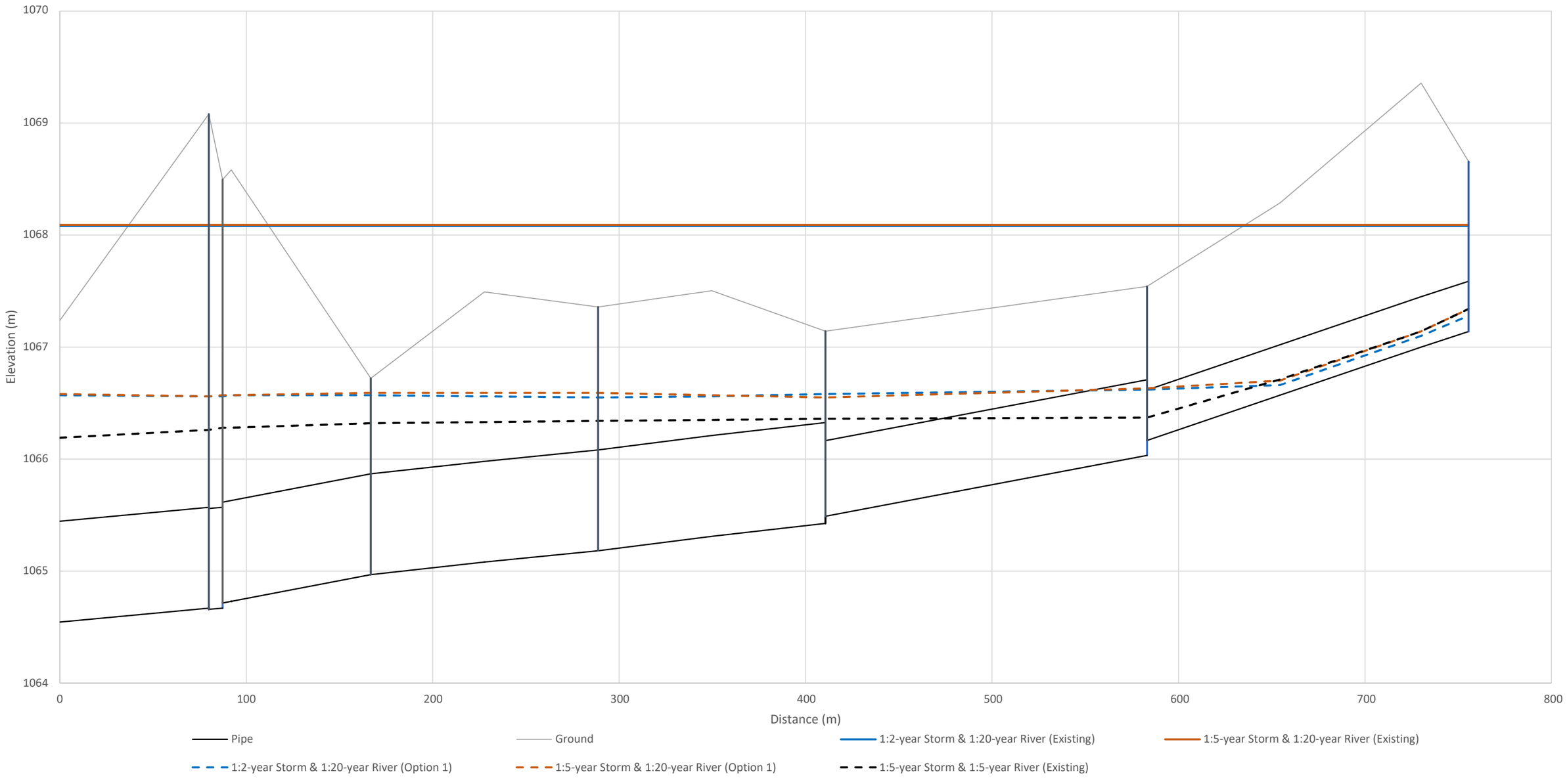
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HGL | B108
Option 1 – Design Condition 1

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Figure A3-1



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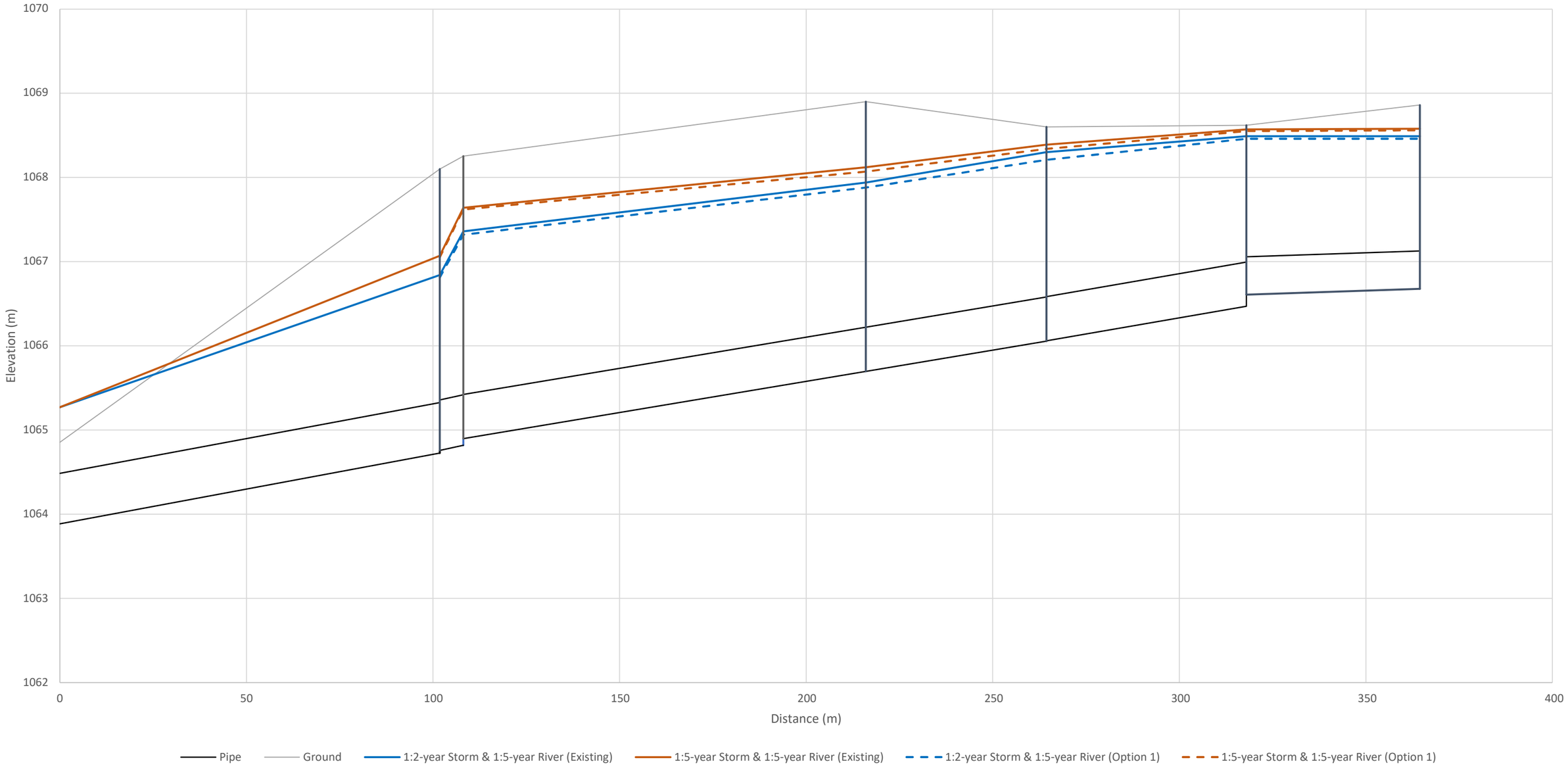
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Option 1 – Design Condition 2

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Figure A3-2



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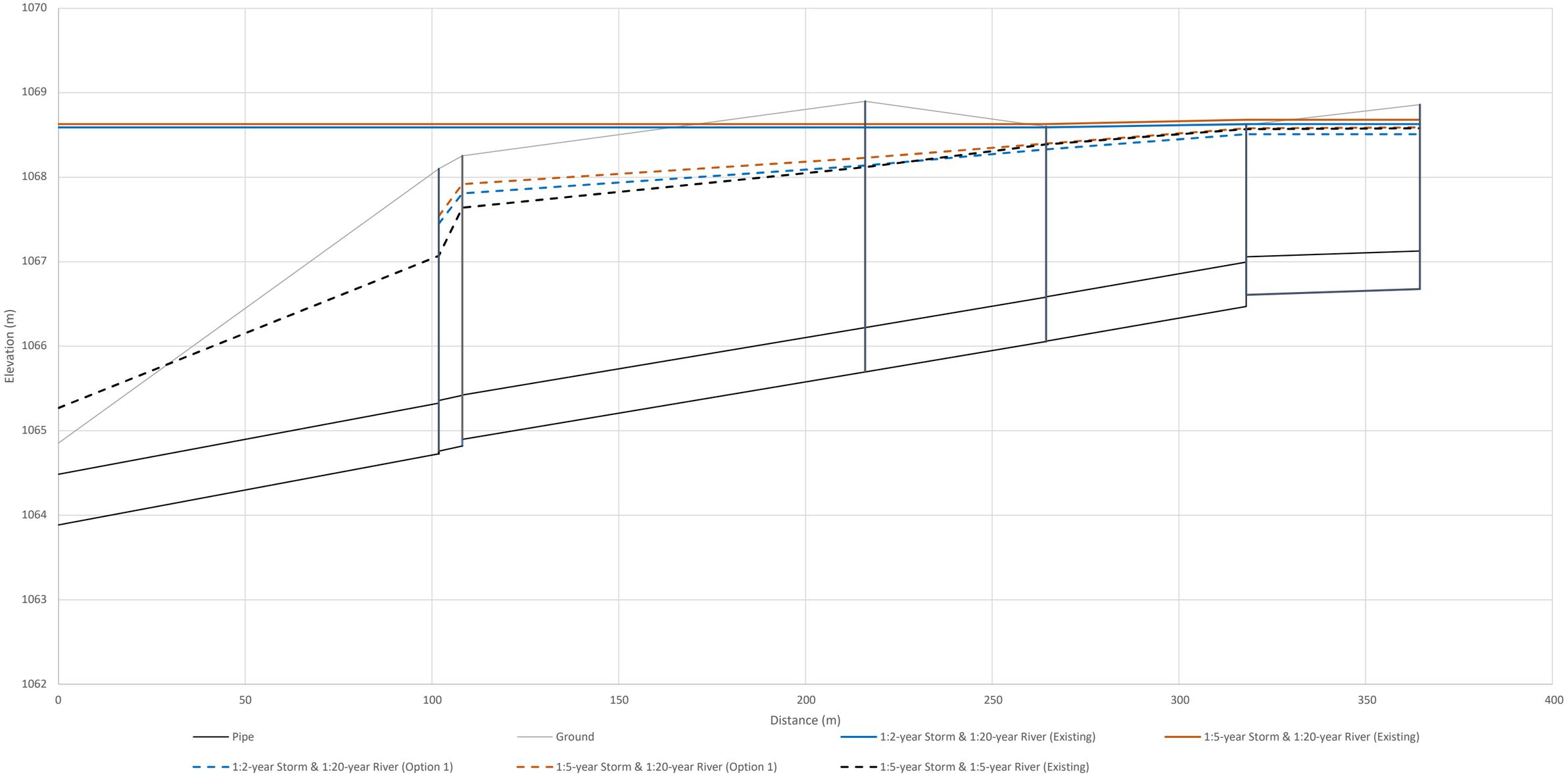
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Figure A3-3



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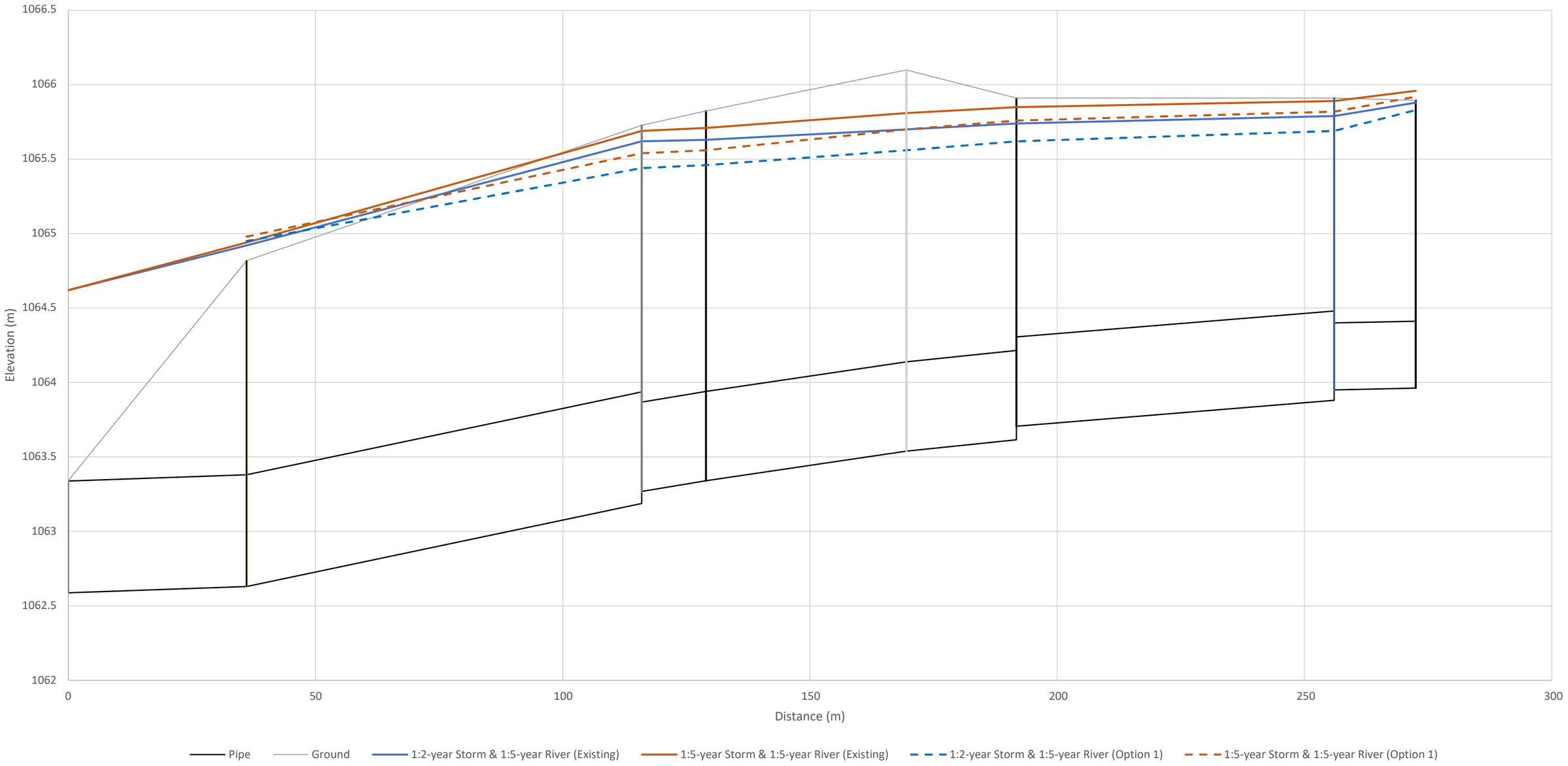
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Option 1 – Design Condition 2

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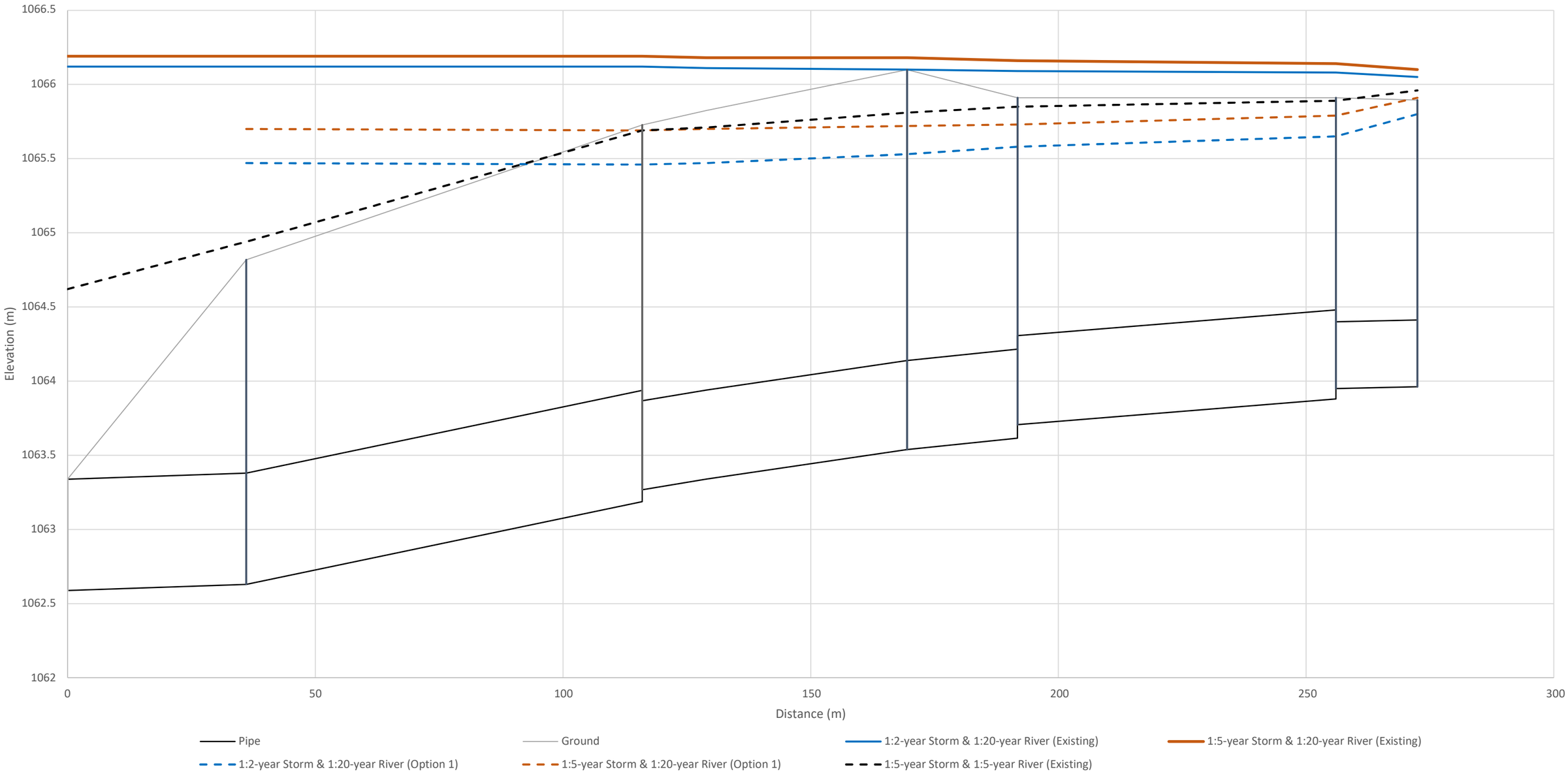
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HGL | B104
Option 1 – Design Condition 1

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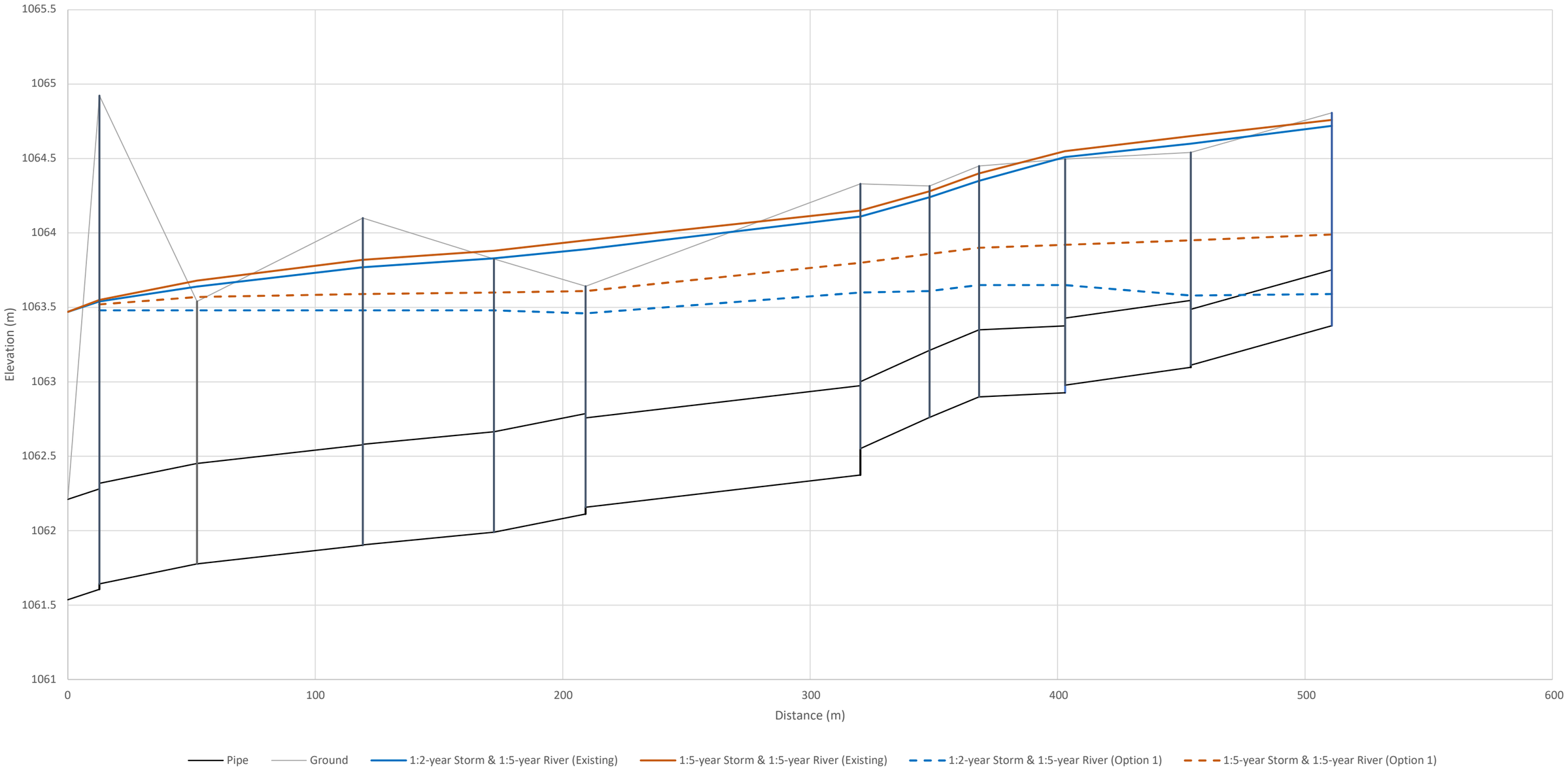
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Option 1 – Design Condition 2

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Figure A3-6



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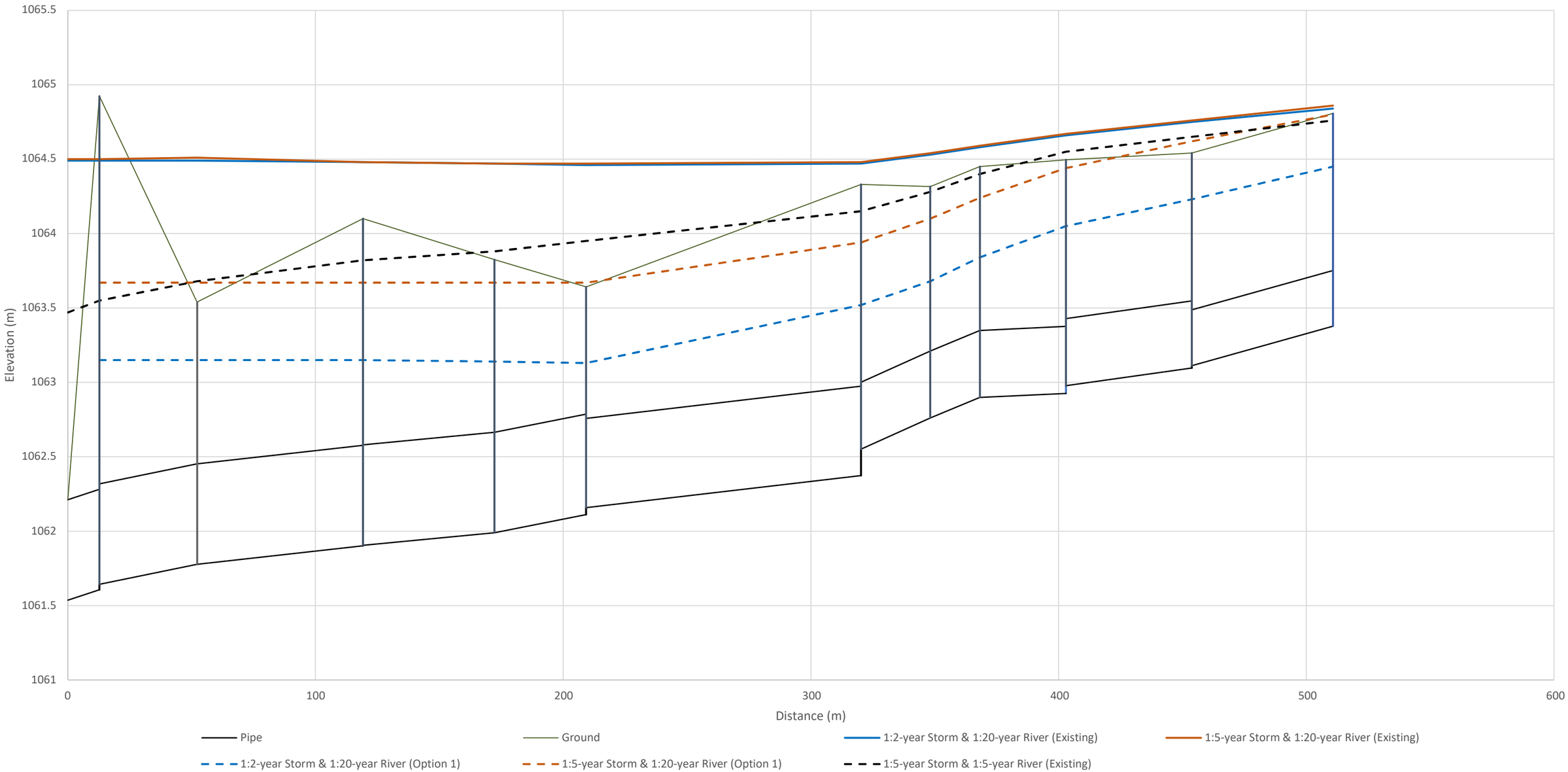
City of Calgary
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Option 1 – Design Condition 1

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Figure A3-7



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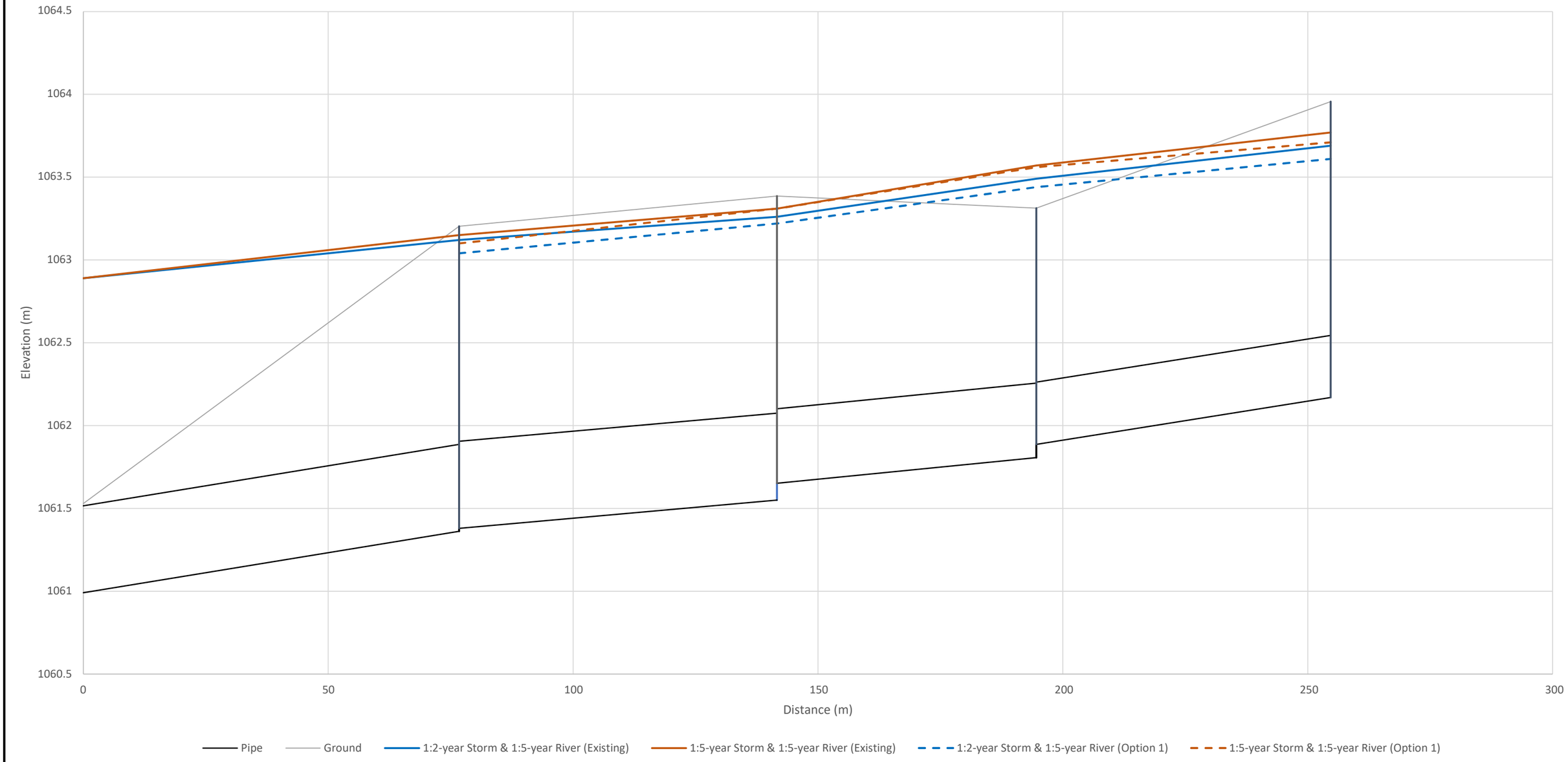
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Option 1 – Design Condition 2

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Figure A3-8



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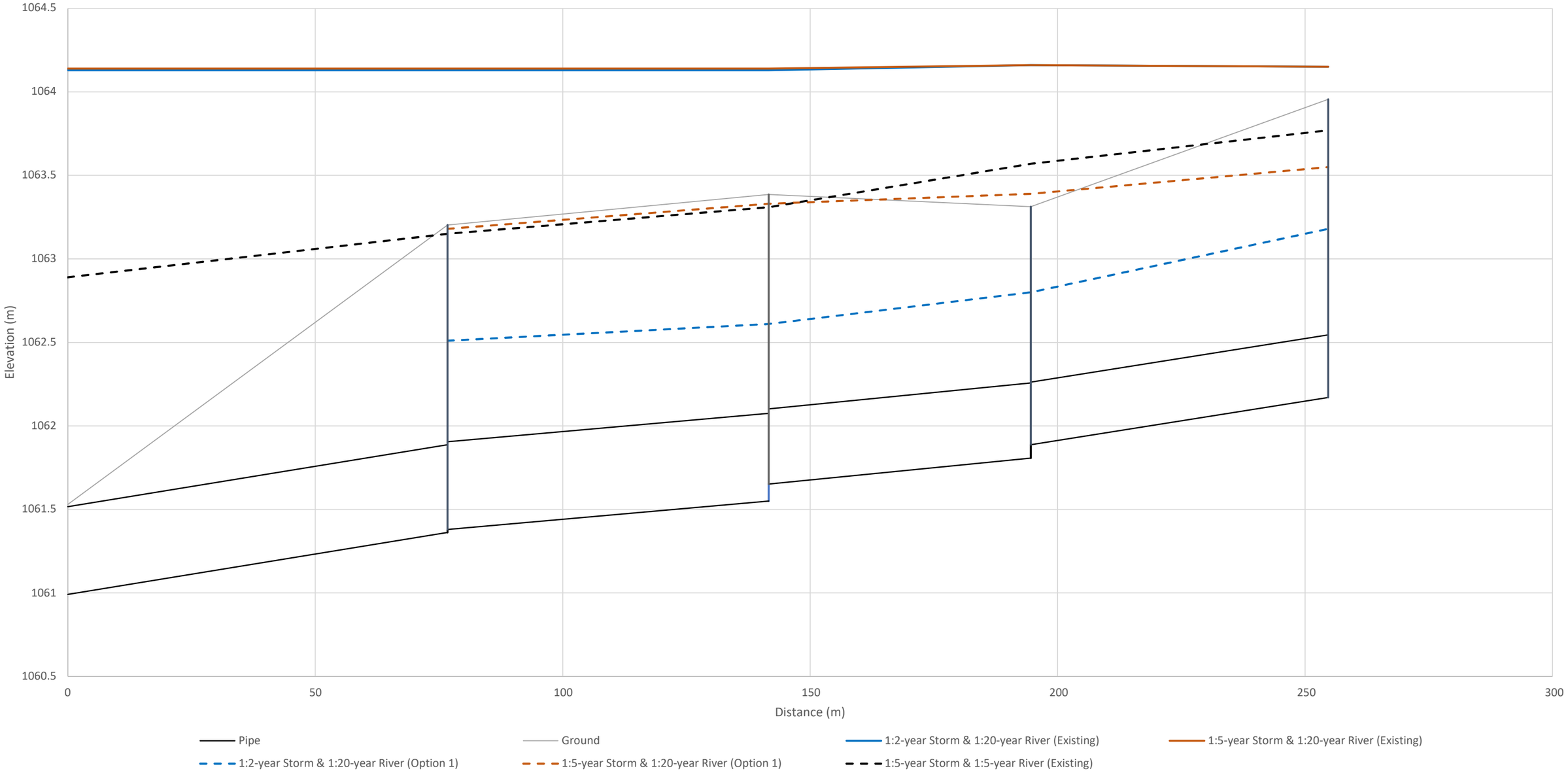
City of Calgary
Bowness Flood Barrier Project

HGL | B100
Option 1 – Design Condition 1

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Figure A3-9



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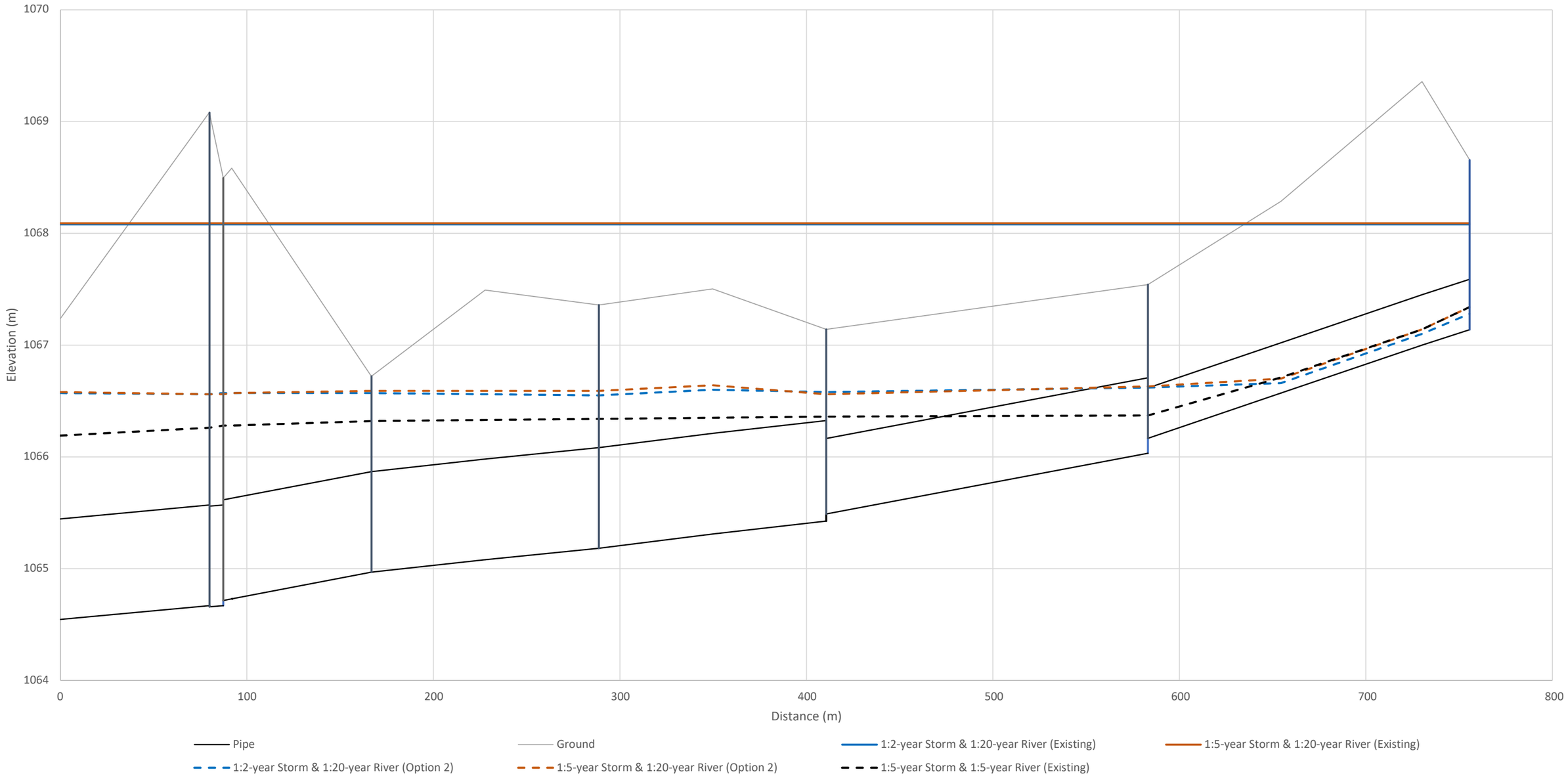
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Figure A3-10

APPENDIX A4
Proposed Conditions: Option 2



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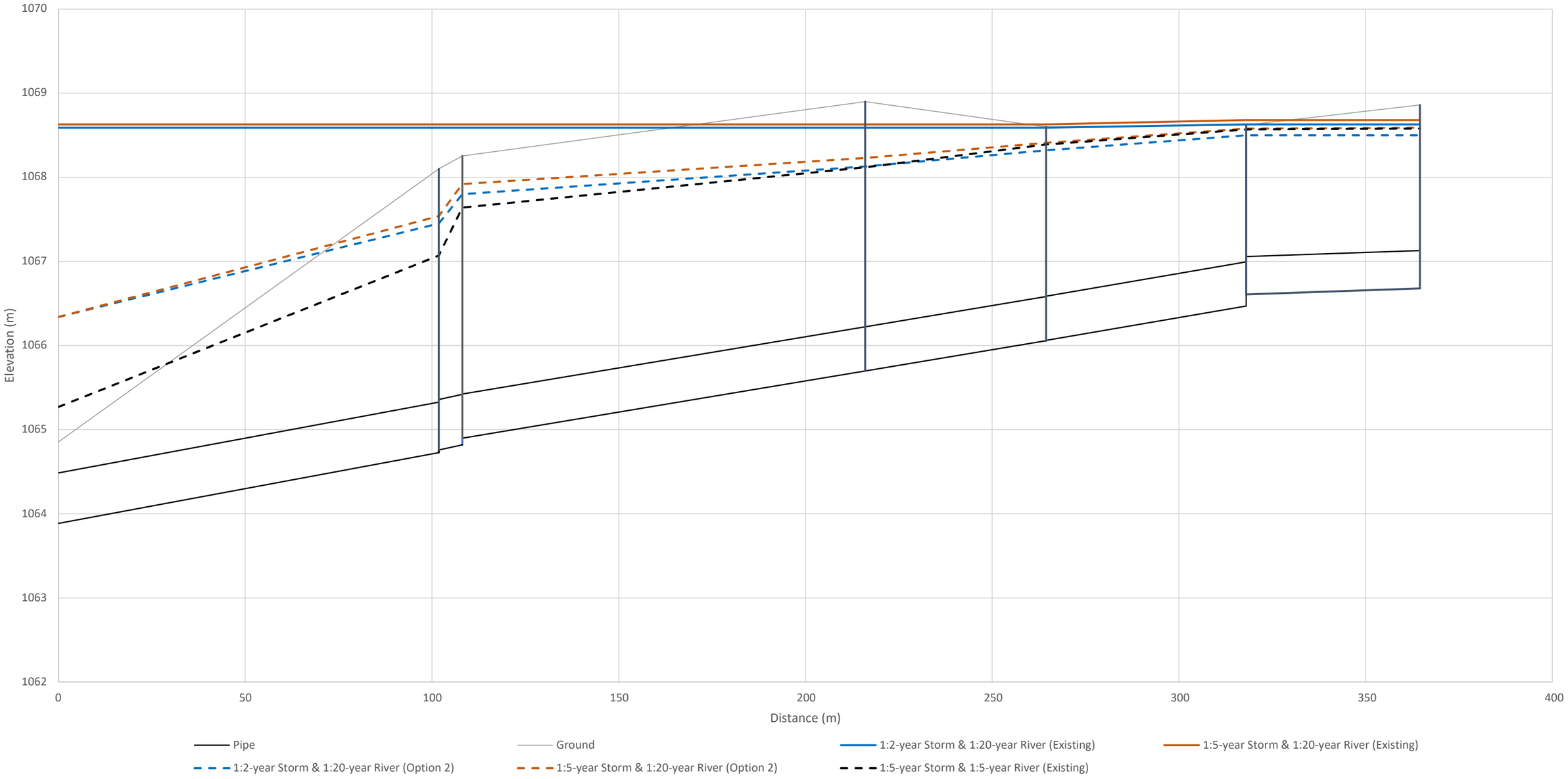
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Bowness Flood Barrier Project

HGL | B108
Option 2 – Design Condition 2

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Figure A4-1



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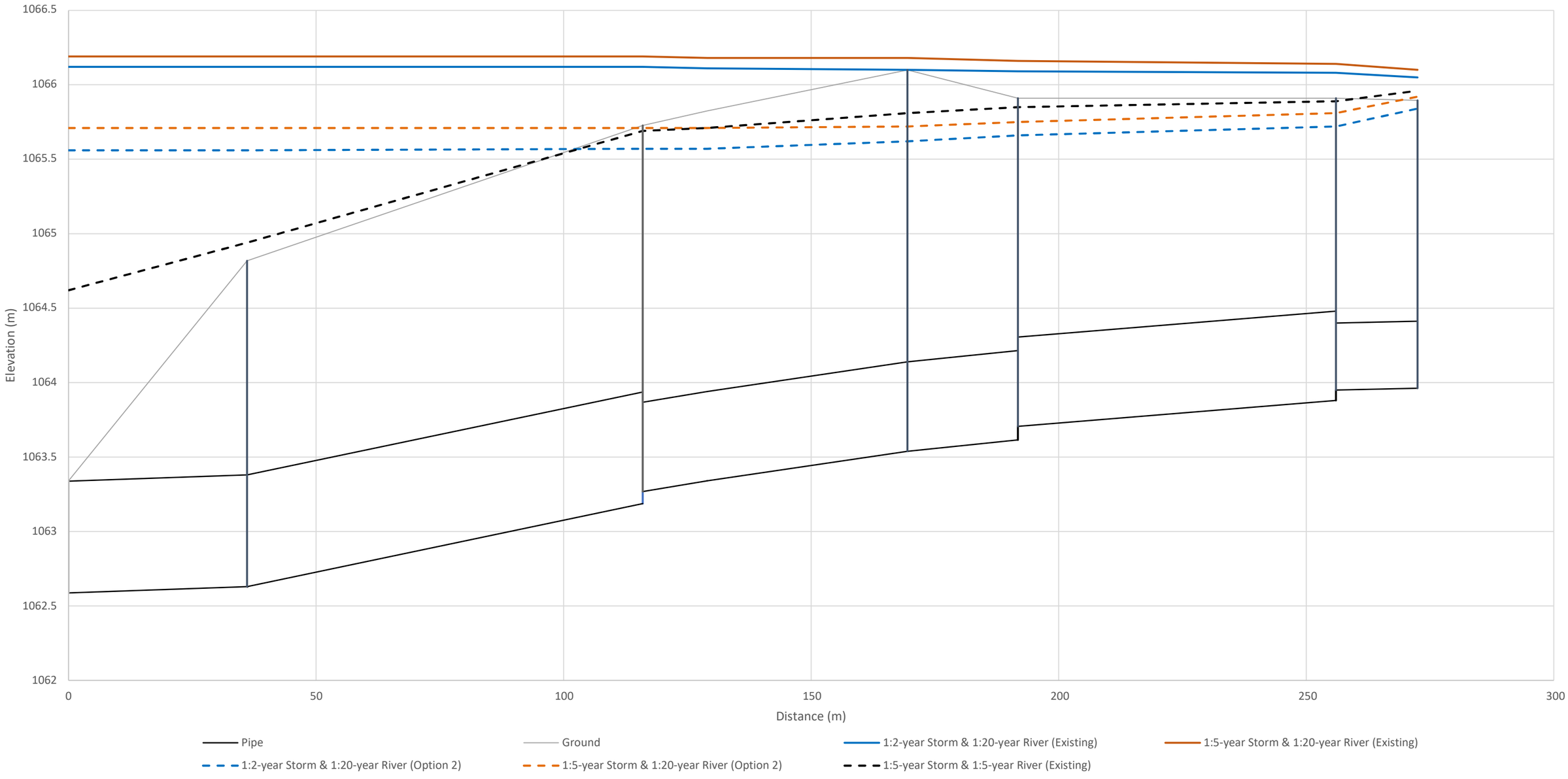
City of Calgary
Bowness Flood Barrier Project

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Option 2 – Design Condition 2

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Figure A4-2



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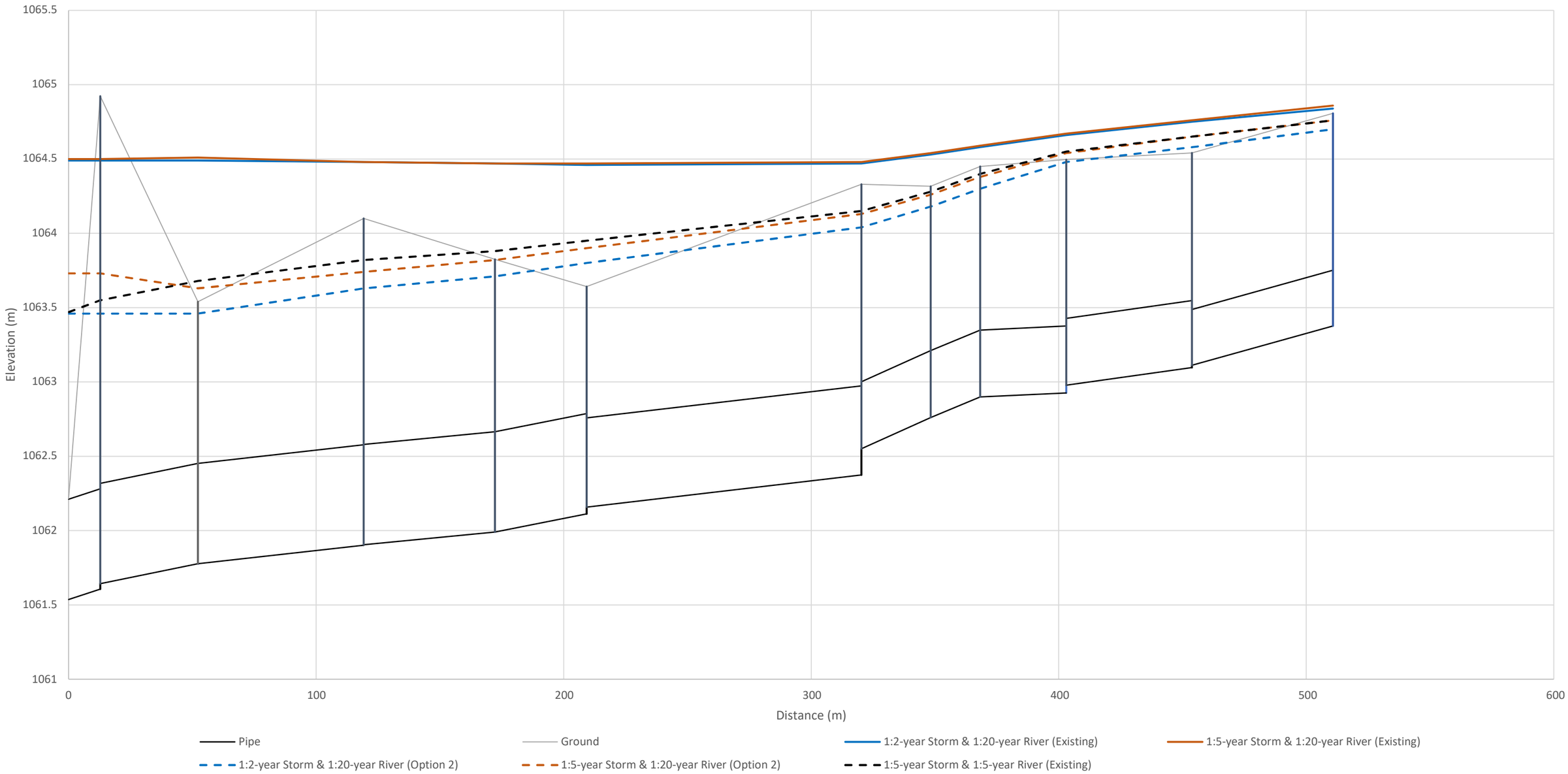
City of Calgary
Bowness Flood Barrier Project

HGL | B104
Option 2 – Design Condition 2

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Figure A4-3



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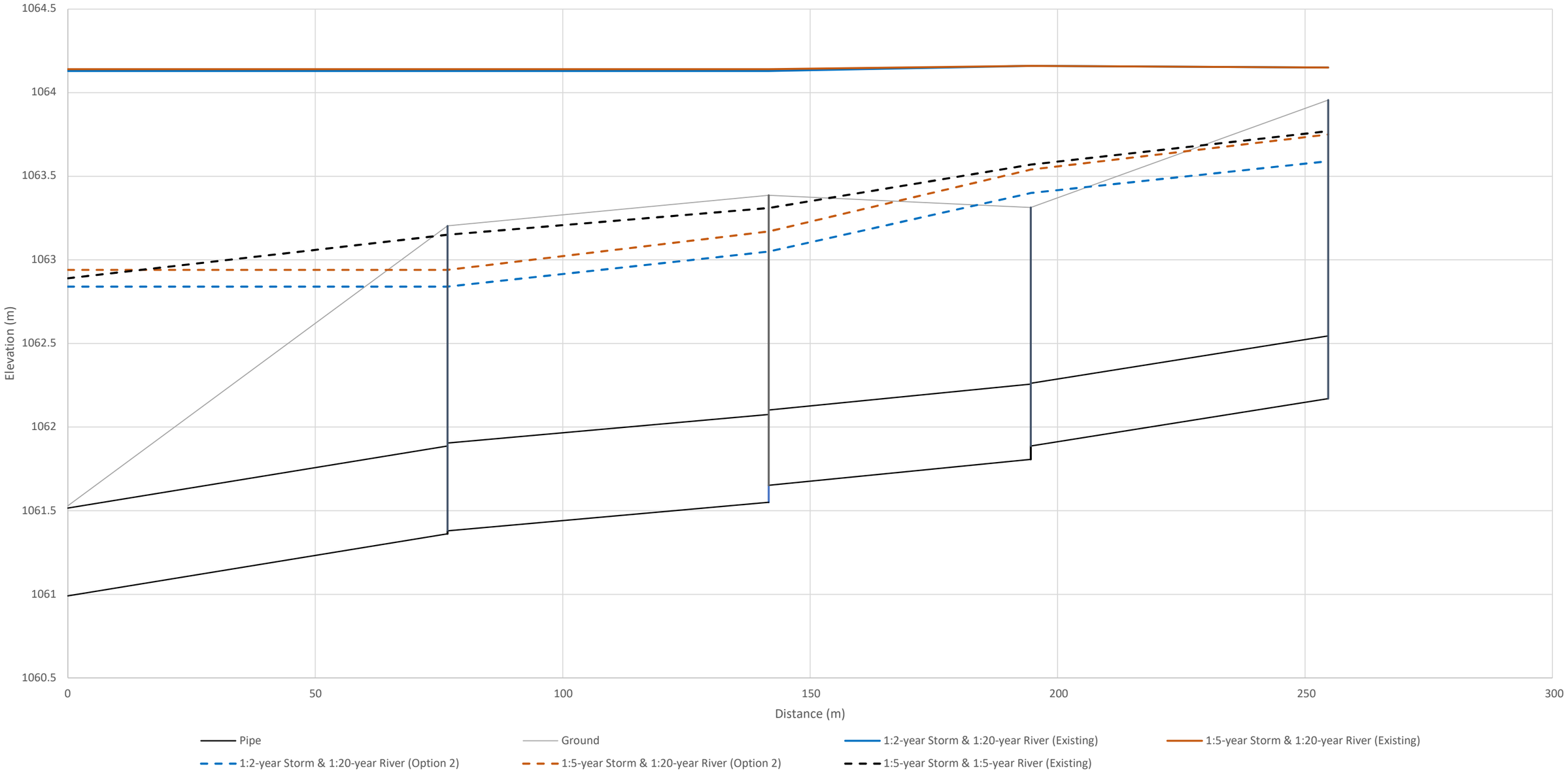
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Bowness Flood Barrier Project

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Option 2 – Design Condition 2

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Figure A4-4



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Bowness Flood Barrier Project

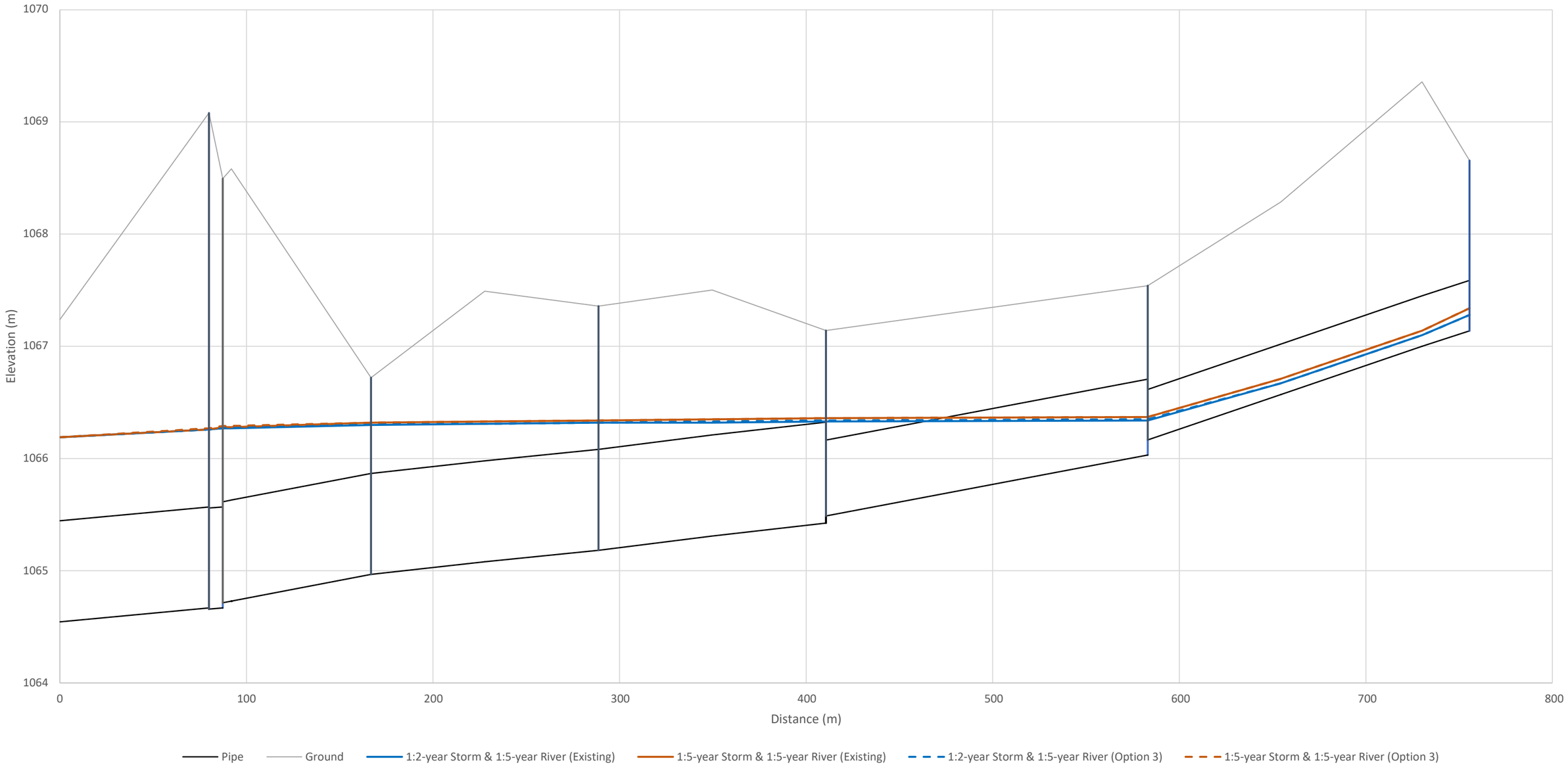
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Figure A4-5

APPENDIX A5
Proposed Conditions: Option 3



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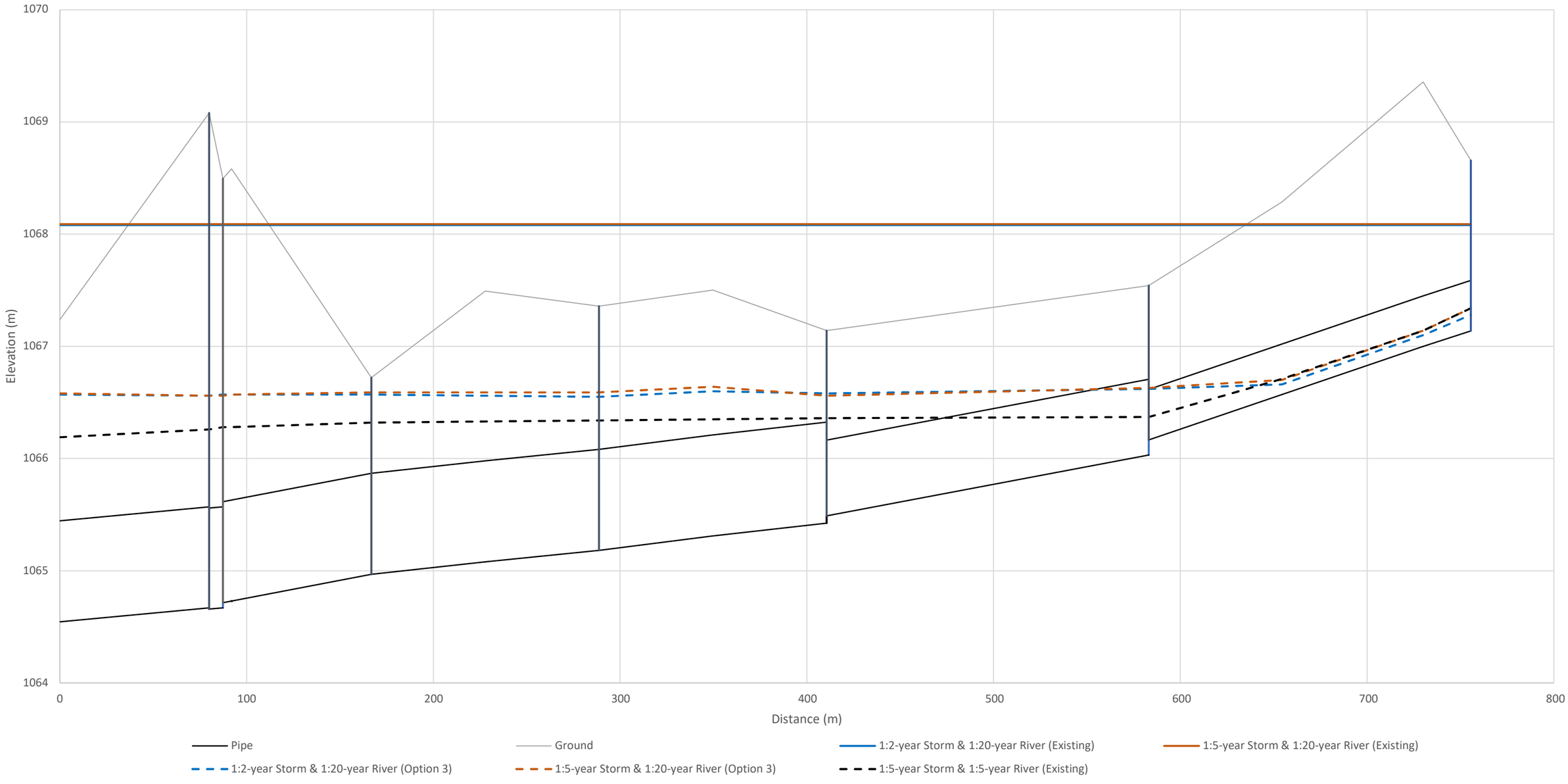
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Bowness Flood Barrier Project

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Option 3 – Design Condition 1

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Figure A5-1



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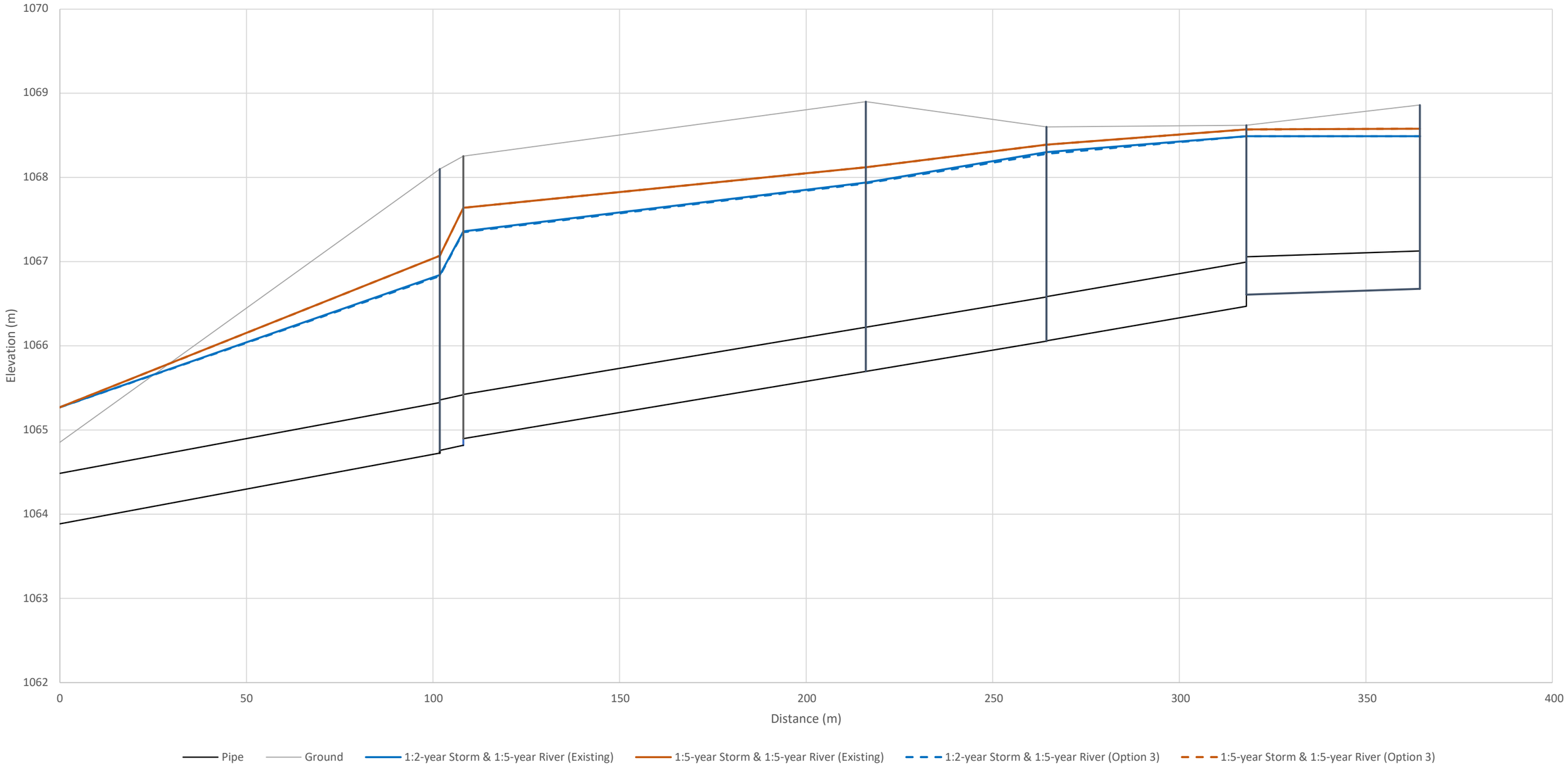
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Bowness Flood Barrier Project

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Option 3 – Design Condition 2

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Figure A5-2



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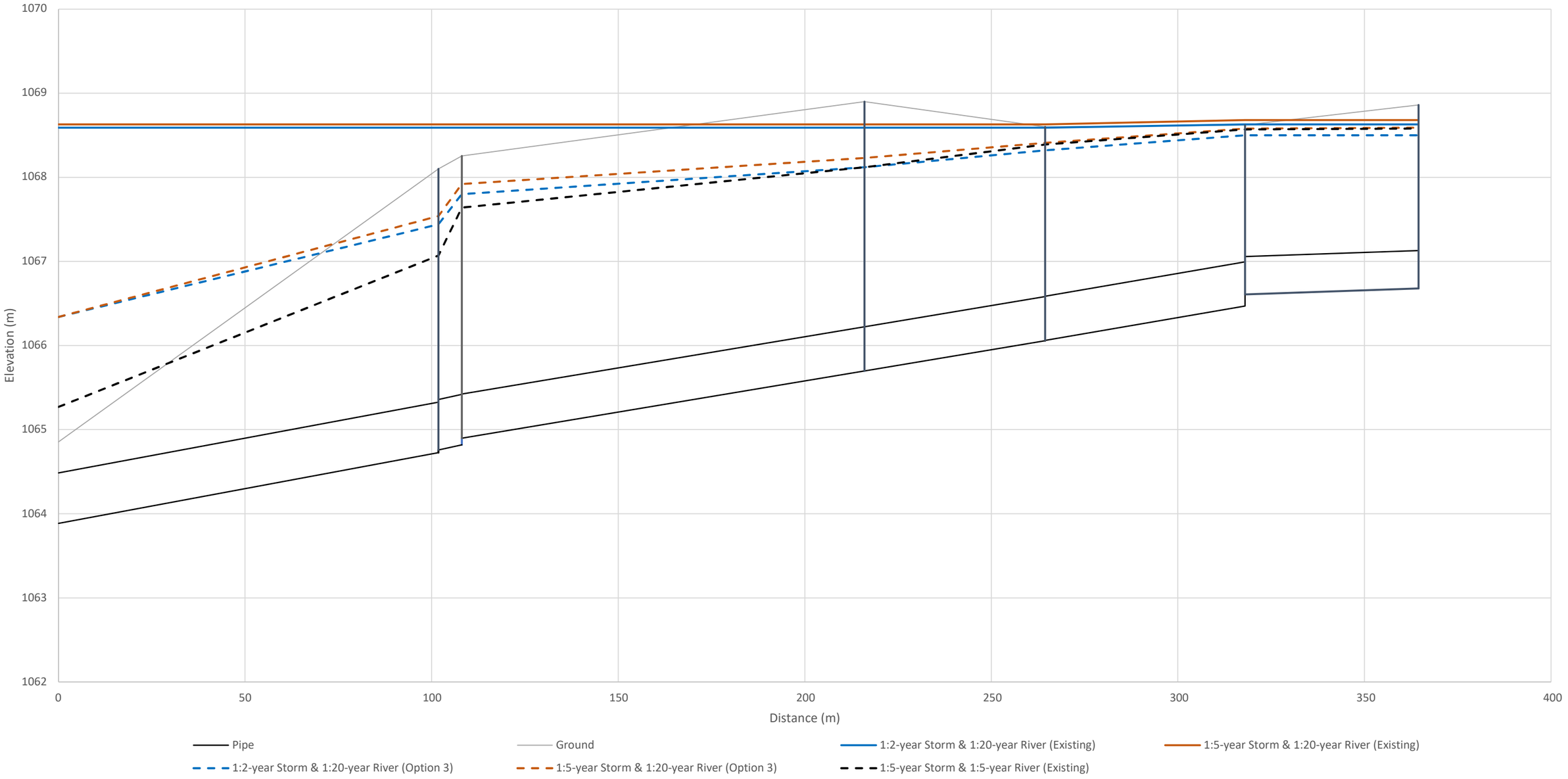
City of Calgary
Bowness Flood Barrier Project

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Option 3 – Design Condition 1

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Figure A5-3



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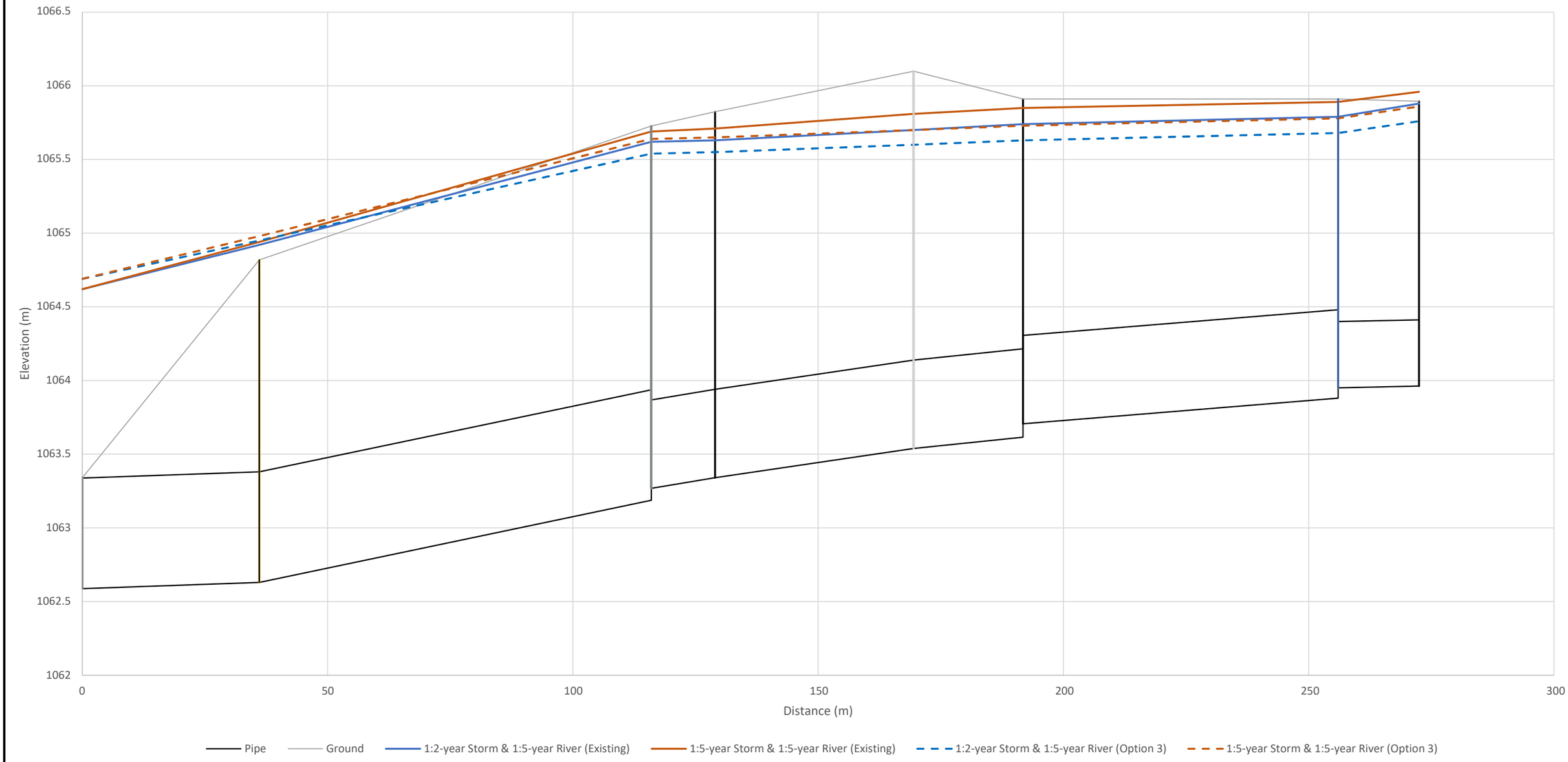
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Figure A5-4



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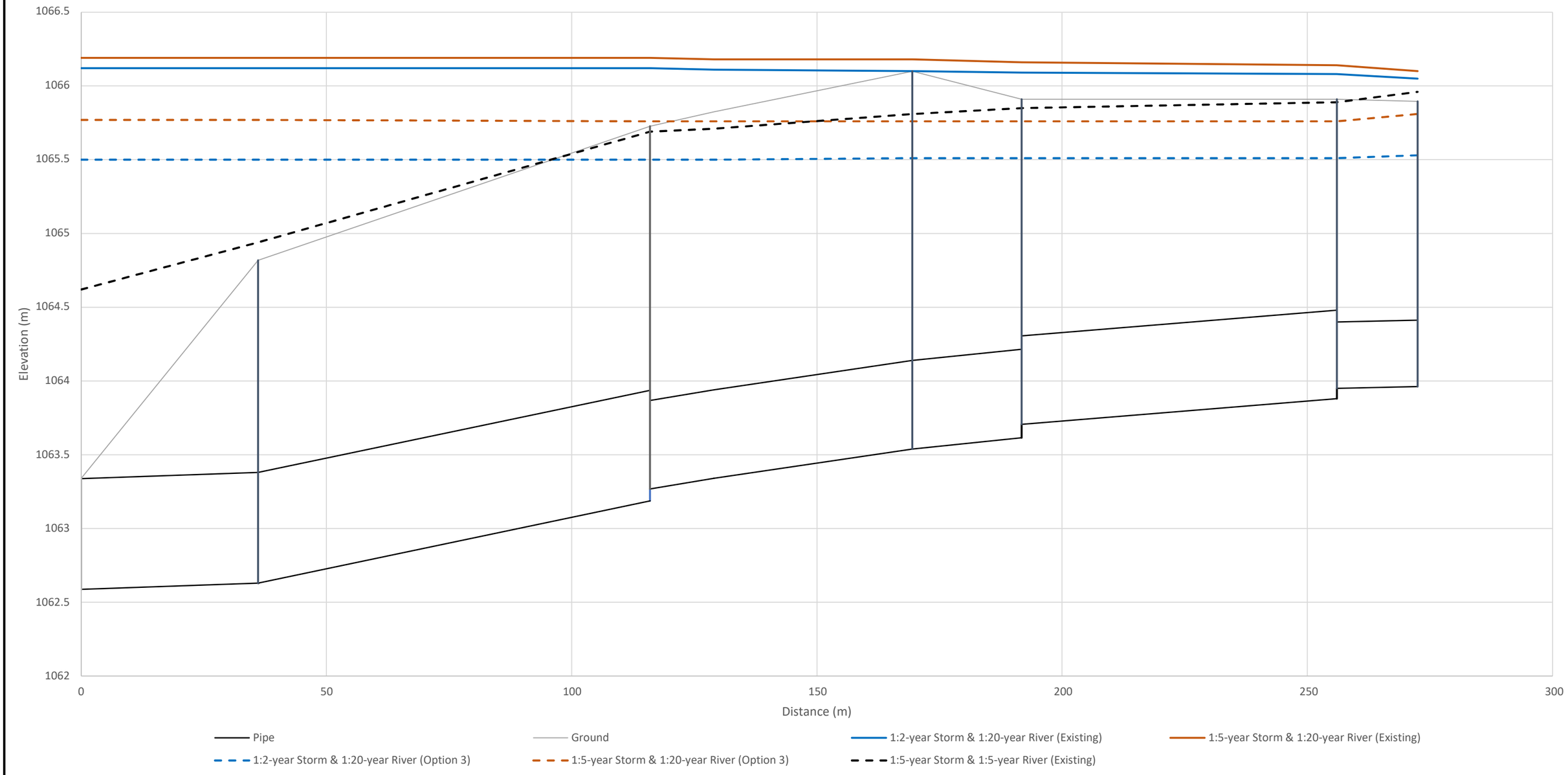
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Bowness Flood Barrier Project

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Figure A5-5



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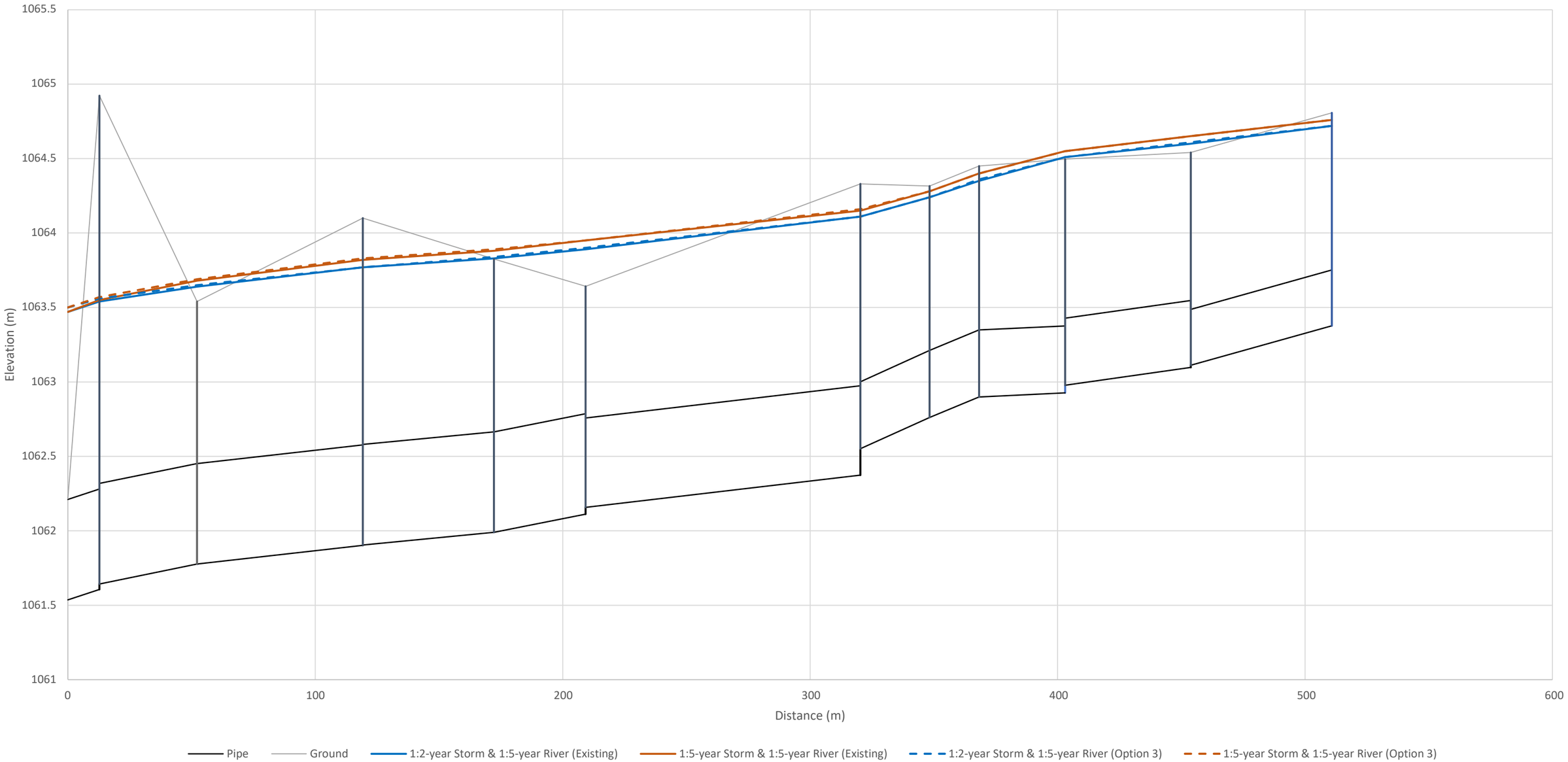
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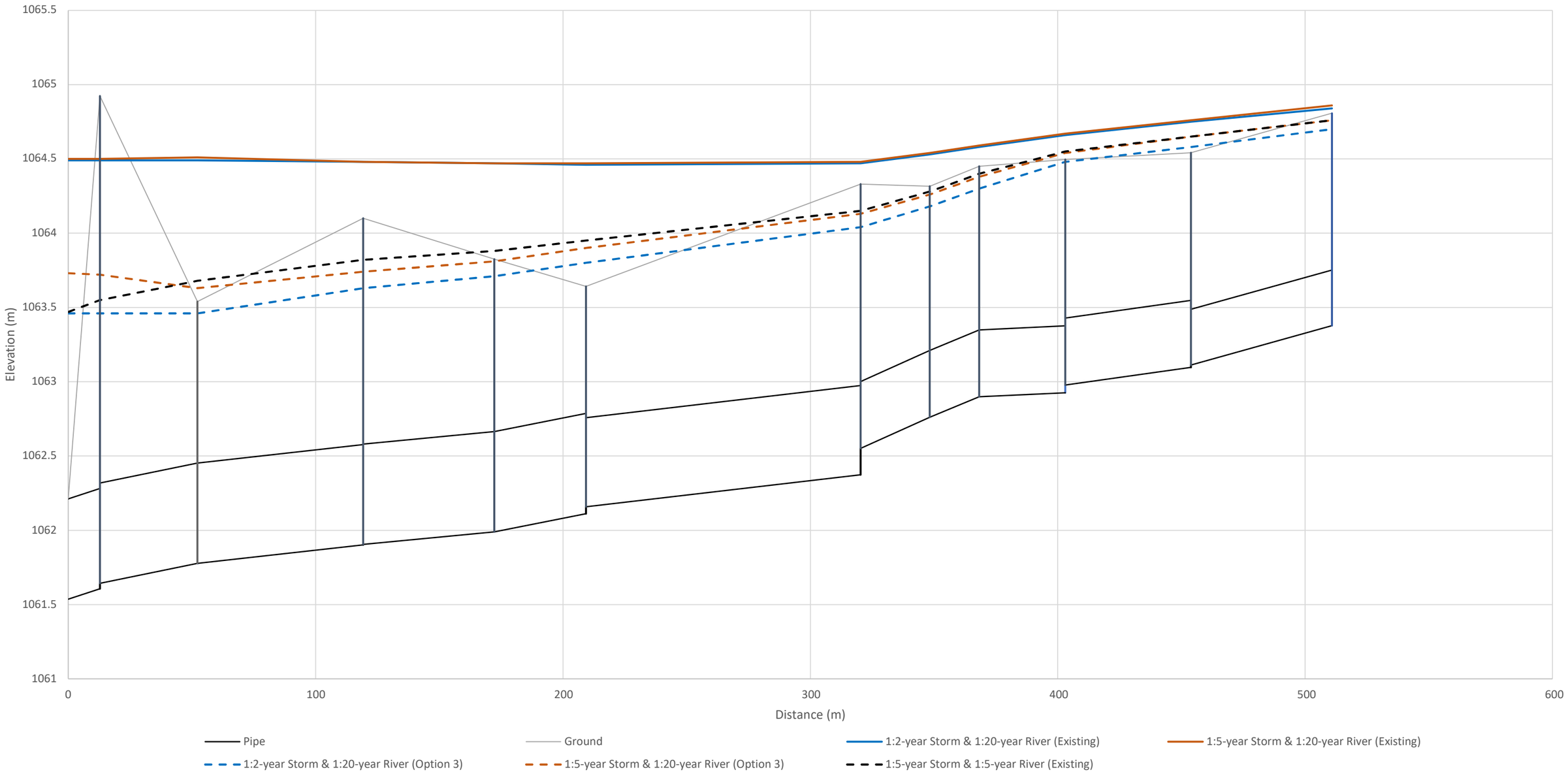
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Option 3 – Design Condition 1

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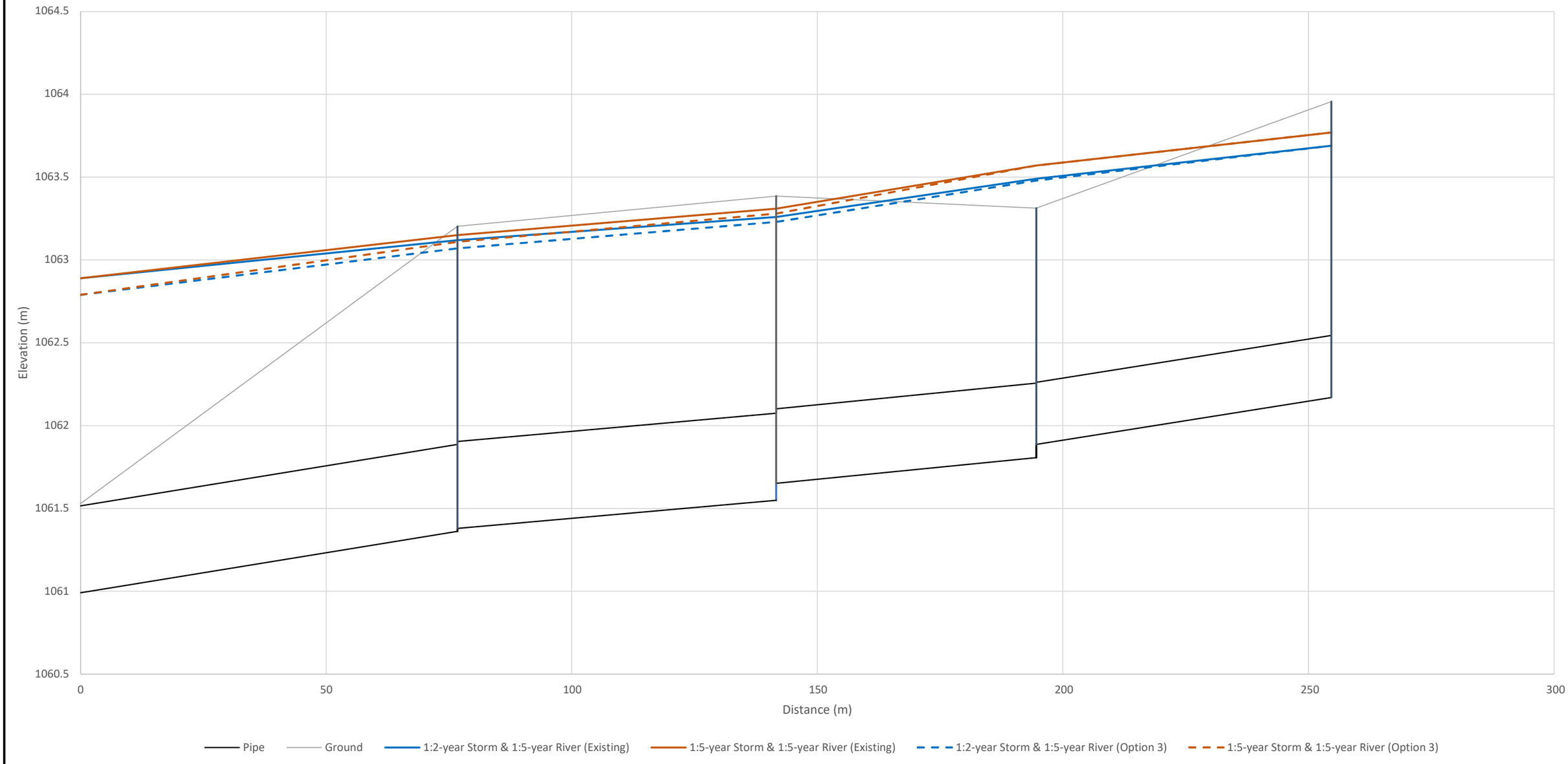
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Option 3 – Design Condition 2

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Figure A5-8



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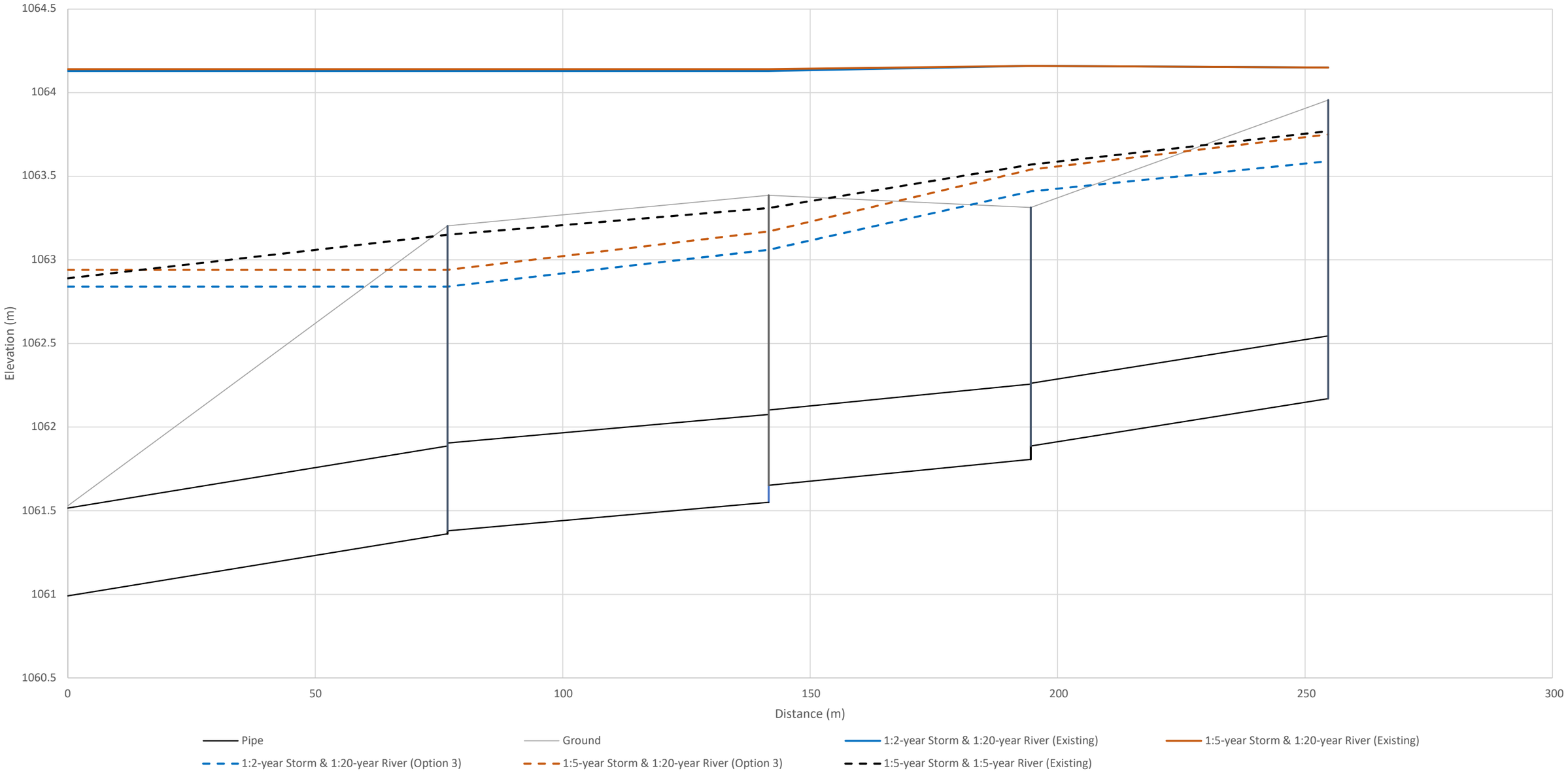
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Figure A5-10

APPENDIX B
Bow River Water Levels (MIKE HYDRO Results)

APPENDIX B

BOW RIVER WATER LEVELS (MIKE HYDRO RESULTS)

Table B1 presents the 1:5 year and 1:20 year Bow River water levels from the results of the 3-way coupled MIKE HYDRO simulations. Water levels are provided at each of the outfalls in the Study Area. Outfall invert levels are provided for context.

TABLE B1

Outfall	Invert Level	1:5-year Bow River Water Level at Outfall (m)	1:20-year Bow River Water Level at Outfall (m)
B100	1060.99	1062.79	1063.88
B101	1061.54	1063.50	1064.55
B104	1062.59	1064.69	1065.78
B106	1063.89	1065.27	1066.34
B107	1063.1	1065.89	1066.95
B108	1064.55	1066.19	1067.19
B108A	1066.14	1068.00	1069.11
B109	1067.73	1068.51	1069.74
B98	1060.95	1062.35	1063.39
B97	1062.95	1061.70	1062.85