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Final Report for:

FOOTHILLS OKOTOKS REGIONAL WATER

Phase 1 Reservoir Dam Consequence Classification
Rev. 1

Date: January 29, 2025
Project #: 29121-005-11

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January 29, 2025
File: N:\29\121-005\11\R01-1.0

Attention: **Jeremy Huet, P.Eng.**
Operations and Utilities Director

Dear Mr. Huet:

Re: Phase 1 Reservoir Dam Consequence Classification Rev. 1

We are pleased to submit the *Phase 1 Reservoir Dam Consequence Classification Rev. 1* final report to the Town of Okotoks. This document summarizes the background information, methodologies undertaken and results of the inundation analyses, dam consequence classification, and includes the inundation mapping resulting from a breach of the Phase 1 Reservoir.

If you have any questions or require clarification, please contact the undersigned at 403-831-8564.

Yours truly,

MPE a division of Englobe

Noor Mirza, P.Eng.
Project Manager

NM/vv
Enclosure

CORPORATE AUTHORIZATION

This report has been prepared by MPE a division of Englobe under authorization of the Town of Okotoks. The material in this report represents the best judgment of MPE a division of Englobe given the available information. Any use that a third party makes of this report, or reliance on or decisions made based upon it is the responsibility of the third party. MPE a division of Englobe accepts no responsibility for damages, if any, suffered by a third party as a result of decisions made or actions taken based upon this report.

Should any questions arise regarding content of this report, please contact the undersigned.

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PERMIT TO PRACTICE
MPE, a division of Englobe Corp.

Signature

APEGA ID 106756

Date January 29, 2025

PERMIT NUMBER: P 7841

The Association of Professional Engineers and Geoscientists of Alberta (APEGA)

Corporate Permit

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Appendices

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ACRONYMS

AEPA	Alberta Environment and Protected Areas
AER	Alberta Energy Regulator
BR	Average Breach Width
CDA	Canadian Dam Association
DA	Drainage Area
DBIS	Dam Breach Inundation Study
DEM	Digital Elevation Model
DSR	Dam Safety Review
DS	Downstream
EL	Elevation
Fb	Freeboard
FSL	Full Supply Level
GIS	Geographical Information System
H	Height (Depth) of Water
HD	Height of Dam
HEC-RAS	Hydrologic Engineering Center - River Analysis System
HW	Height of water above breach bottom
IDF	Inflow Design Flood
LiDAR	Light Detection and Ranging
LOL	Loss of Life
NOL	Normal Operating Level
PAR	Population at Risk
PMF	Probable Maximum Flood
Q	Discharge or Flow
T	Time from initial breach to full breach of dam
TOD	Top of Dam
US	Upstream
V	Volume
WSC	Water Survey of Canada
Z	Horizontal component of breach side slope

UNITS

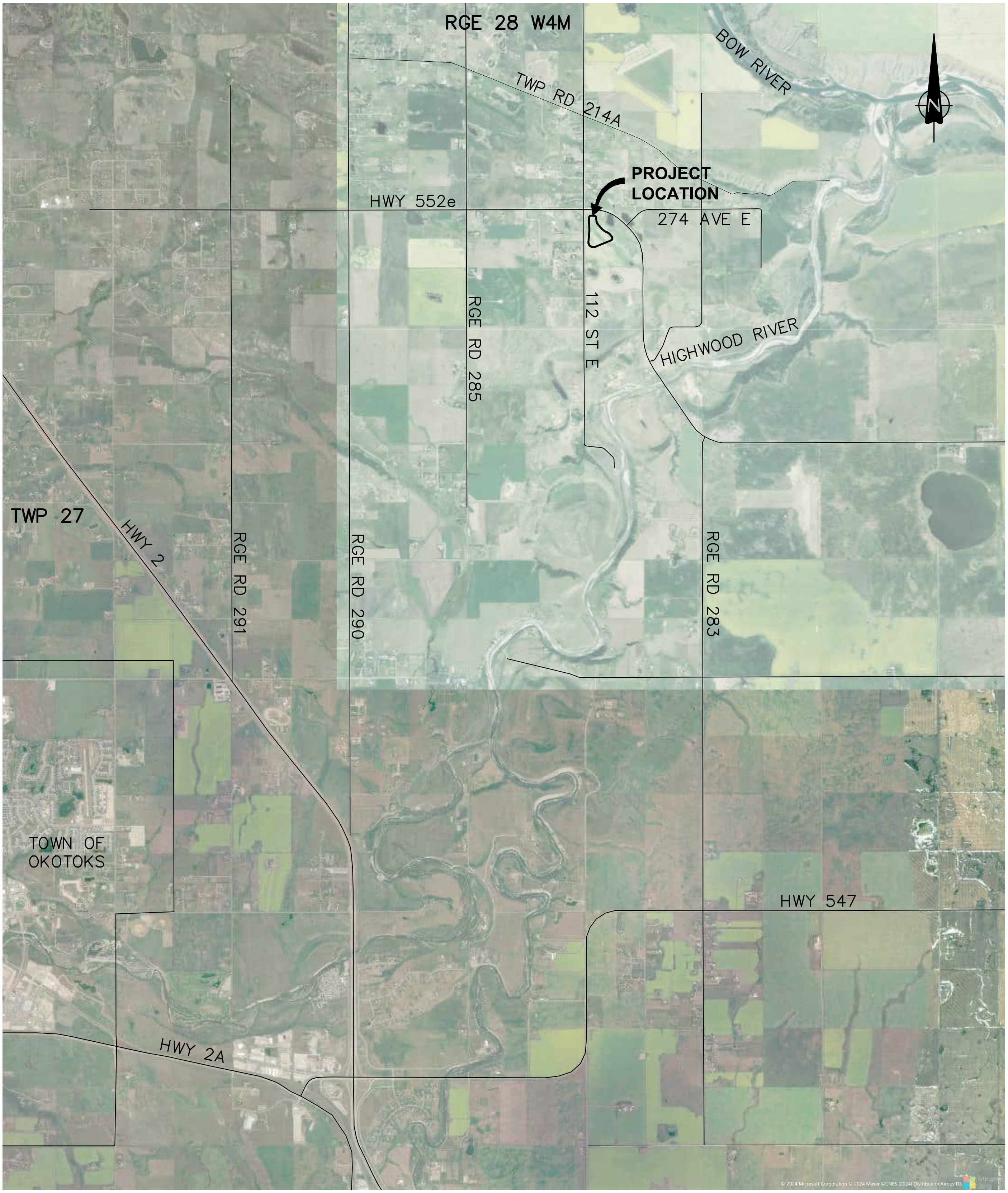
dam^3	cubic decametre (1 dam^3 = 1000 m^3)
ha	hectare
hr	hour
km	kilometre
km^2	square kilometre
m	metre
m^3	cubic metre
m^3/s	cubic metre per second

1.0 INTRODUCTION

As part of the Foothills Okotoks Regional Water (FORW) partnership, the Town of Okotoks is proposing to construct a raw water reservoir called the FORW Phase 1 Reservoir on an undeveloped property legally described as NW 21-T21-R28 W4M in Foothills County, Alberta. Raw water will be delivered to this storage reservoir via a pipeline originating from the proposed FORW raw water intake located at the confluence of the Bow and Highwood Rivers.

The Phase 1 Reservoir is bound on the west by 112 Street E and bound on the north and east by Highway 552E (see location plan in ***Figure 1.1***). The reservoir design was completed by Urban Systems Ltd. (USL) and indicates storage volume and embankment heights that exceed the minimum values for the facility to be defined as a dam which is height of 2.5 m or greater and live storage volume of 30,000 m^3 or greater.

MPE a division of Englobe (MPE) was retained to complete a dam consequence classification for the Phase 1 Reservoir. The purpose of this report is to review and analyze the collected data to determine a realistic worst-case failure scenario of the reservoir and determine the resulting consequences.



TOWN OF OKOTOKS AND FOOTHILLS COUNTY	
FOOTHILLS OKOTOKS REGIONAL WATER PROJECT RAW WATER RESERVOIR LOCATION PLAN	

a division of Englobe

SCALE: 1:75 000	DATE: JULY 2024	JOB: 29121-005-11	FIGURE: 1.1

2.0 BACKGROUND AND SCOPE

The Alberta Dam and Canal Safety Directive (Alberta Directive) requires that dams be classified in terms of reasonable, foreseeable consequences of failure including loss of life, injury, property, environmental damage, and general disruption of the lives of the population in the inundated area. The Phase 1 Reservoir is a proposed new structure, as such there is no existing consequence classifications.

The following provincial and national guidelines and directives were considered in the completion of this dam classification:

- 2007 Canadian Dam Safety Guidelines (CDA Guidelines), 2007 & 2013.
- Alberta Dam and Canal Safety Directive (Alberta Directive), 2018, Section 3.2 and Schedule 1.
- Pertinent Sections of the Alberta Water (Ministerial) Regulation and *Water Act*.

According to the CDA Guidelines, the dam consequence classification is based on the incremental losses incurred due to the event, which are over and above those losses which would have been incurred for the same event had the dam not failed.

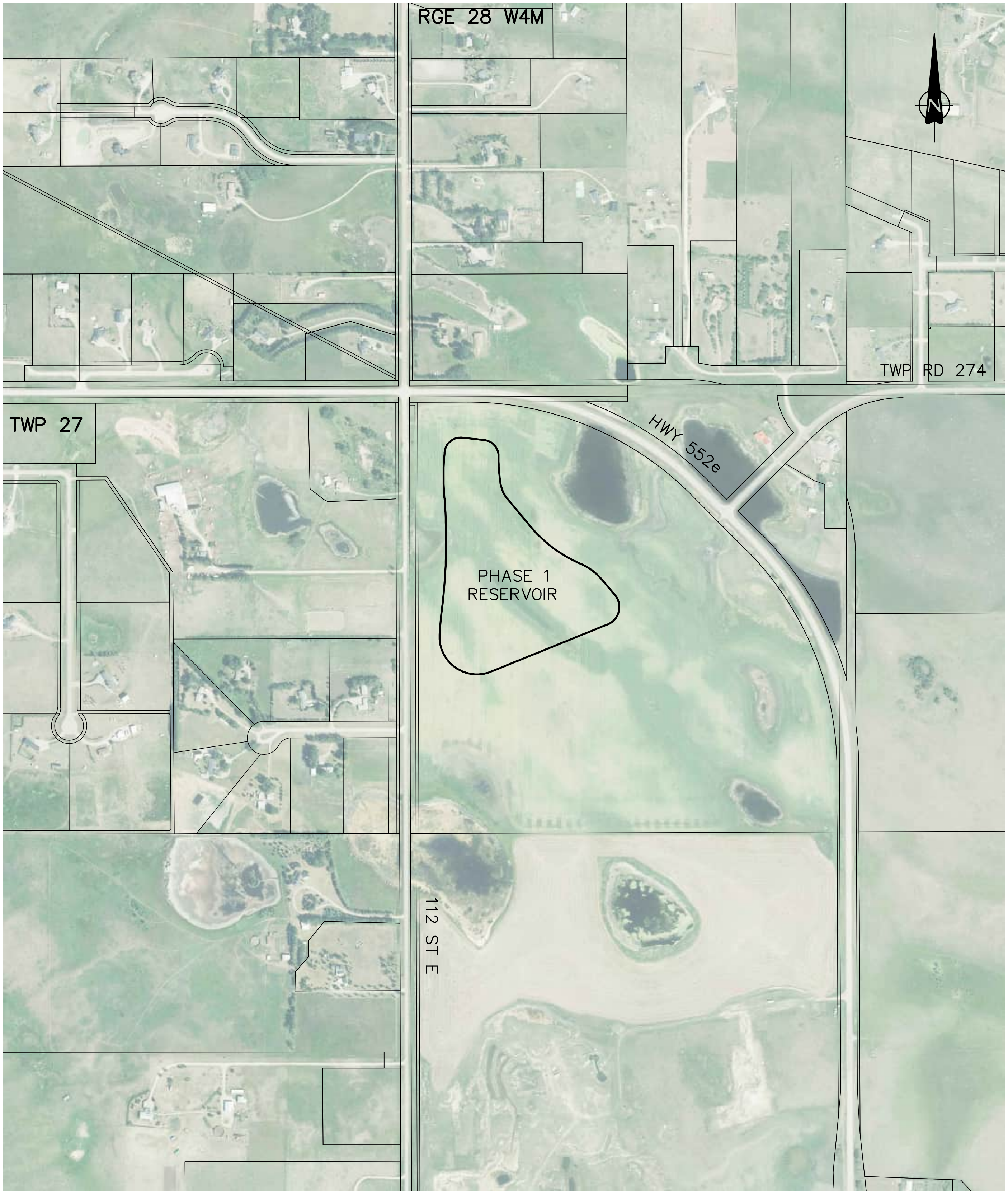
Figure 2.1 depicts a site plan for the Phase 1 Reservoir.

A qualitative review of the downstream consequences was completed as part of this consequence classification, based on the Alberta Directive. Inundation mapping and breach flow analysis provided by USL was generated using LiDAR terrain data, drone survey, aerial imagery, and information from the Preliminary Design.

The landform surrounding the Phase 1 Reservoir is characterized by rural undeveloped land and low-density acreage communities. In the general vicinity of the Phase 1 Reservoir, the land falls from southwest to northeast with a low-lying trapped low area north and east of Highway 552.

Based on Section 3.2 (4b) of the Alberta Directive, a "qualitative assessment" methodology of dam classification was utilized, which included the following steps:

- General Structure Characteristics – Identify the general characteristics of the dam.
- Breach Flow Estimates – Estimate the potential range of the peak breach flow out of the dam utilizing empirical estimate approaches.
- Impacts to Downstream Infrastructure – Identify the downstream infrastructure and estimate the impacts to the infrastructure and determine the resulting impacts at road crossing, and homes based on the dam breach flow.
- Loss of Life (LOL) Analysis – A simplistic analysis using USBR (2015) methodology.
- Environmental and Cultural Losses – A simplistic generalization of impact based on the area impacted.
- Infrastructure and Economic Losses – An order-of-magnitude estimate and discussion of the potentially impacted downstream infrastructure.
- Dam Consequence Classification – Identification of the dam consequence classification based on Schedule 1 of the 2018 Alberta Directive, the findings of the LOL analysis, as well as cultural and economic damages for the worst-case failure event.



Okotoks

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TOWN OF OKOTOKS AND FOOTHILLS COUNTY

FOOTHILLS OKOTOKS REGIONAL WATER PROJECT
RAW WATER RESERVOIR
SITE PLAN

SCALE: 1:10 000	DATE: JULY 2024	JOB: 29121-005-11	FIGURE: 2.1

3.0 GENERAL RESERVOIR CHARACTERISTICS

The design of the Phase 1 Reservoir is shown in the drawings provided in ***Appendix A***; key reservoir and embankment characteristics are provided in ***Table 3.1.***

Table 3.1: FORW Phase 1 Reservoir Characteristics

Characteristic	Phase 1 (Phase 1 Reservoir)
Full Supply Level – FSL (m)	1,022
FSL Volume (m^3)	296,619
Top of Bank (TOB) – FSL + 1 m (m)	1,023
TOB Volume – FSL + 1 m (m^3)	379,150
Embankment Slope (upstream/downstream)	3:1 and 5:1/5:1
Top Width – Perimeter Berm (m)	10
Max Embankment Height (m)	6.09
Reservoir Bottom	1,016.5
Controlled Inflow (L/s)	116

The proposed reservoir design includes one containment cell surrounded by a 10.0 m wide top berm with a 5:1 side slope on the downstream side and a combination of 3:1 and 5:1 side slopes on the upstream sides. Centered on the top of the berm is a maintenance access road ranging from 5 m to 6 m wide. A synthetic liner covers the reservoir bottom and berm slopes, and the liner edges will be secured in an anchor trench.

The full supply level (FSL) of the Phase 1 Reservoir is set at an elevation of 1,022 m and the FSL volume is 296,619 m^3. The reservoir has 1.0 m of freeboard above the FSL level and the volume at bank full level (FSL + 1 m) is 379,150 m^3/s.

The reservoir will have a controlled inflow pipeline originating from a pump station located at the confluence of the Bow and Highwood Rivers. A controlled discharge via a proposed on-site pump station (FORW Midline Pumpstation) which will deliver flow to the Okotoks water treatment plant. The reservoir is isolated from drainage inflow except for precipitation falling directly on the surface area of the reservoir which is considered negligible in this case. As such, the inflow design flood (IDF) is 0.

4.0 POTENTIAL FAILURE SCENARIOS

A worst-case failure scenario is an event that has limited warning time and causes the greatest impact to the population, infrastructure, and environment.

During extreme rainfall or snowmelt events where a reservoir is designed to receive inflow from the surrounding drainage catchment, the resulting runoff can inundate and overtop a reservoir. This is an example of a flood-induced overtopping failure or ‘rainy-day’ failure. Given the absence of inflow from the surrounding drainage catchment, this is not a potential failure scenario. As such, further hydrological analysis to determine the IDF or hydrotechnical analysis for sizing emergency spillway channels was not required.

In an earth-filled embankment reservoir with a potentially pervious structure, the stored water can find its way through the embankment or foundation and escape in the form of seepage. If seepage is not controlled, it can lead to internal erosion or piping of the embankment material and can lead to a failure of the structure. Enforcing quality control measures and recommendations from the geotechnical engineer during construction will help mitigate most major concerns. Post-construction dam safety reviews and inspections can help identify early signs of seepage and piping and help prevent full-scale failure. The reservoir will be constructed with compacted clay fill so the possibility for such a failure does exist, but the presence of synthetic liner and a seepage control underdrain system will mitigate the risk. This failure scenario would be an embankment failure due to piping when the reservoir is at its FSL. A nighttime failure would result in the least warning time. This scenario is identified herein as ‘**FSL**’. This is a ‘sunny day’ piping event.

The Phase 1 Reservoir will have a raw water supply pipeline (intake) and regional raw water distribution pipe (outlet) system that will be controlled by pumps, valves, and other instruments. Upset conditions caused by equipment or system failure could result in overtopping the reservoir. For example, if pumps failed to shut off and the intake valves failed in the open position, the reservoir could overfill. Similarly, if instrumentation failed to detect a high-water level in the reservoir and prevented the pumps from shutting off, the reservoir could overtop. Redundancy and other safeguards can be built into the SCADA programming to reliably prevent equipment and system malfunction from occurring. This failure scenario would have a very low likelihood of occurring but is still possible.

Another failure scenario is when a reservoir overtopping breach occurs at night. This scenario would release the highest breach volume with the least amount of warning time. Of the three scenarios discussed, this corresponds to an overtopping failure caused by equipment or system malfunction or operator error. This is a very unlikely scenario; however, it is considered in the analysis to determine absolute worst-case consequences and is identified herein as the **'FSL + 1 m'**. This is a 'sunny day' overtopping event.

5.0 BREACH FLOW AND INUNDATION ANALYSIS

Dam inundation mapping and breach analysis was performed by USL and completed using GeoHECRAS Version 5.0.0125. As a check, the methodology discussed in *Predicting Peak Discharge from Gradually Breached Embankment Dam* (Froehlich, 2016) was used to determine whether the estimated breach flow fell within an acceptance range. In his paper, Froehlich *describes two nonlinear mathematical models to predict peak discharge from a breached embankment dam based on evaluation of measured outflows from 41 dam failures. Reported outflow rates from these failures have been examined carefully for accuracy and believed to be reliable. The first model is purely empirical, while the second is based on a semi theoretical approach that reduces the maximum possible peak discharge that would be produced by instantaneous formation of a breach having prescribed dimensions. Results are more accurate predictions of peak discharge from breached embankment dams (2016).*

A breach location along the east side of the reservoir at the deepest section of the embankment was selected to assess the greatest consequences to the factors at risk. In a breach event, flows would initially be directed northeast toward Highway 552E. Breach water would overtop Highway 552E and the bisecting roadway of 274 Avenue/Township Road 274, flow into naturally low-lying areas, and inundate parts of the country residential community immediately north and east of Highway 552E. The surrounding topography is characterized by low-lying wetland vegetation, traplows and the absence of a drainage outlet. Release of the volume of the reservoir would be contained in this low area with no discharge flow beyond. This would be the case for both scenarios.

The results are summarized in ***Table 5.1***.

Table 5.1: Breach Flow Summary

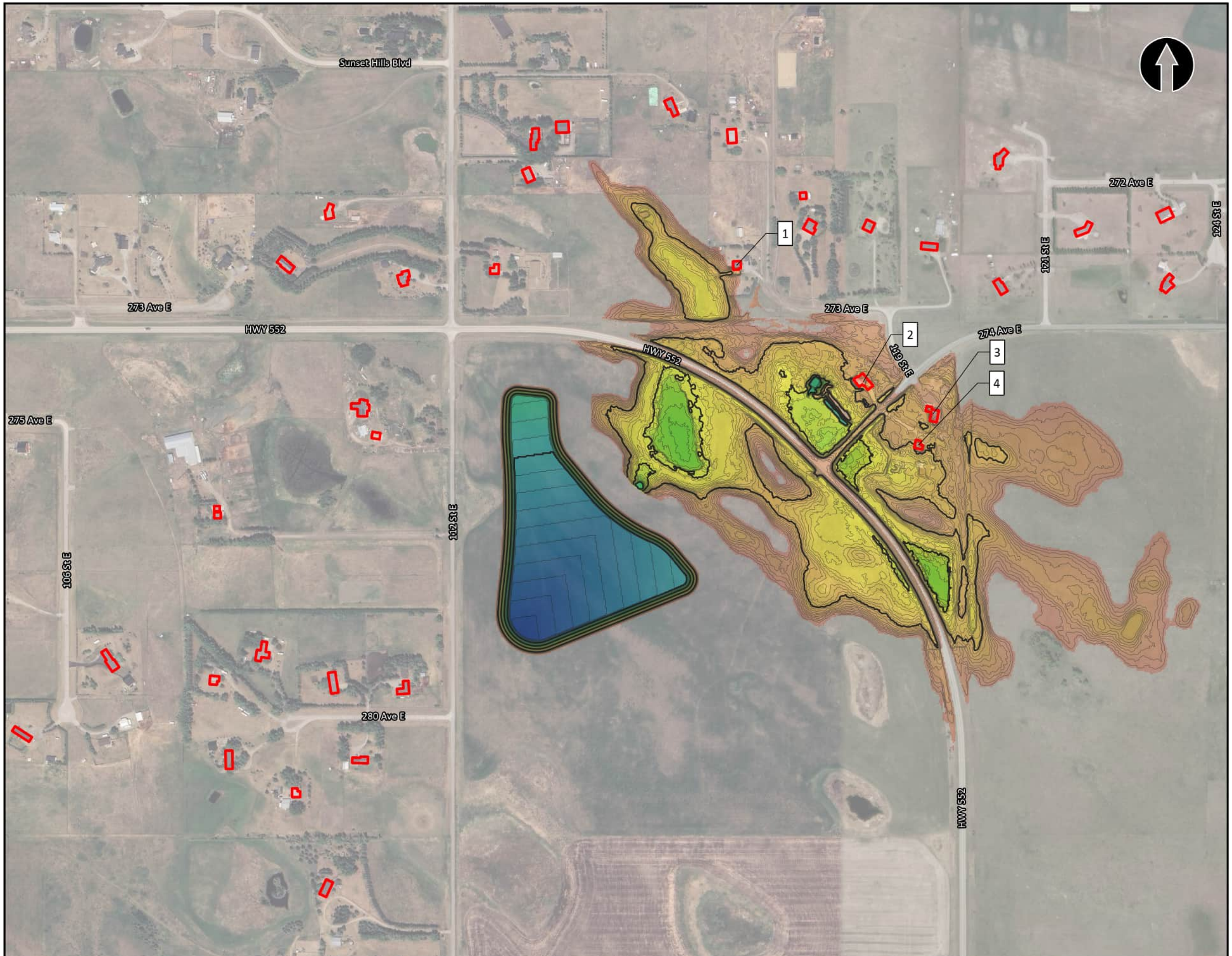
Methodology	FSL (m^3/s)	FSL +1m (m^3/s)
GeoHECRAS (USL)	77	77
Froehlich 1995 – Empirical	75	173
Froehlich 1995 – Semitheoretical	100	175

A peak breach flow of 77 m^3/s was determined by USL for both breach scenarios. Based on the comparison above, the USL breach flow value for the FSL breach is within a reasonable range. It is reasonable to estimate that an overtopping event would produce a larger breach flow than a piping failure based on head difference. In both scenarios, although the initial breach flow through the embankment would be high, the initial flood wave would discharge from a channelized outflow into the wide open and low-lying terrain east of the dam and would result in immediate energy dissipation and transition to lower flow depth and flow velocities downstream. As such, the Geo TIFF files produced by the USL Geo HEC-RAS model containing flow-depth and velocity data are considered reasonable and adequate for further analysis on downstream impacts.

Inundation mapping produced by USL for the FSL (***Figure 5.1***) and FSL + 1 m scenarios (***Figure 5.2***) shows the inundation extents for each scenario and is overlaid on a base map of the aerial imagery of the area.

In the piping failure scenario (FSL), the Phase 1 Reservoir would release 290,228 m^3 of breach volume while 6,391 m^3 of dead storage would remain within the reservoir footprint. As shown in ***Figure 5.1***, residence 2, 3, and 4 are fully surrounded by the breach flow while residence 1 is partially affected on the south side of the home.

In the overtopping failure scenario (FSL + 1 m), the Phase 1 Reservoir would release a larger breach volume of 372,759 m^3 compared to the FSL scenario and 6,391 m^3 of dead storage would remain within the reservoir footprint. As show in ***Figure 5.2***, residence 2, 3, and 4 are fully surrounded by the breach flow, and given the larger breach volume, the inundation depth is slightly greater. Residence 1 is still partially affected on the south side of the home by a greater inundation depth compared to the FSL scenario.



Building Footprint

Contour - 1m Interval

Contour - 10cm Interval

Water Depth (m)

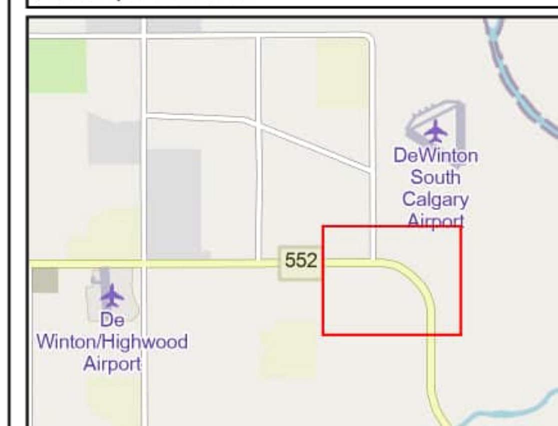
4.99

0

0 200 m

Scale: 6,000
(ANSI B 11"x17")

1. **Background Layers:** Google Earth Satellite; Google; OpenStreetMap; Map data © OpenStreetMap contributors, Microsoft, Facebook, Inc. and its affiliates, Esri Community Maps contributors, Map layer by Esri
2. **Data Sources:** Altalis, NRCAN, Statistics Canada
3. **Coordinate System:** NAD 1983 3TM 114



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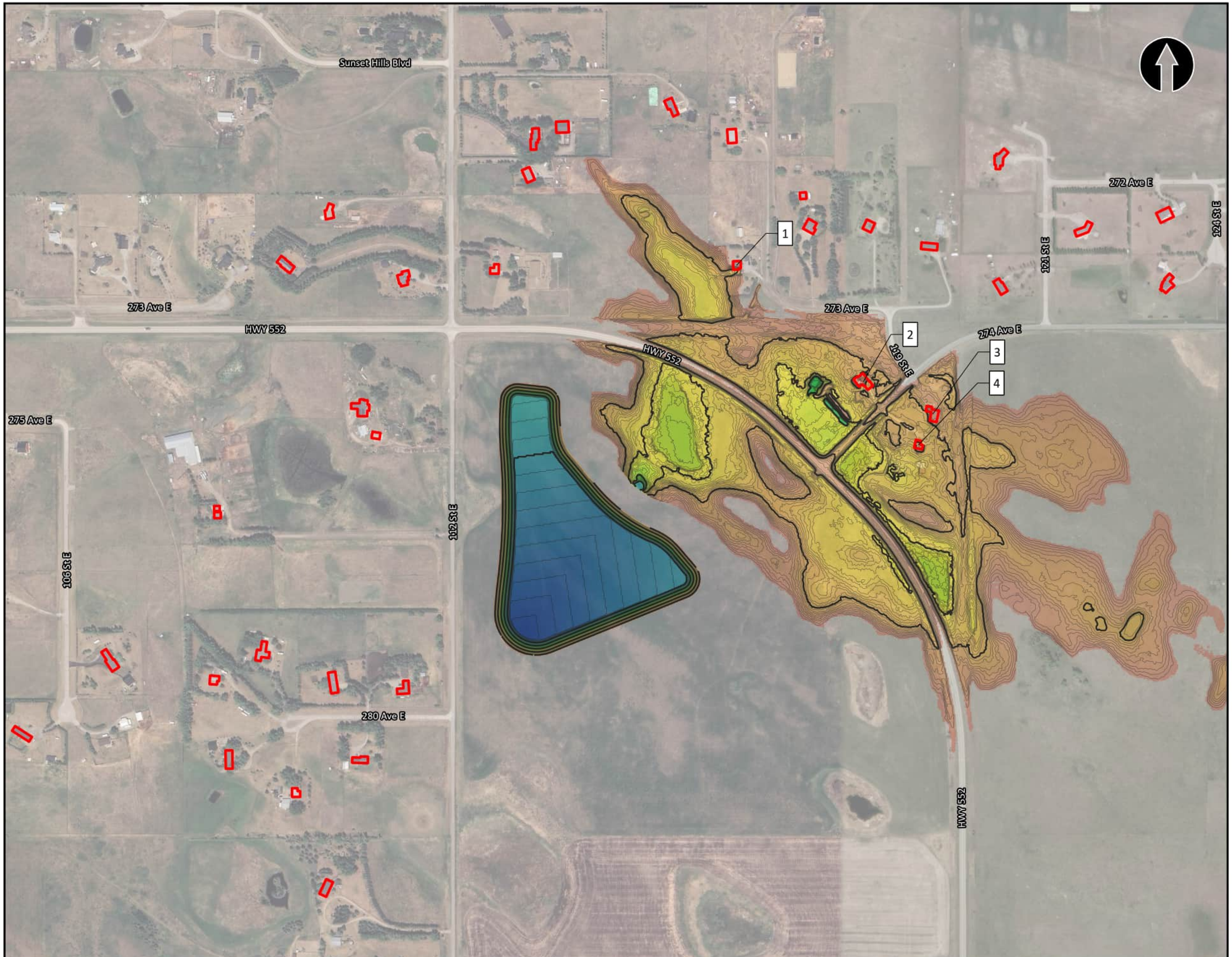
TITLE

FSL Piping Breach
FORW Reservoir Design
Urban Systems

LOCATION	REVIEW
21-21-28-W4M	Drawn by DM on 22 Jul 2024
Foothills County, Alberta	Review by NM on 22 Jul 2024

JOB	FIGURE	DATE
29121-005-11	5.1	22 Jul 2024



Building Footprint
Contour - 1m Interval
Contour - 10cm Interval
Water Depth (m)
5.99
0

0 200 m
Scale: 6,000
(ANSI B 11"x17")

1. **Background Layers:** Google Earth Satellite; Google; OpenStreetMap; Map data © OpenStreetMap contributors, Microsoft, Facebook, Inc. and its affiliates, Esri Community Maps contributors, Map layer by Esri
2. **Data Sources:** Altalis, NRCAN, Statistics Canada
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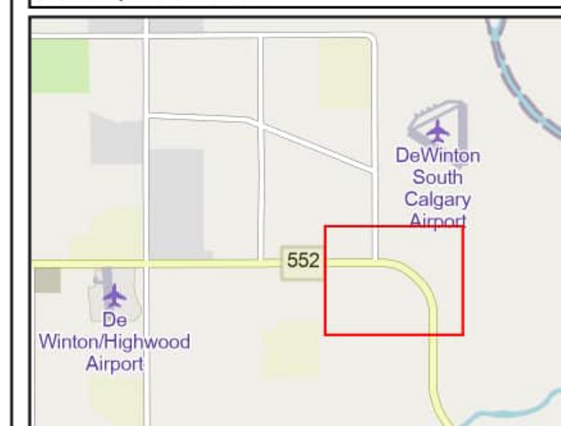

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TITLE
FSL +1m Overtopping Breach
FORW Reservoir Design
Urban Systems

LOCATION	REVIEW
21-21-28-W4M	Drawn by DM on 19 Jul 2024
Foothills County, Alberta	Review by NM on 19 Jul 2024

JOB	FIGURE	DATE
29121-005-11	5.2	19 Jul 2024

Table 5.2: Breach Volume

	Phase 1 Reservoir
FSL Reservoir Volume (m^3)	296,619
Breach Volume (m^3)	290,228
Dead Storage (m^3)	6,391
FSL + 1 m Reservoir Volume (m^3)	379,150
Breach Volume (m^3)	372,759
Dead Storage (m^3)	6,391

Highway 552E would be overtopped and impacts to residential properties would begin soon after breach flows overtop the highway. Given the proximity of the roadway and residences, a conservative approach is taken, and minimal warning time is assumed (less than 15 minutes) and all damages are considered incremental.

5.1 Inundation Depth and Velocity – FSL Breach

In the FSL breach scenario, maximum inundation depth at each residence is measured from water level to building grade level and ranges between 0.55 m to 1.20 m. Maximum flow velocity ranges from 0.03 m/s to 0.34 m/s.

Maximum inundation depth at roadways is measured from the water level to the top of roadway to determine the overtopping depth. Overtopping depth at Highway 552E and 274 Avenue E is 0.36 m and 0.93 m at the deepest points, respectively. Overtopping velocity at Highway 552E and 274 Avenue E is 1.10 m/s and 1.27 m/s, respectively.

A summary of the maximum inundation depths and velocities are provided in ***Table 5.3***.

Table 5.3: Inundation Summary (FSL)

Residence/ Roadway	D/S Distance from Reservoir (m)	Max Inundation Depth Relative to Ground (m)	Max Velocity (m/s)	Anticipated Damage
1	730	0.55	0.03	Basement seepage and water damage
2	475	1.27	0.34	Basement seepage and water damage
3	496	0.72	0.10	Basement seepage and water damage
4	510	1.20	0.32	Basement seepage and water damage
Highway 552E	320	0.36	1.10	Minimal scour and erosion damage
274 Avenue E	350	0.93	1.27	Minimal scour and erosion damage

5.2 Inundation Depth and Velocity – FSL + 1 m

In the FSL + 1 m scenario, maximum inundation depth at each residence is measured from water level to building grade level and ranges between 0.79 m to 1.51 m. Maximum flow velocity ranges from 0.05 m/s to 0.47 m/s.

Maximum inundation depth at roadways is measured from the water level to the top of roadway to determine the overtopping depth. Overtopping depth at Highway 552E and 274 Avenue E is 0.40 m and 1.16 m at the deepest points, respectively. Overtopping velocity at Highway 552E and 274 Avenue E is 1.30 m/s and 1.83 m/s, respectively.

A summary of the maximum inundation depths and velocities are provided in ***Table 5.4***.

Table 5.4: Inundation Summary (FSL +1m)

Location	D/S Distance from Reservoir (m)	Max Inundation Depth (m)	Max Velocity (m/s)	Anticipated Damage
1	730	0.79	0.05	Basement seepage and water damage
2	475	1.51	0.42	Basement seepage and water damage
3	496	0.95	0.17	Basement seepage and water damage
4	510	1.43	0.47	Basement seepage and water damage
Highway 552E	200	0.40	1.30	Minimal scour and erosion damage
274 Avenue E	530	1.16	1.83	Minimal scour and erosion damage

Given the larger breach volume in the FSL + 1 m scenario homes flow depth, inflow into residences is expected to seep into basements. Similar to the FSL scenario, minimal warning time is assumed (less than 15 minutes) and all damages are considered incremental.

5.3 Comparing Impacts of the FSL and FSL + 1 m

As described above, the Phase 1 Reservoir is a raw water reservoir that has a controlled inflow and outflow pipeline. Typically, an overtopping breach would occur as a result of a flood-induced failure or a 'rainy day' event. This reservoir is not hydraulically connected to the drainage basin and as such does not receive storm drainage inflows. Therefore, a major operational malfunction would need to occur for the reservoir to breach in this manner. This is highly unlikely given the reliability of SCADA control and the safeguards available in the instrumentation and control architecture of such a facility. Furthermore, of the 41 dam failures that are identified in the Froehlich 2016 study, one dam failure is attributed to an 'outlet works' failure, whereas 20 dam failures are attributable to 'internal erosion' (piping) failure. The benefit of assessing an overtopping failure (FSL + 1 m) is to determine if it would cause a significantly higher impact when compared to the FSL failure. The resulting impacts based on the results in ***Tables 5.3 and 5.4*** do no suggest there is materially significant variance between the two scenarios; however, to adequately assess worst case impacts, it is prudent to analyze the resulting consequences of both scenarios.

6.0 CONSEQUENCE CLASSIFICATION

The consequence classification for dams in Alberta is governed by the 2018 Alberta Directive. The classification categories range from 'Low Consequence' to 'Extreme Consequences' and is based on the incremental consequences of failure on loss of life, impact on environmental and cultural values, and impact on infrastructure, economics, and other property. The incremental consequence of failure is the impact above what would be expected from the same event or conditions but where dam failure does not occur. ***Table 6.1*** details the consequence classification categories and is taken from the 2018 Alberta Directive.

Table 6.1: Dam Safety Directive Consequence Classification

Consequence Classification	Population at Risk	Incremental Consequence of Failure		
		Loss of Life	**Environmental and Cultural Values**	**Infrastructure, Economics, and Other Property**
Low	None Identifiable	No possibility of loss of life other than through unforeseeable misadventure	Minimal short-term loss or damage and no long-term loss or damage to: a) Fisheries, b) wildlife habitats, c) rare or endangered species, d) unique landscapes, or e) sites of cultural significance.	Minimal economic losses mostly limited to the dam owner's property, and no potential for development within the dam inundation zone.
Significant	Temporary Only	Low potential for loss of life	No significant loss or damage to: a) important fisheries, b) important wildlife habitats, c) rare or endangered species, d) unique landscapes, or e) sites of cultural significance. Restoration or compensation in kind for losses and damages highly possible.	Low economic losses affecting limited infrastructure and residential buildings, public transportation or services or commercial facilities, or some destruction or damage to locations used occasionally and irregularly for temporary purposes.

High	Permanent	10 or fewer	Significant loss or damage to: a) important fisheries, b) important wildlife habitats, c) rare or endangered species, d) unique landscapes, or e) sites of cultural significance. Restoration or compensation in kind for losses and damages highly possible.	High economic losses affecting infrastructure, public transportation or services or commercial facilities, or some destruction or severe damage to scattered residential buildings.
Very High	Permanent	100 or fewer	Significant loss or damage to: a) critical fisheries, b) critical wildlife habitats, c) rare or endangered species, d) unique landscapes, e) sites of cultural significance. Restoration or compensation in kind for losses and damages possible but impractical.	Very high economic losses affecting important infrastructure, public transportation or services or commercial facilities, or some destruction or severe damage to residential areas.
Extreme	Permanent	More than 100	Major loss or damage to: a) critical fisheries, b) critical wildlife habitats, c) rare or endangered species, d) unique landscapes sites of cultural, e) significance. Restoration or compensation in kind for losses and damages is impossible.	Extremely high economic losses affecting critical infrastructure, public transportation or services or commercial facilities, or some destruction or damage to residential areas.

6.1 Population at Risk (PAR) and Loss of Life (LOL)

Before determining the potential loss of life (LOL), it is necessary to determine the number of people who are potentially in the inundation zone, or the population at risk (PAR). The PAR is divided into two groups: permanent PAR for those who live within the inundation zone, and temporary PAR for those who may be passing through the inundation zone including motorists, workers, or people there for recreation.

The number of PAR will fluctuate based on time of day, day of the week, the season, and many other factors; for instance, the PAR is expected to change from day to night as residents move out of the inundation area for work and school during the day, and then move back into the inundation area during the evenings. As a dam breach can happen at any point in the day and on any day, some simplifying assumptions can be used to produce a conservative estimate of PAR.

Several sources (USBR, 2015 and MDNRC, 2019) indicate that historically dam failures during the night result in higher casualty rates as people in the inundation zone are likely asleep resulting in slower responses and warning times, which is further complicated by the lack of light. Dam breaches during the day tend to have lower casualty rates as people are awake and often concentrated in a workplace or school which expedites warning and evacuation. Additionally, as flood waters often take more than an hour to raise to peak levels, this allows a significant amount of time during the day to organize evacuation whereas this advantage is lost during the night.

Therefore, for this analysis, it is assumed that the dam breach takes place at night. The permanent PAR is assumed to have returned home. Temporary PAR is then limited to vehicles on the roads.

6.1.1 Permanent PAR

There are four (4) residences within the breach flow inundation area. Three (3) of the affected residences are adjacent to 274 Avenue E and are approximately 300 m east of the reservoir, aerially. One (1) affected residence is north of Highway 552E and approximately 200 m north of the reservoir, aerially. During a nighttime breach, it is assumed there are three (3) persons per residence. As such, there is a total of 12 PAR during a nighttime breach.

In the FSL scenario, Residences 2 and 4 would be the most affected with the water depth estimated to reach 1.27 m and 1.20 m, respectively. The water depth at Residences 1 and 3 is estimated to be less than 1.0 m. Breach flows are estimated to have a velocity much less than 1.0 m/s and would not remove homes from their foundation.

Similarly, in the FSL scenario, Residences 2 and 4 would be the most affected with the water depth estimated to reach 1.51 m and 1.43 m, respectively. The water depth at Residences 1 and 3 is estimated to be less than 1.0 m. Breach flows are estimated to have a velocity much less than 1.0 m/s and would not remove homes from their foundation.

Although damages are expected to the residences, the impacts are considered minimal and as discussed in **Section 6.1.3**, the potential for loss of life is considered extremely low.

Table 6.2: Number of Permanent PAR

Time of Breach	Number of Residences	Permanent PAR	Warning Time
FSL Nighttime	4	12	15 to 60 minutes
FSL +1m Nighttime	4	12	15 to 60 Minutes

6.1.2 Temporary PAR

Temporary PAR are potentially present where breach flows overtop roadways. Inundation depth at each roadway is measured from water level to top of roadway. For both scenarios, as indicated in ***Table 6.3***, overtopping is expected at each of the roadway crossing locations. No warning time is expected (less than 15 minutes) at Highway 552E and 274 Avenue E and all damages are considered incremental.

During a nighttime breach, it is assumed there is one (1) vehicle with one (1) occupant present at each of Highway 552E, 274 Avenue E, and Range Road 283. As such, there is a total of two (2) temporary PAR.

Table 6.3: Number of Temporary PAR

Breach Scenario	Number of Roads	Temporary PAR	Warning Time
FSL Nighttime	2	2	Less than 15 minutes
FSL +1m Nighttime	2	2	Less than 15 minutes

Overtopping flows would cause erosion and scour damage to the roadway, and the flood depth may prevent passage, rendering sections of the roadway impassible. Motorists (temporary PAR) on the roadway at the time of breach would be impacted but potential for LOL is considered low.

6.1.3 Estimated Loss of Life

To determine potential LOL, the USBR (2015) methodology was used. This is the most recently published methodology and has replaced the older Graham (1999) methodology. The USBR (2015) method uses a graphical approach to relate LOL probability with depth-times-velocity (DV) and warning time and presents several curves which define the probable lower and upper LOL limits for a given DV and warning time. For this study, the upper probable bound was used to calculate the LOL probability.

Warning time is divided into two categories for this method: 'little or no warning' and 'adequate warning', however, these categories are not defined by USBR. For this study, the 'little to no warning' was applied to all PAR.

The DV value was calculated at peak inundation for each of the residences and roads and used to calculate the estimated LOL. The estimated LOL for each of the scenarios are presented in ***Table 6.4*** and all estimated LOL is incremental.

The estimated LOL is largely governed by flow passing across Highway 522 E and 274 Avenue E immediately downstream of the Phase 1 Reservoir. After passing the road, the flow spreads out over the downstream terrain and the estimated LOL at individual residences and roads decrease significantly as the flow becomes both shallow and slow.

Table 6.4: Estimated Loss of Life

	FSL		FSL + 1 m	
Residence/Roadway	**Flood Severity – D x V (m^2/s)**	**Estimate LOL**	**Flood Severity – D x V (m^2/s)**	**Estimate LOL**
1	0.017	0	0.040	0
2	0.432	0.0003	0.634	0.0003
3	0.072	0	0.162	0.0003
4	0.384	0.0003	0.672	0.0003
Highway 552E	0.396	0.0001	0.520	0.0001
274 Avenue E	1.18	0.0002	2.123	0.0015
	Total	**0.0009**	**Total**	**0.0025**

Consequence

Given these parameters, the total estimated LOL is significantly less than 1 in both scenarios and the potential for LOL is considered very low. This determination is consistent with a **Significant** consequence.

6.2 Infrastructure, Economics, and Other Property Risk

Two (2) roadways are impacted by the breach flows. Highway 552E is a paved provincial highway located immediately northeast of the Phase 1 Reservoir. Initial breach flows would inundate the low area between the reservoir embankment and the highway, causing erosion and scour along the shallow highway embankment. As the breach continues, it would overtop the roadway.

In the FSL scenario, up to a 400 m long section of this roadway is expected to be inundated up to a depth of 0.36 m. In the FSL+1m scenario, up to 550 m long section of this roadway is expected to be inundated up to a depth of 0.40 m. Given the depth of flow expected, the roadway would become impassible, and erosion and scour would damage a portion of the roadway.

274 Avenue E is a paved roadway located northeast of the Phase 1 Reservoir. This roadway provides access to several acreage residences and farms. Three (3) of the four (4) impacted residences identified in ***Table 3*** are accessed from 274 Avenue E. Downstream of Highway 552E, 274 Avenue E would be next to overtop.

In the FSL, scenario up to a 170 m long section of this roadway is expected to be inundated up to a depth of 0.93 m. In the FSL+1m scenario, up to a 200 m long section of this roadway is expected to be inundated up to a depth of 1.16 m. Given the depth of flow expected, the roadway would become impassible, and erosion and scour would damage and portion of this road.

Based on preliminary estimates, the Phase 1 Reservoir will cost approximately $11M (-30%/+50% accuracy) to construct. If 25% of the embankment structure is damaged, it is estimated that repair costs would be approximately $2.75M.

Using a rough approximation of road building costs in Southern Alberta, if 50% of this length needs to be repaired at a cost of $1 million per km of road, the cost of repair these roads (including any culverts) would be approximately $285,000.

Where residences are impacted, basement flooding would occur and damages to interior finishings, furnishings, and appliances are expected. Based on the Provincial Flood Damage Assessment Study (IBI, 2015), the damage to a typical Alberta home (category B-2 in the report) including both damage to contents in the house and house structure is approximately $130,000. Therefore, a conservative estimate of the total damage to residences is approximately $520,000.

Consequence

Total cost of damage to Infrastructure, Economics, and Other property is approximately $3.5M. This is consistent with a **Significant** consequence which is described in Schedule 1 (Alberta Directive, 2018) as low economic losses affecting limited infrastructure and residential buildings, public transportation or services or commercial facilities, or some destruction or damage to locations used occasionally and irregularly for temporary purposes.

6.3 Environment and Cultural Values

To determine the environmental and cultural impact of a dam breach, the Wetland Assessment and Impact Report (WAIR) prepared by USL in February 2023 was consulted to determine the presence of sensitive or at-risk plant, fish, bird, and other animal species as well as historic resources within the inundation zone.

6.3.1 Affected Fish and Wildlife Species

The WAIR states that sensitive species historically recorded within 3 km of the project site included the ferruginous hawk (at risk), great blue heron (sensitive), and the northern leopard frog (at risk). Amphibian survey results did not detect the northern leopard frog.

Table 6.5: Wildlife Species

Type	Species Common Name	Species Scientific Name	Alberta Designation
Bird	Great Blue Heron	Ardea herodias	Sensitive
Amphibian	Northern Leopard Frog	Lithobates pipiens	At Risk
Bird	Ferruginous Hawk	Buteo regalis	At Risk

During a sunny day dam breach event, bird species are not expected to be impacted as they mainly nest in trees. Given their historical presence in the area, the northern leopard frog could potentially be impacted during a breach event, however, with shallower water levels in the wetlands and ephemeral water bodies, impacts would be limited.

6.3.2 Fish and Wildlife

Within the current project site boundary, there are three (3) wetlands, all with an ABWRET-A score of ‘C’; one (1) of these wetland is located immediately east of the Phase 1 Reservoir and has been Crown claimed. Raw water would enter the wetland during a breach event however the impacts are expected to be minimal or short-term.

6.3.3 Historical Resource Value

No historical resources have been identified, and impacts are not anticipated.

Consequence:

The impacts to Environment and Cultural Value are consistent with a **Low** consequence which is described as no significant loss of damage to: a) important fisheries, b) important wildlife habitat, c) rare or endangered species, d) unique landscapes, or e) sites of cultural significance,

Restoration or compensation in kind for losses and damages highly possible.

7.0 SUMMARY OF CONSEQUENCES

Following the guidance in Schedule-1 (Alberta Directive, 2018) and in accordance with the impact to the factors at risk as described in **Section 6**, the corresponding Consequence Classification for the Phase 1 Reservoir is **Significant**.

It is noted that AGI has communicated their support of a Significant consequence classification provided that:

- A comprehensive Dam Safety and Emergency Management Plan is developed to mitigate risks to the downstream population during operation.
- Risks may also be effectively managed at the design stage by incorporating measures such as engineered spill areas (or emergency outflow drainage provisions), redundancies for detecting unintended reservoir level rises, and early intervention plans.

Table 7.1 summarizes the factors contributing to the proposed consequence classification.

Table 7.1: Consequences Classification Summary

Consequence Classification	Loss of Life (LOL)	Environmental and Cultural Values	Infrastructure, Economics and Other Property
Significant	**Significant**	**Low**	**Significant**
	Permanent LOL << 1 Temporary LOL << 1 • Very low potential for LOL. • Worst case is nighttime failure. • Greatest LOL potential is a vehicle on 274 Avenue E along breach path.	• Similar erosion damage to a large natural flood event. • Some downstream sediment deposition.	• Dam embankment damage. • Potential failure of two road crossing. • Financial loss approximately $3.5MM.

8.0 FREEBOARD REQUIREMENTS

Based on a Significant consequence structure, the 2007 CDA guidelines require the dam to meet the following criteria for freeboard:

- For normal operation, there will be no overtopping by 95% of the waves caused by the 1:1000 year wind when the reservoir is at FSL.

Wind speed data from Calgary International Airport was used. The Phase 1 Reservoir site is located approximately 40 km north of the site in a location that would be considered comparable for wind activity. Fetch length was taken from the northwest corner to the southeast corner as 418 m. The values present for effective fetch were also calculated as 426 m. This orientation is to a northwest wind which is typically the most severe wind direction in this region.

Table 8.1: Freeboard Requirements

Return Period (Year)	Overwater Wind Speed, U (km/h)	Wind Stress Factor, UA (m/s)	Wave Period, T (sec)	Wavelength, L (m)	Wave Run-up, Rs (m)	Wind Set-up, S (m)	Freeboard Required (m)
1:1000	99.79	42.26	1.63	4.17	0.26	0.02	**0.29**

The available freeboard at FSL is 1.0 m; the calculated freeboard is contained within the available freeboard. Based on the wave run-up and set-up values in ***Table 8.1***, the provided freeboard would be adequate.

9.0 LIMITATIONS AND USE

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10.0 REFERENCE

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APPENDIX A

Design Drawings

FOOTHILLS OKOTOKS REGIONAL WATER PROJECT

PHASE 1 RESERVOIR DESIGN DRAWINGS

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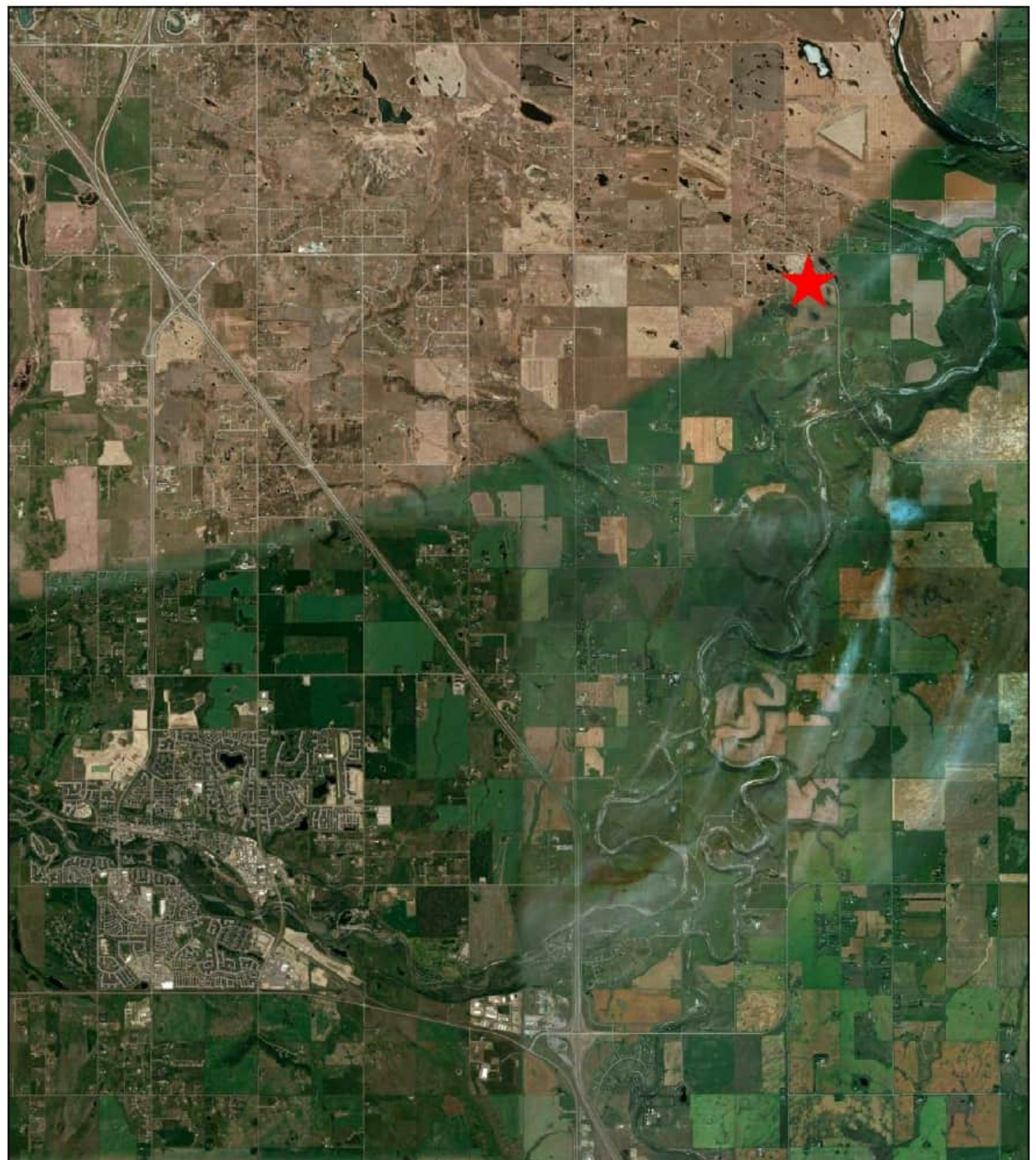

SITE LOCATION
NOT TO SCALE

List of Drawings

URBAN systems

TOWN OF OKOTOKS & FOOTHILLS COUNTY / FOOTHILLS OKOTOKS REGIONAL WATER PROJECT / 1306.0120.06

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FOOTHILLS OKOTOKS REGIONAL WATER PROJECT
PHASE 1 RESERVOIR
EXISTING SITE CONDITIONS

Sheet Number		1 of 7
Project Number	Drawing Number	Revision
1306.0120.06	001-01	1

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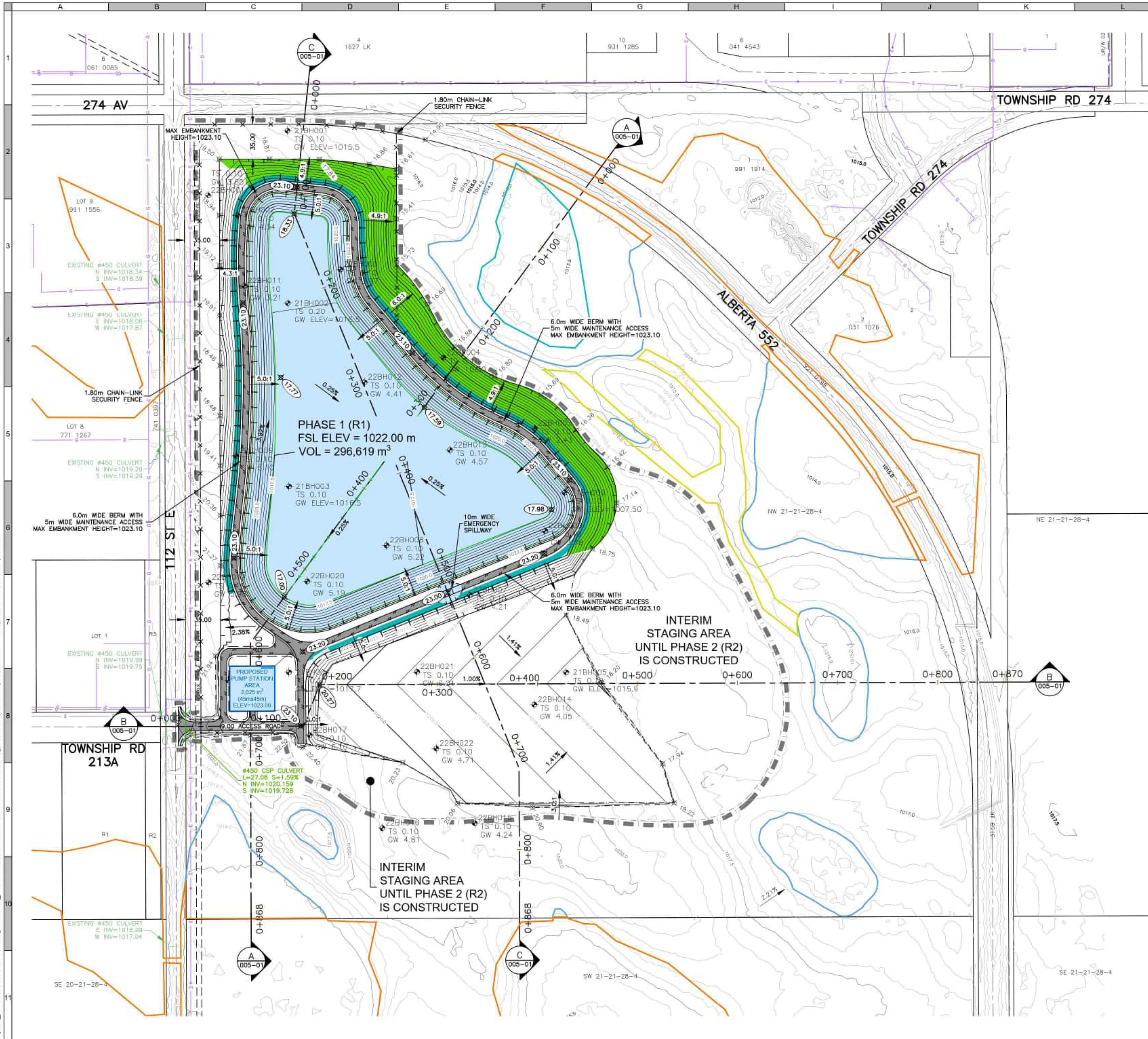

LEGEND

PROPOSED FEATURES

- SITE BOUNDARY
- MAJOR CONTOUR LINE (1025.0)
- MINOR CONTOUR LINE (1026.0)
- SPOT ELEVATION (12.85)
- CULVERT
- SLOPE / GRADE (5.0:1, 9.08%)
- TOP OF SLOPE
- TOE OF SLOPE
- BREAK LINE
- EDGE OF GRAVEL
- SHOULDER
- CHAIN-LINK SECURITY FENCE
- ENVIRONMENTAL ENHANCEMENT AREA
- DAM SCENARIO (DESIGN DETAILS TO BE CONFIRMED BY GEOTECHNICAL ENGINEER)

EXISTING FEATURES

- MAJOR CONTOUR LINE (1025.0)
- MINOR CONTOUR LINE (1026.0)
- SPOT ELEVATION (15.74)
- SLOPE / GRADE (5.0:1, 9.08%)
- WETLAND BOUNDARY
- BED AND SHORE
- EPHEMERAL WATERBODY
- WETLAND BOUNDARY (OFFSITE)
- EXISTING GAS LINE
- EXISTING ELECTRICAL LINE
- EXISTING CULVERT

NOTE:
RESERVOIRS TO BE CONSTRUCTED IN A PHASED APPROACH. ONLY PHASE 1 (R1) TO BE CONSTRUCTED AS PART OF THIS CONSTRUCTION CONTRACT. PHASE 2 (R2) WILL BE CONSTRUCTED AT A FUTURE TIME WHEN WATER DEMAND REQUIRES THE ADDITIONAL STORAGE. CONSTRUCTION OF PHASE 1 WILL REQUIRE DISTURBANCE AND RESTORATION OF THE PHASE 2 AREA.

FORWP – RESERVOIR R1 STORAGE VOLUME CHARACTERISTICS

STAGE	ELEVATION (m)	VOLUME (m3)	AREA (m2)
FULL SUPPLY LEVEL (FSL)	1022.00	296,619	80,643
FSL +1m	1023.00	379,150	84,428
MINIMUM SUPPLY LEVEL (MSL)*	1020.50	182,609	71,429
EMPTY SUPPLY LEVEL (ESL)	1017.00	0	0

* MSL BASED ON MINIMUM 3m WATER DEPTH REQUIREMENT AS PER RECOMMENDATION FROM PACE

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FOOTHILLS OKOTOKS REGIONAL WATER PROJECT
PHASE 1 RESERVOIR
SITE LAYOUT AND GRADING PLAN

Sheet Number 2 of 7
Project Number 1306.0120.06
Drawing Number 002-01
Revision 1

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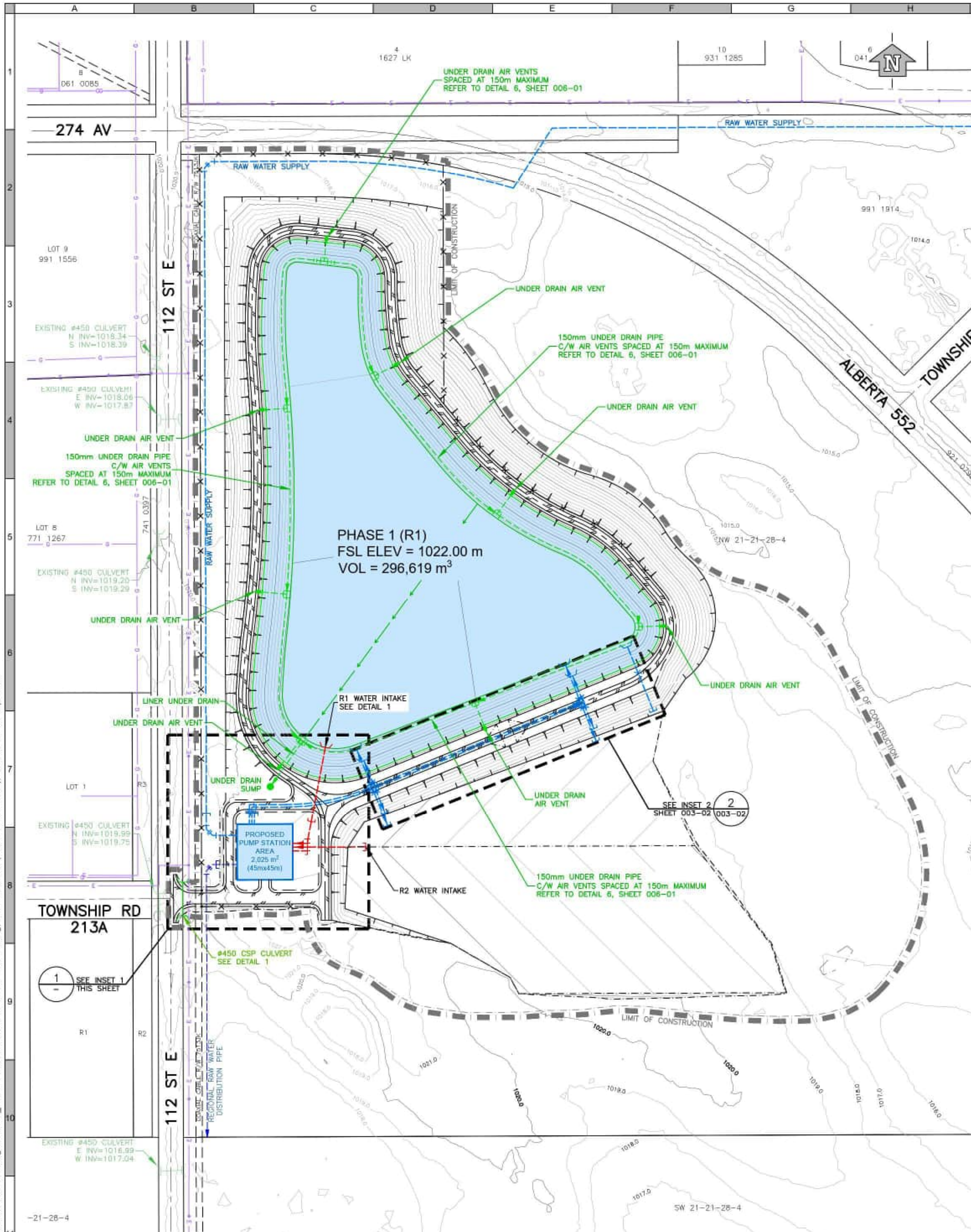
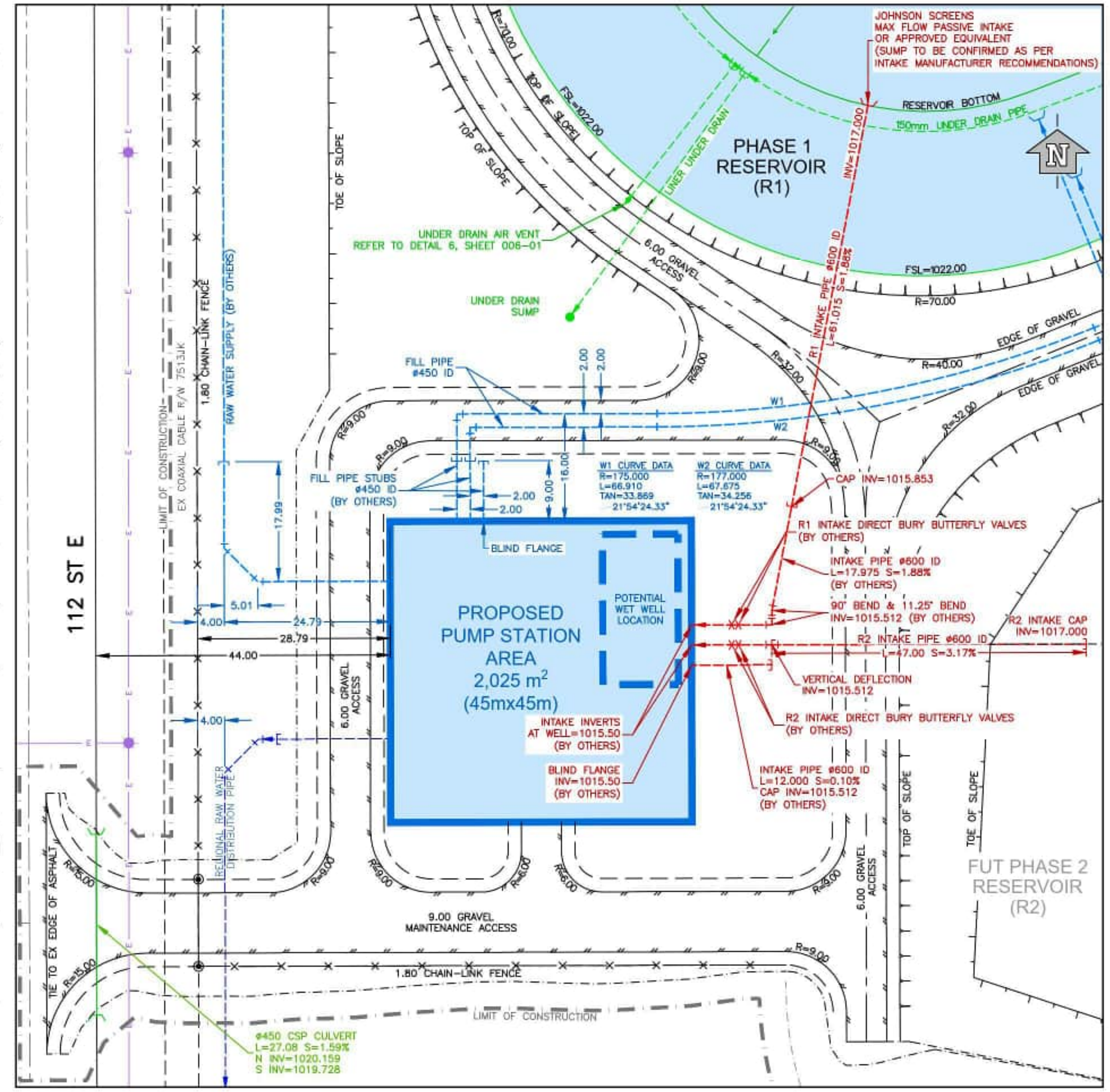


SITE PIPING PLAN
SCALE 1:2000



1 PIPING DETAIL
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PHASE 1 RESERVOIR
UTILITY PIPING PLAN

Sheet Number: 3 of 7
Project Number: 1306.0120.06
Drawing Number: 003-01
Revision: 1

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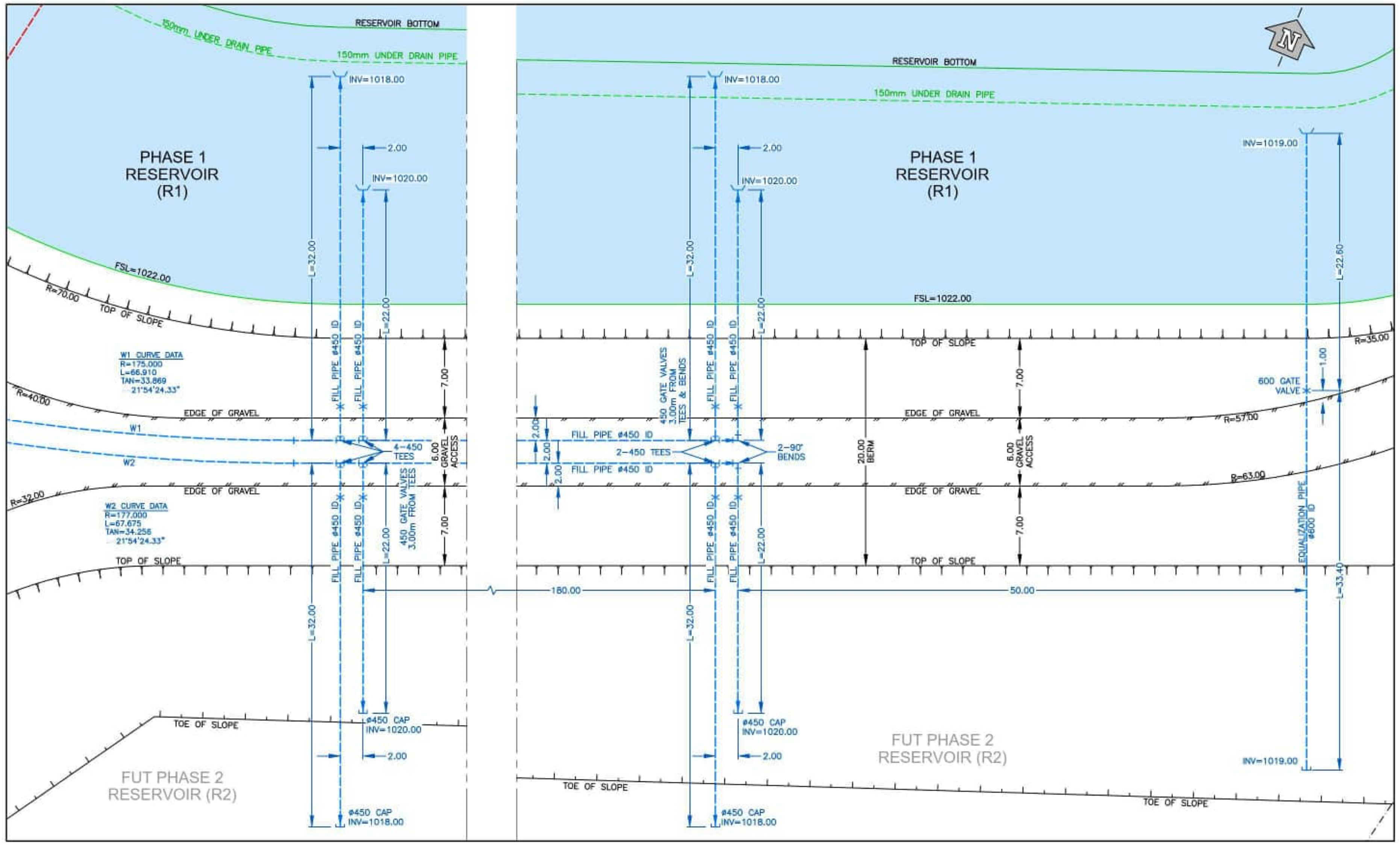

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003-01

SCALE 1:250

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PHASE 1 RESERVOIR
UTILITY PIPING PLAN

Sheet Number: 4 of 7

Project Number	Drawing Number	Revision
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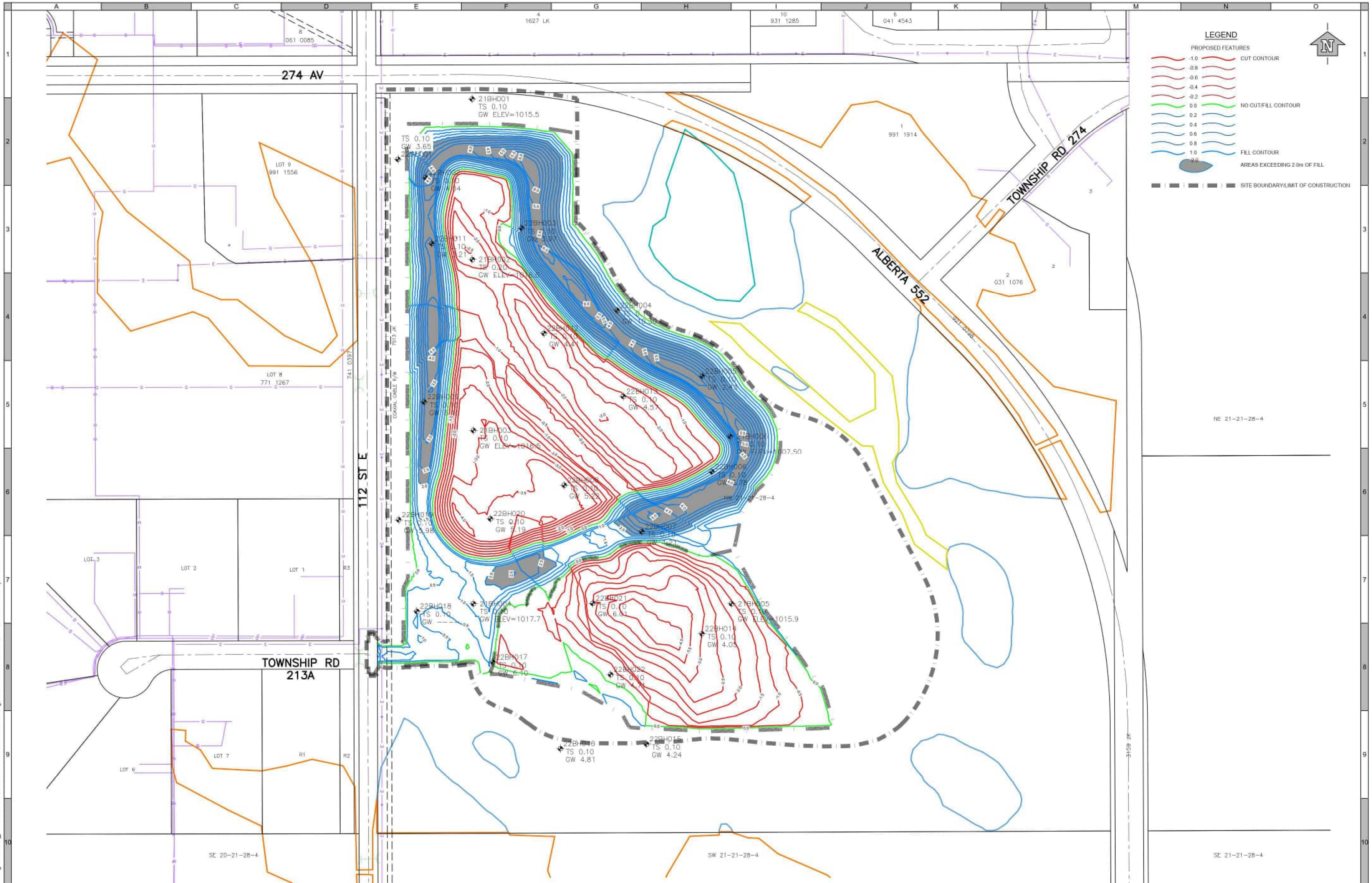

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VOL-ST_vs_RG (COMMON)	1.000	1.150	194921.92sq.m	203892.30 Cu. M.	203018.65 Cu. M.	873.66 Cu. M.<Cut>

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PHASE 1 RESERVOIR
CUT FILL PLAN

Sheet Number 5 of 7

Project Number	Drawing Number	Revision
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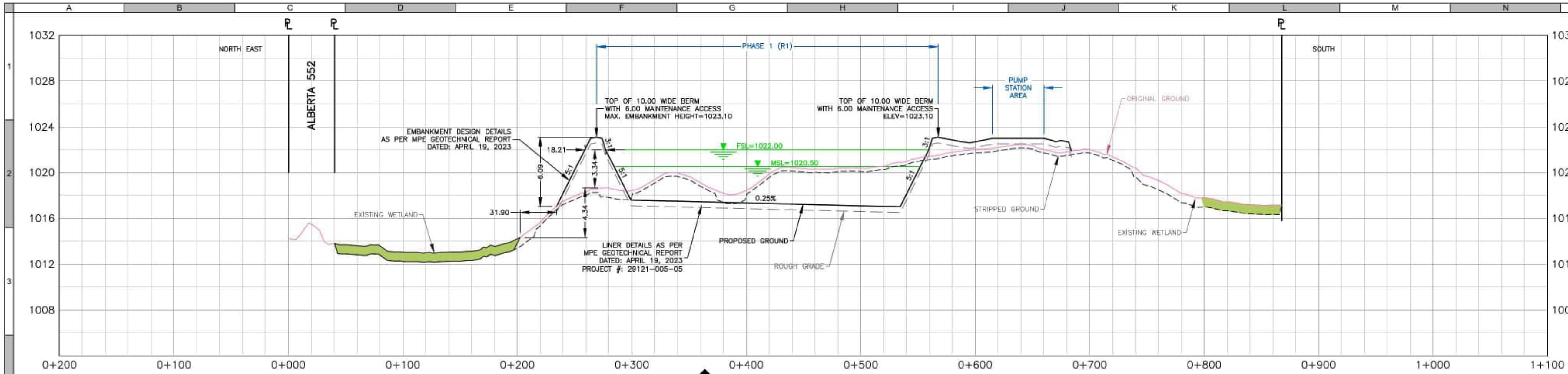
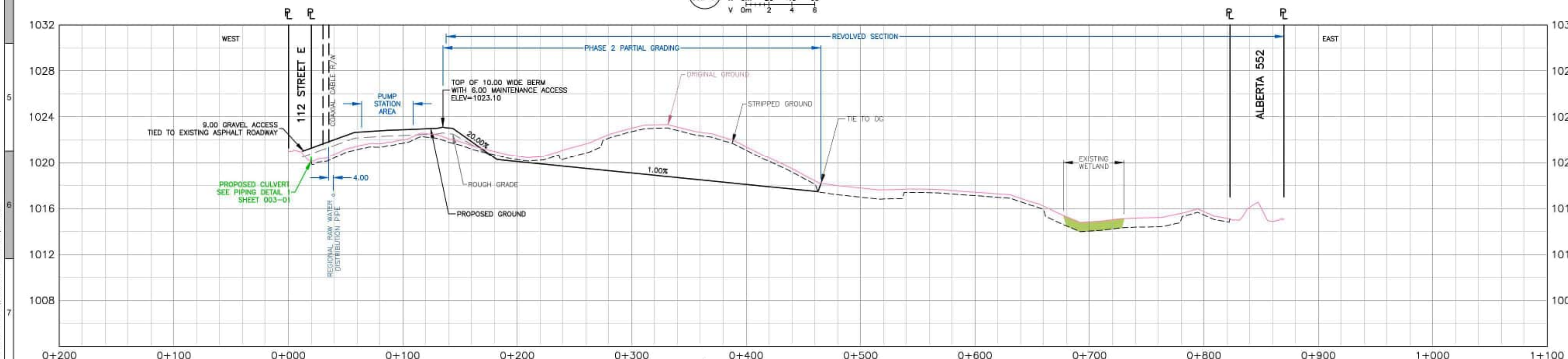
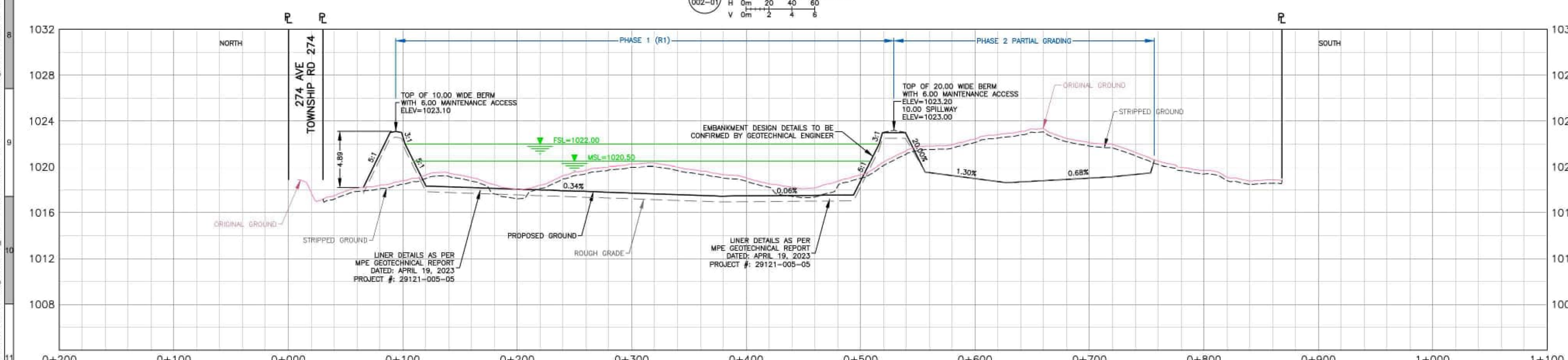


A CROSS SECTION 'A'
002-01
H 0m 20 40 60
V 0m 2 4 6



B CROSS SECTION 'B'
002-01
H 0m 20 40 60
V 0m 2 4 6



C CROSS SECTION 'C'
002-01
H 0m 20 40 60
V 0m 2 4 6

ATTENTION
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No representations of any kind are made by Urban Systems Ltd. or its employees to any party with whom Urban Systems Ltd. does not have a contract.

WARNING
Utilities or structures shown on this drawing were compiled from information supplied by various parties and may not be complete or accurate. Expose and conclusively confirm the location in the field all underground utilities and structures indicated on this drawing, all underground utilities in the area of the proposed work and any utilities or structures reasonably apparent from an inspection of the proposed work. Urban Systems Ltd. assumes no responsibility for loss or damage caused by third party negligence or failure to comply with the above.

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Prepared by: URBAN SYSTEMS SURVEY INC.
Coordinate System: 3TM-NAD83-114
Compilation Date: APRIL 2024

ISSUED FOR APPROVAL
JUNE 19, 2024
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Professional Seals

PROFESSIONAL ENGINEER DANIEL NYENTAP ALBERTA
2024-06-19

PERMIT TO PRACTICE
URBAN SYSTEMS LTD.
RM SIGNATURE:
RM APEGA ID #: 74627
DATE: June 19, 2024
PERMIT NUMBER: P003836
The Association of Professional Engineers and Geoscientists of Alberta (APEGA)

#	Date	Issue / Revision	App
1	2024-06-19	ISSUED FOR APPROVAL	DN

FOOTHILLS COUNTY
Okotoks

URBAN systems

Scale: AS SHOWN

Quality Control by: DN
Designed by: DN/TL
Drawn by: TL

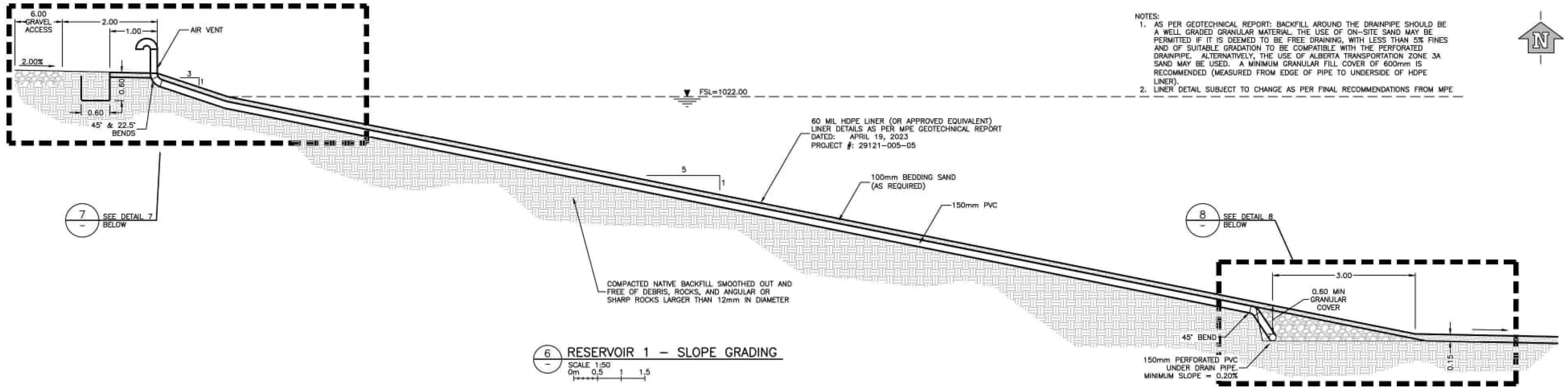
FOOTHILLS OKOTOKS REGIONAL WATER PROJECT
PHASE 1 RESERVOIR CROSS SECTIONS

Sheet Number: 6 of 7
Project Number: 1306.0120.06
Drawing Number: 005-01
Revision: 1

ISSUED FOR APPROVAL

U:\Projects_CAL\1306\0120\06\D-Design\CAD\20_PROD\Phase1\FORWP-03-C-SGP-002-01.dwg, 005-01-CROSS SEC (34x22-VERT PLAN), 2024-06-19 03:48 pm tlam

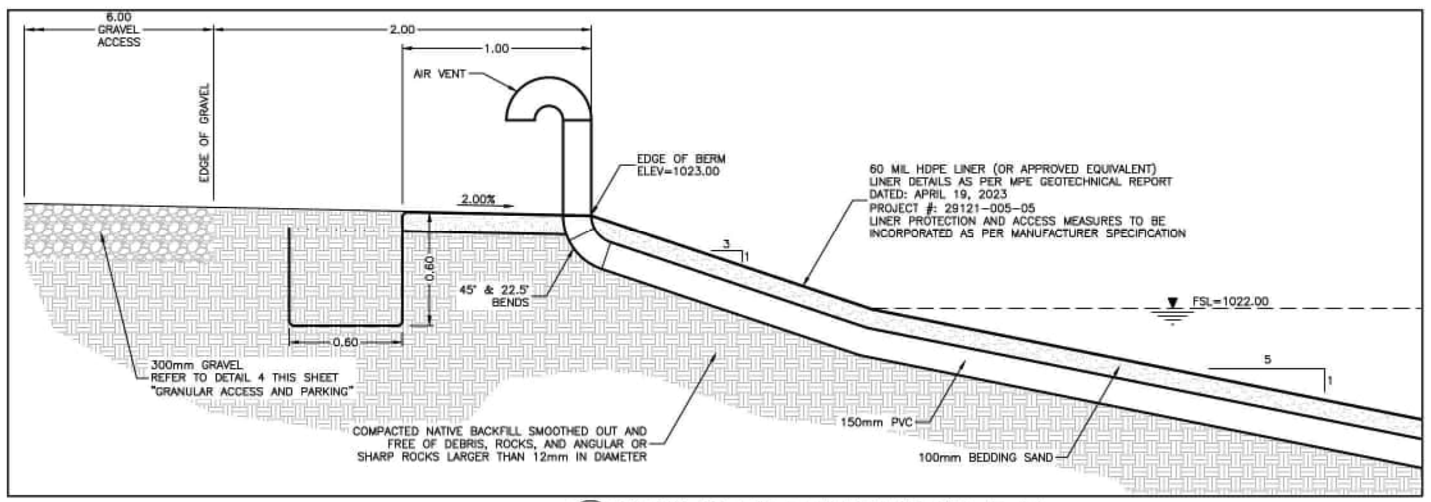
NOTES:
1. AS PER GEOTECHNICAL REPORT: BACKFILL AROUND THE DRAINPIPE SHOULD BE A WELL GRADED GRANULAR MATERIAL. THE USE OF ON-SITE SAND MAY BE PERMITTED IF IT IS DEEMED TO BE FREE DRAINING, WITH LESS THAN 5% FINES AND OF SUITABLE GRADATION TO BE COMPATIBLE WITH THE PERFORATED DRAINPIPE. ALTERNATIVELY, THE USE OF ALBERTA TRANSPORTATION ZONE 3A SAND MAY BE USED. A MINIMUM GRANULAR FILL COVER OF 600mm IS RECOMMENDED (MEASURED FROM EDGE OF PIPE TO UNDERSIDE OF HDPE LINER).
2. LINER DETAIL SUBJECT TO CHANGE AS PER FINAL RECOMMENDATIONS FROM MPE



6 RESERVOIR 1 – SLOPE GRADING

SCALE 1:50

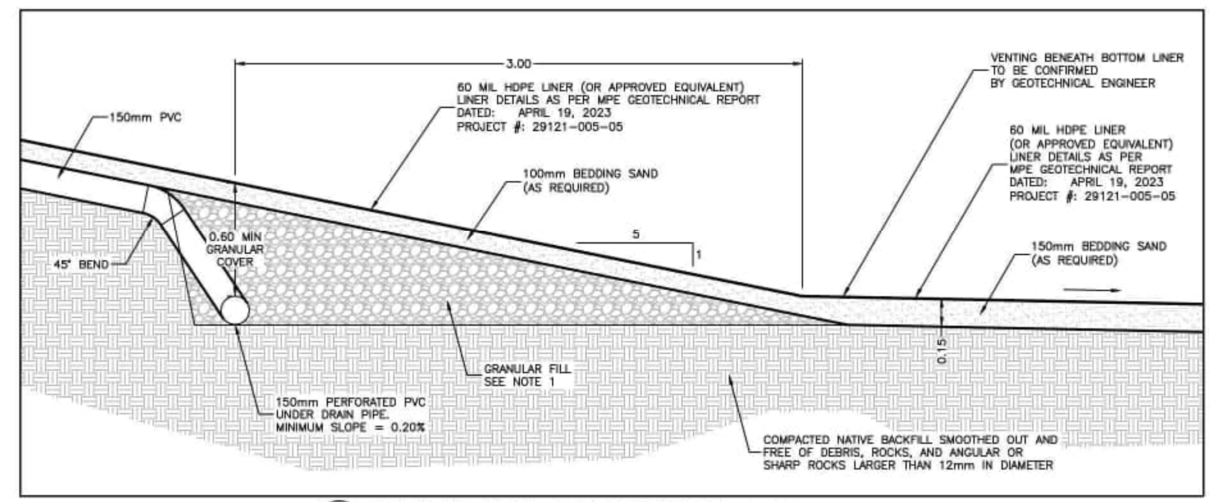
0m 0.5 1 1.5



7 SYNTHETIC LINER ANCHOR TRENCH DETAIL

SCALE 1:20

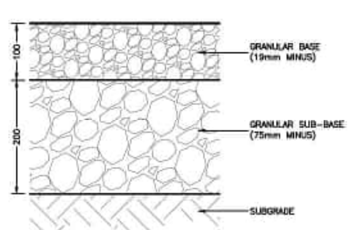
0m 0.2 0.4 0.6



8 SYNTHETIC LINER AND UNDERDRAIN DETAIL

SCALE 1:20

0m 0.2 0.4 0.6



4 GRANULAR ACCESS AND PARKING

SCALE 1:10

0m 0.1 0.2 0.3

NOTE:
ROAD ACCESS STRUCTURE TO BE CONFIRMED BY GEOTECHNICAL ENGINEER

SURVEY INFORMATION

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URBAN systems

Scale: AS SHOWN

Quality Control by: DN
Designed by: DN/TL
Drawn by: TL

FOOTHILLS OKOTOKS REGIONAL WATER PROJECT
PHASE 1 RESERVOIR DETAILS

Sheet Number: 7 of 7
Project Number: 1306.0120.06
Drawing Number: 006-01
Revision: 1

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APPENDIX B

Calculations

Freeboard Design Spreadsheet

Project:	Phase 1 Reservoir
Project Number:	29121-005-11
Designer:	Noor Mirza
Checker:	Jeff Hust
Date:	November 30, 2022

Phase 1 Reservoir - Freeboard Calculations

WIND DATA (Data from AT, 2007)
Phase 1 Reservoir

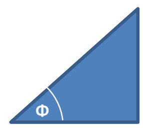
Station Used :	Calgary			
1:2 Wind Speed (km/h)	79	Design Wind Direction	NW	(AT, 2007)
1:10 Wind Speed (km/h)	89	Wind Reduction Factor	0.84	(AT, 2007)
1:100 Wind Speed (km/h)	92	Overwater Factor	1.2	(CDA, 2007)
1:1000 Wind Speed (km/h)	99	5% Overtopping Height (H'_S)	1.37 H_s	(CDA, 2007)

RESERVOIR DATA
Phase 1 Reservoir

Longest Fetch, F (km)	0.418
Effective Fetch, F_E (km)	0.426
Embankment Slope (XH : 1V)	5
Reservoir Depth (m)	6.5

Dam Face Angles

0.447 **Φ** 11.31
Cot(Φ) X/1



1

X

Wave Calculations
Phase 1 Reservoir

Criteria	AEP Return Period			
	1:2	**1:10**	**1:100**	**1:1000**
Overwater Wind Speed, U (km/h)	79.63	89.71	92.74	99.79
Overwater Wind Speed, U (m/s)	22.12	24.92	25.76	27.72
Wind Stress Factor, U_A (m/s)	32.01	37.07	38.61	42.26
Significant Wave Height, H_S (m)	0.33	0.39	0.40	0.44
Design Wave Height H'_S, (m)	0.46	0.53	0.55	0.60
Wave Period, T (sec)	1.49	1.57	1.59	1.63
Wavelength, L (m)	3.47	3.82	3.93	4.17
Wave Run-up, R_S (m)*	0.21	0.23	0.24	0.26
Wave Setup, S (m)**	0.02	0.02	0.02	0.02
Freeboard Required (m), Run-up + Setup	**0.22**	**0.25**	**0.26**	**0.29**
Minimum Riprap D_{50} (mm)	**100**	**150**	**150**	**150**

Wind Setup Sensitivity Analysis

Fetch (km)	Wind setup (m)			
	1:2	**1:10**	**1:100**	**1:1000**
0.25	0.00	0.00	0.01	0.01
0.5	0.01	0.01	0.01	0.01
0.75	0.01	0.01	0.02	0.02
1	0.02	0.02	0.02	0.02

WAVE FORMULAS

$$S = \frac{U^2 * F_E}{4850 * d}$$ CDA, 2007

$$H_s = 1.616x10^{-2} * U_A * F_E^{0.5}$$ CDA, 2007

$$T = 6.238x10^{-1}(U_A * FE)^{1/3}$$ CDA, 2007

$$U_a = 0.71 * U^{1.23}$$ CDA, 2007

$$H'_S = 1.37H_S$$ CDA, 2007

$$L = 1.56T^2$$ CDA, 2007

$$R_s = \frac{H'_s}{0.4 + \left(H'_s/L\right)^{0.5} * \cot(\theta)}$$ USBR, 1981*

* Runup (R_S) assumes a riprap slope, if a smooth slope is present run-up must be mutlitied by up to 1.5 depending on smoothness of surface.

$$D_{50} = 0.57 * \frac{H_S}{cot^{\frac{1}{3}}(\theta)}$$ FHWA, 2000

* D_{50} size is estimated using a rock weight of 2650 kg/m^3

References Used:

1. Hydrotechnical Considerations for Dam Safety Design, Canadian Dam Association (CDA); 2007
2. Freeboard Criteria and Guidelines for Computing Freeboard Allowances for Storage Dams; United States Bureau of Reclamation (USBR), 1981
3. Shoreline Protection Manual; United States Army Corps of Engineers (USACE), 2003
4. Analysis of Alberta Hourly Wind Data; Alberta Transportation (AT), 2007
5. Design of Riprap Revetment, Federal Highway Administration (FHWA), 2000

If half the wavelength is more the depth of the reservoir a depth limited analysis must be performed using the USACE Shoreline Protection Manual (Chapter 3 section VI).

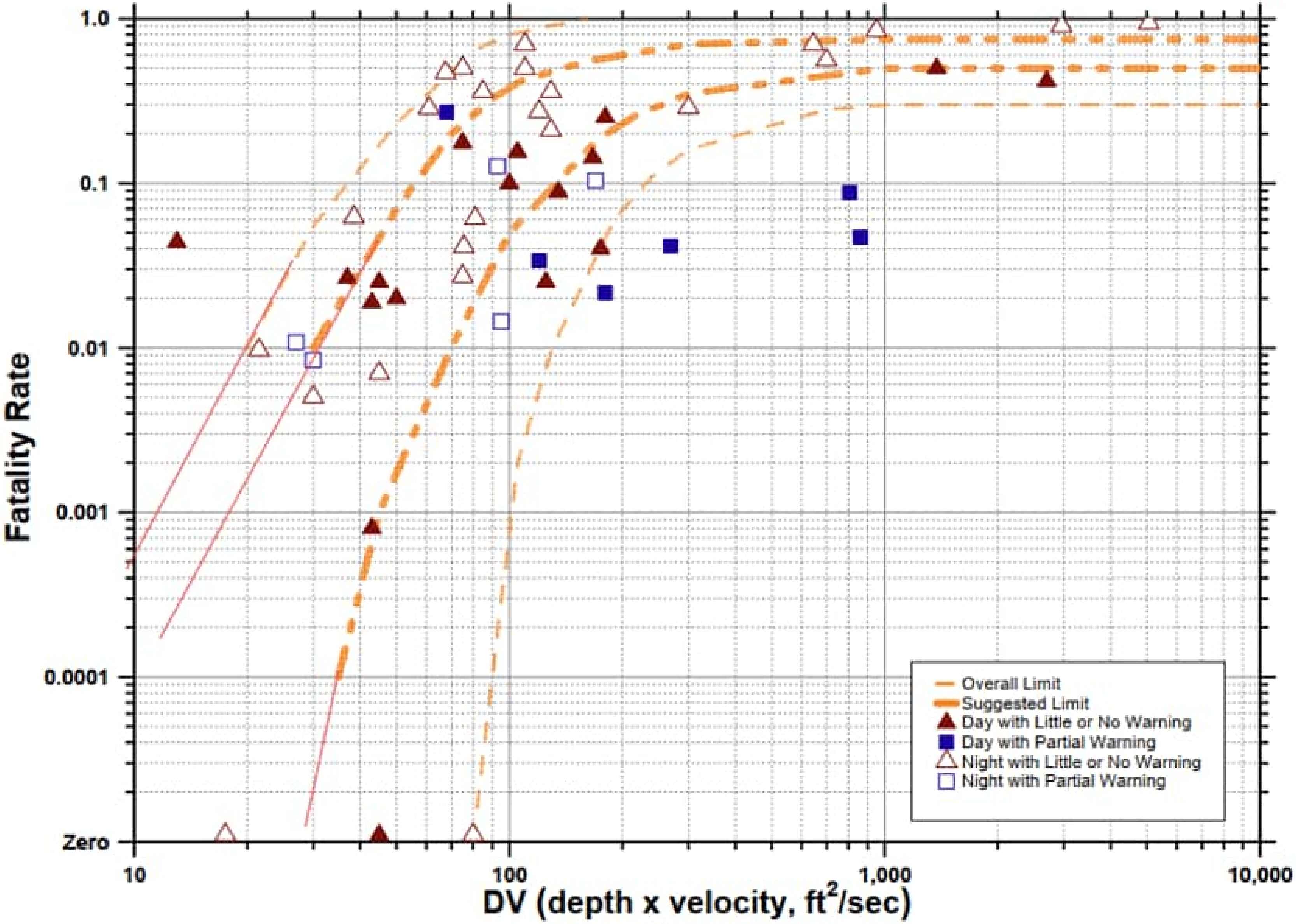
A wavelength analysis was performed and determined that the Wave Period, T (sec) was in fact lower than the value currently used in the analysis.

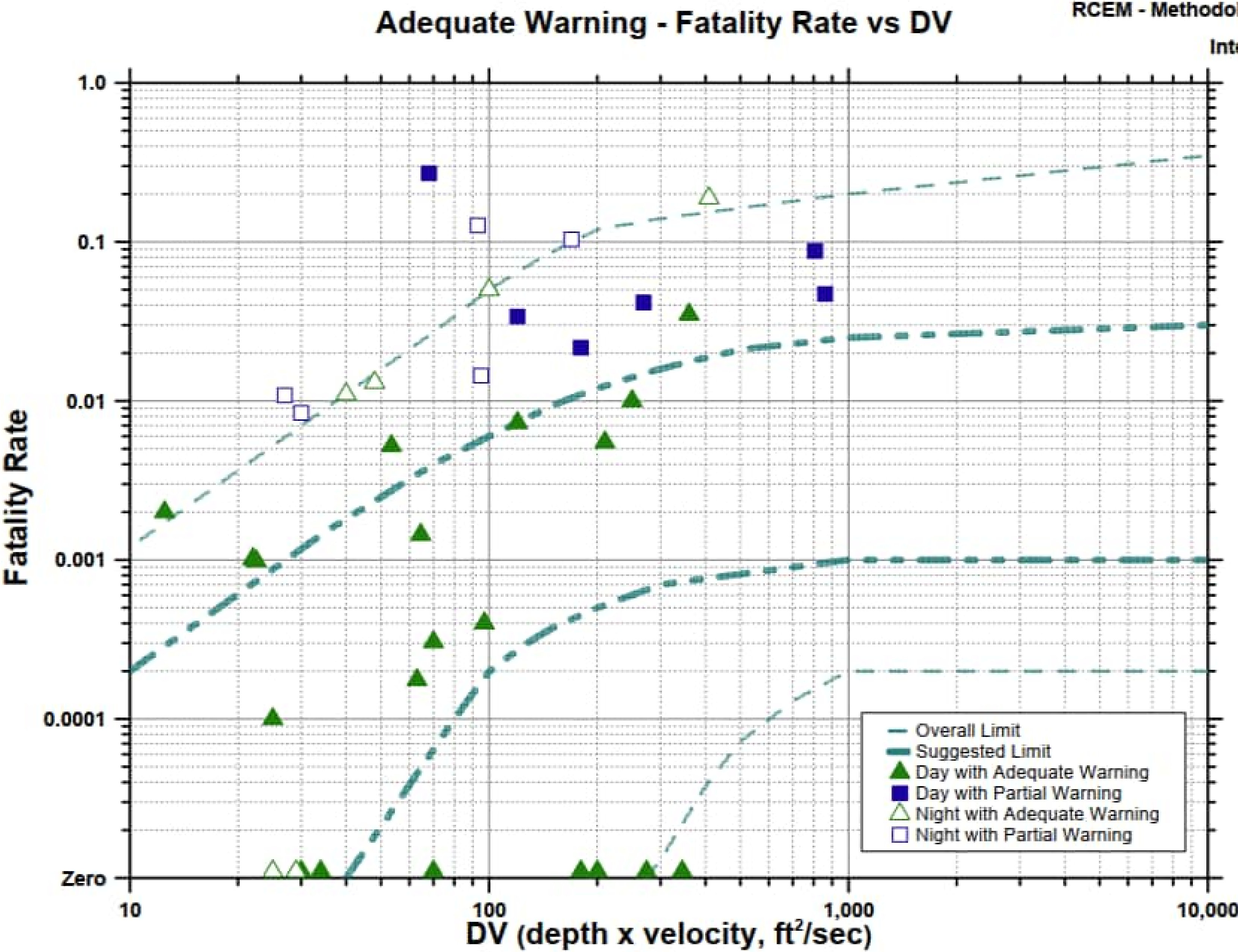
Based on the wind setup sensitivity analysis, the fetch length does not have considerable impact on the wind setup result. Therefore the full length of the maximum fetch was used for the wind set-up calculation.

Assumptions and Additional Information

Fetch for wind height calculations is considered to be the longest distance between the dam and the opposing shoreline. (2007)
Effective Fetch for reservoirs is calculated by drawing 9 radials from a point on the Dam to the opposing shoreline at 3 degree intervals. The length of these radials were measured and arithmetically averaged.
If half the wavelength is more the depth of the reservoir a depth limited analysis must be performed using the USACE Shoreline Protection Manual (Chapter 3 section VI).
Effective Fetch for wind setup can be longer and should be assessed with a sensitivity analysis for long reservoirs.
Wind speed reduction factors were not used for the significant wave height calculation according to AT 2007, which is conservative but reasonable for freeboard.
Reservoir Depth (d) refers to the average depth of the reservoir. This was assumed to be the dam height instead, 4.1m.
Riprap Sizing rounded to nearest 25 mm. Wind speed reduction was considered for riprap sizing. Although it is not expected that riprap will be placed to such a quantity.

Little or No Warning - Fatality Rate vs DV




Adequate Warning - Fatality Rate vs DV
Fatality Rate
1.0
0.1
0.01
0.001
0.0001
Zero
10
100
1,000
10,000
DV (depth x velocity, ft²/sec)
Overall Limit
Suggested Limit
Day with Adequate Warning
Day with Partial Warning
Night with Adequate Warning
Night with Partial Warning