Breach Analysis and Inundation Mapping

Springbank Off-Stream Reservoir (SR1)

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Alberta Transportation

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Sign-off Sheet

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1.0 INTRODUCTION

1.1 BACKGROUND INFORMATION

The Springbank Off-Stream Reservoir (SR1) is located approximately 12 km west of the City of Calgary, approximately 28 km upstream of the Glenmore Reservoir on the Elbow River. The project is comprised of three primary elements: diversion structure, diversion channel and off-stream storage dam. Both the Diversion Structure and Off-Stream Storage Dam are considered dams. A location map of SR1 is provided in Figure 1.

The Off-Stream Storage Dam is a flood storage facility comprised of an earthen embankment, outlet works, and emergency spillway that will store diverted flood waters and release the flow once the flood has passed. The Off-Stream Storage Dam has a maximum storage capacity at the Emergency Spillway (Elevation 1210.75 m) of 77900 dam^3 and a pool area of 7.8 km^2. The dam embankment has a crest elevation of 1213.5 m corresponding to a maximum height of approximately 28.5 m and length of approximately 4.4 km. The impoundment area will remain dry before flood events. Inflow will be controlled to limit the maximum water level to 1210.75 m.

The Diversion Structure is a regulating structure comprised of an earthen Floodplain Berm, regulating Diversion Inlet and Service Spillway gate structures, and Roller Compacted Concrete (RCC) Auxiliary Spillway that will be operate during floods to control the flow into the Off-Stream Storage Dam via the Diversion Channel. The Diversion Structure is designed to safely pass the Probable Maximum Flood (PMF) with a maximum headwater elevation of 1217.8 m at the Auxiliary Spillway and gate structures. The Floodplain Berm spans the floodplain for approximately 1.0 km and has a crest elevation of 1218.3 m at the downstream end and 1221.4 m at the upstream end. The maximum height of the Floodplain Berm is approximately 6 m which is above the simulated PMF water surface profile. The impoundment created by the structure is not a well-defined pool, but behaves more like a roadway embankment.

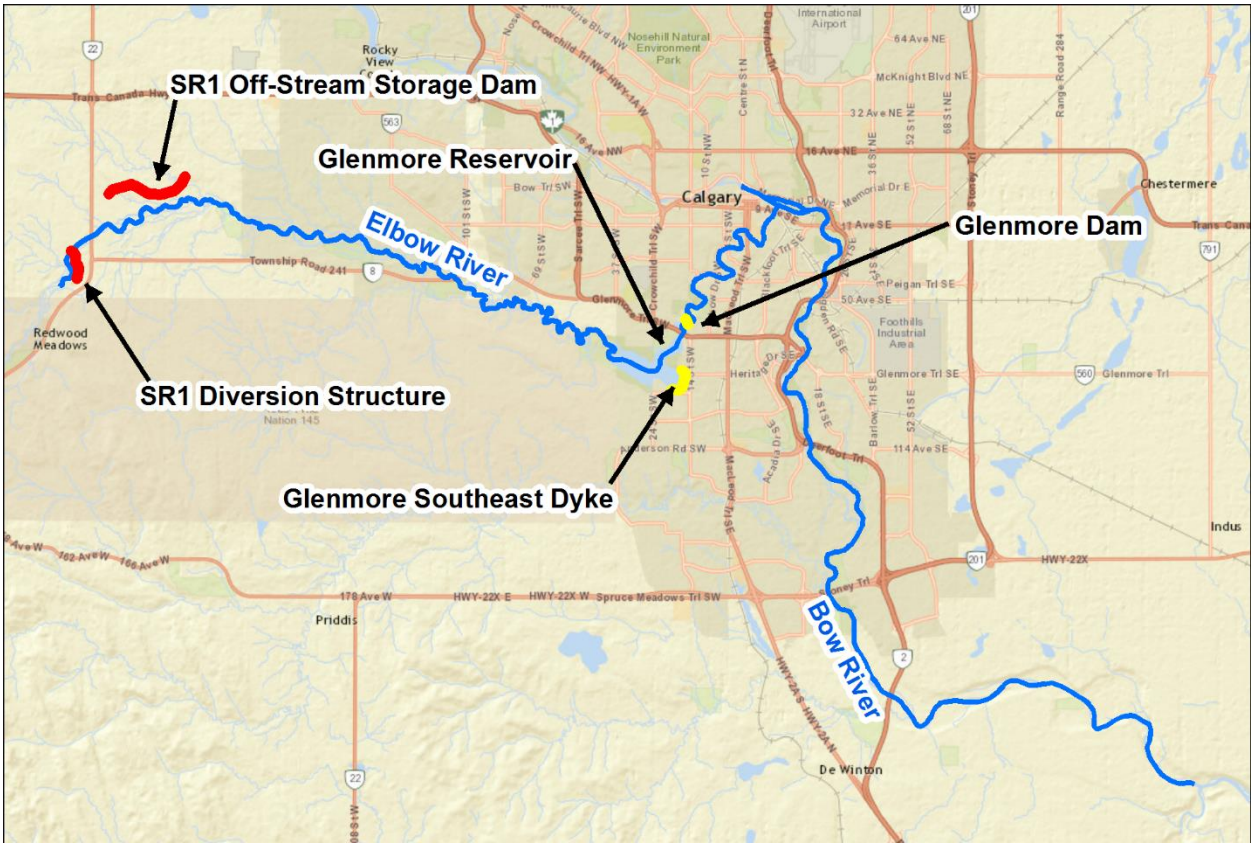

Figure 1 - SR1 Location Map

1.2 SCOPE OF STUDY

The methods and results of these breach analyses and inundation mapping are summarized, but this report does not provide commentary on dam hazard classification or recommended actions to be taken on mitigating potential hazards posed by SR1.

Methodology used in this analysis is consistent with guidance outlined by the Canadian Dam Association (CDA) *Dam Safety Guidelines, 2007* (Reference 1).

2.0 SOURCE DATA

The following information was used to perform the breach analyses and develop inundation mapping for SR1:

- Aerial imagery from Amec (dated 2013) (Reference 2)
- 1m Lidar data from Amec (dated 2013) (Reference 3)
- Aerial imagery from Government of Alberta (dated 2014) (Reference 4)
- 15m Lidar data from AltaLIS (dated 2013) (Reference 5)
- 0.5m Lidar data from Tarin Resource Services (dated 2015) (Reference 6)
- Glenmore Reservoir bathymetric data (dated 2013) (Reference 7)
- Golder Working HEC-RAS model for Elbow and Bow Rivers (dated 2014) (Reference 8)
- Structure drawings for Highway 8 bridge on Elbow River (dated 2014) (Reference 9)
- Structure drawings for Highway 22 bridge on Elbow River (dated 1986) (Reference 10)
- Glenmore Dam spillway rating curve data (dated 2014) (Reference 11)
- SR1 preliminary design drawings and surfaces

3.0 BREACH ANALYSIS

3.1 BREACH SCENARIOS

The CDA recommends the analysis of two scenarios when conducting a dam breach and inundation analysis. These would typically be a "sunny-day" failure and a "flood-induced" failure. In the case of SR1, a "sunny-day" failure is not realistic because neither the Off-Stream Storage Dam or Diversion Structure is designed to have a permanent pool. The "sunny-date" scenario has been replaced with a post-flood failure scenario.

3.1.1 Flood-Induced Failure Scenario of Off-Stream Storage Dam

The flood-induced failure scenario assumes a failure of the Off-Stream Storage Dam coincident with a flood of magnitude greater than the dam can safely pass. The SR1 Off-Stream Storage Dam has been designed assuming a dam classification of "Extreme" (Reference 1) and therefore is capable of safely passing an Inflow Design Flood (IDF) equivalent to the portion of the PMF which would be diverted to SR1 if the Diversion Inlet gates failed to be closed when SR1 reaches its design capacity of 1210.75 m. The pool elevation will maintain 1.5 m freeboard to the crest of the Off-Stream Storage Dam under this scenario, so a failure by piping would be the only potential failure mode. Because a flood-induced failure of the Off-Stream Storage Dam would require the coincident failure of both operation and a piping failure during a transitory period of elevated flows, Stantec does not consider it a valid failure scenario and no further analysis was performed to evaluate it.

3.1.2 Post-Flood Failure Scenario of Off-Stream Storage Dam

The post-flood failure scenario assumes a failure of the Off-Stream Storage Dam after the IDF event as the reservoir is being slowly drained. This scenario assumes a piping failure when SR1 is filled to the emergency spillway at elevation 1210.75 m, representing conditions immediately after a major flood event, but before significant volume can be released from SR1. The Elbow River, Glenmore Reservoir, and Bow River are simulated with elevated flows, below the flood damage threshold, to simulate conditions just after a major flood has occurred but before significant storage has been recovered from Glenmore Reservoir. Appendix A1 presents a schematic cross section detailing the assumed configuration of the Off-Stream Storage Dam for the post-flood failure scenario.

3.1.3 Flood-Induced Failure Scenario of Diversion Structure

The flood-induced failure scenario assumes a failure of the Diversion Structure coincident with a flood of magnitude greater than the dam can safely pass. The SR1 Diversion Structure has been designed assuming a dam classification of "High" (Reference 1), however critical components have been designed to safely pass the PMF event. This structure has been assessed in this analysis using the PMF as the IDF as a conservative assumption. During this scenario, failure was

assumed to occur in the Auxiliary Spillway by overtopping at the maximum head elevation of 1217.8 m during the PMF event. The Bow River is assumed to be at the 100-year flood flow. Appendix A2 presents a schematic cross section detailing the assumed configuration of the Diversion Structure for the post-flood failure scenario.

3.1.4 Post-Flood Failure Scenario of Diversion Structure

The post-flood failure scenario assumes a failure of the Diversion Structure after the IDF event. The Diversion Structure does not function as a dam except during a flood event, so Stantec does not consider this a valid failure scenario and no further analysis was performed to evaluate it.

3.1.5 Cascade Failure Potential

Glenmore Reservoir is located approximately 28 km downstream of the SR1 Off-Stream Storage Dam. The Glenmore Reservoir facility is comprised of Glenmore Dam and the Southeast Dyke. A failure of the SR1 Off-Stream Storage Dam would release 77,900 dam^3 of water and has the potential to cause a cascade failure at Glenmore Reservoir.

The Glenmore Reservoir Southeast Dyke is an earthen embankment approximately 1.4 km long with a crest elevation of 1080.4 m and maximum height of approximately 8.4 m. An alternative post-flood induced failure of the SR1 Off-Stream Storage Dam was considered where the Southeast Dyke fails by overtopping when Glenmore Reservoir's pool reaches elevation 1080.4 m.

The Glenmore Dam is a concrete gravity dam approximately 280 m long with a crest elevation of 1079.92 m and maximum height of approximately 24 m. A detailed structural analysis would be required to determine whether a cascade failure of Glenmore Dam is probable which is outside the scope of this study. Therefore, a cascade failure of Glenmore Dam has not been evaluated.

3.2 BREACH LOCATION

A single breach location was considered for the failure of the SR1 Off-Stream Storage Dam near the outfall corresponding to the maximum dam height as shown in Appendix A3. The single breach location is suitable to produce the greatest potential impact to downstream areas.

A single breach location was considered for the failure of the SR1 Diversion Structure in the Auxiliary Spillway where it is expected to overtop as shown in Appendix A4. The single breach location is suitable to produce the greatest potential impact to downstream areas.

3.3 BREACH HYDROGRAPH DEVELOPMENT

Breach hydrographs were developed using the "Dam Break" capabilities of the US Army Corps of Engineers (USACE) Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS)

software, Version 4.1 (Reference 12) for the Off-Stream Storage Dam. For the Diversion Structure failure or cascade failures, the breach was simulated within the breach routing model using the same "Dam Break" functions. The breach function requires the input of estimated dam breach parameters and impounded volumes. Breach parameters for failures of the SR1 Off-Stream Storage Dam and Glenmore Reservoir Southeast Dyke were estimated using empirical equations. Since there is uncertainty in predicting dam breach parameters, Stantec used several empirical equations and based final breach parameters on the average of the estimates and engineering judgment (References 13 - 21).

Failure of concrete structures such as the SR1 Diversion Structure Auxilliary Spillway cannot be evaluated using the same empirical equations. Breach parameters for this structure were assumed based on engineering judgment to represent a nearly instantaneous failure of approximately one third of the Auxiliary Spillway length.

Table 1 summarizes the breach parameters estimated for this analysis. These values are based on the assumed failure conditions, height of breach, impoundment water volume above breach, and width of the embankment. B_{avg} is the average width of a breach failure and t_f is the time for the breach to fully develop. The results of the empirical calculations that served as the basis for the breach parameters estimation are included in Appendix A5-A6.

Table 1 – Summary of Estimated Dam Breach Parameters

	SR1 Diversion Structure Flood-Induced Failure Scenario	SR1 Off-Stream Storage Dam Post-Flood Failure Scenario	Glenmore Reservoir Southeast Dyke Cascade Failure Scenario
Range of Breach Width Estimates (m)	n/a	49.9 – 119.3	14.7 – 124.5
Range of Failure Time Estimates (hrs)	n/a	0.55 – 1.90	0.42 - 3.63
B_{avg} (m)	72.0	94.4	59.6
T_f (hours)	0.10	1.16	1.50

The IDF used in the flood-induced failure scenario was computed based on a calibrated HEC-HMS model developed as part of the SR1 project and is documented in detail in the Stantec report entitled "Springbank Off-Stream Reservoir Project: Probable Maximum Flood Analysis" (Reference 22). For the flood-induced failure of the SR1 Diversion Structure Auxiliary Spillway, the IDF is the PMF on the Elbow River with a peak discharge of 2770 cms and a total hydrograph duration of 7 days. The IDF hydrograph is included as Appendix A7.

Routing of the IDF through the SR1 Off-Stream Storage Dam was not performed because a flood-induced failure was not considered valid for that structure. For the post-flood failure scenario of the Off-Stream Storage Dam, a starting pool elevation of 1210.75 m was selected matching the the Emergency Spillway elevation. The stage-storage curve for the SR1 reservoir was developed based on 2013 and 2015 LiDAR data and the SR1 design grading. The stage-storage curve and resulting breach hydrograph is presented in Appendix A8-A9.

3.4 HYDRAULIC MODEL DEVELOPMENT

For routing of the breach hydrograph and development of inundation mapping, Stantec used the USACE Hydrologic Engineering Center River Analysis System (HEC-RAS) software, Version 5.0.3 (Reference 23). HEC-RAS is an unsteady, one-dimensional (1D) and two-dimensional (2D) flood routing model. The breach routing model includes approximately 53 km of the Elbow River from the confluence with the Bow River to approximately 1.2 km upstream of the SR1 Diversion Structure. The model includes and approximately 49 km of the Bow River from approximately Centre Street to just upstream of the confluence with Highwood River.

3.4.1 Model Geometry

The routing model geometry for the Elbow River downstream of Glenmore Dam and the Bow River was based on the 2014 Golder Working Model provided by the City of Calgary (Reference 8). The Golder model is a calibrated steady flow model of the Elbow River and Bow River designed to simulate up to the 2013 event. Stantec made modifications to the Golder geometry to make it suitable for an unsteady simulation. These modifications primarily included converting ineffective flow areas designed to simulate buildings to blocked obstructions, eliminating unnecessary split flow reaches to improve unsteady model stability and adding 2D flow areas representing floodplains in the City of Calgary downtown to allow for more accurate simulation of overland flows.

Stantec revised and extended the Golder model upstream of Glenmore Reservoir to Highway 22 using 1m and 15m LiDAR data, 2013 Glenmore Reservoir bathymetric data, and structure drawings / rating curves provided by the City of Calgary (References 3, 5, 6, 7, 9, 10, and 11). The new cross sections have an average spacing of approximately 300 m. Manning's roughness values were selected based on land uses determined from aerial imagery and HEC-RAS guidance as summarized in Table 2.

Table 2 – Summary of Land Use Types for Extended HEC-RAS Geometry

Land Use Type	Manning's Value, n
Woods	0.150
Grass	0.040
Channel	0.038
Brush	0.080

3.4.2 Boundary Conditions

The model uses a normal depth boundary condition at the downstream end of the Bow River reach from the Golder model.

The PMF event hydrograph is used as inflow at the upstream end of the Elbow River during the flood-induced failure scenario. During the flood-induced failure scenario, the Bow River was assumed to be at the 100-year discharge based on flood-frequency data from the Golder and Associates Report entitled "Bow River and Elbow River Basins: Hydrology of 2013 Flood Event" (Reference 24). The 100-year flows were distributed as constant flows along the Bow River based on flow change locations in the original Golder Model.

Inflows at the upstream end of the Bow River and the Elbow River during the post-flood failure scenario are assumed constant values based on flows observed during the 2013 flood event. Table 3 summarizes the boundary conditions used in the model for each failure scenario.

To maintain stability of the post-flood failure routing model, a minimum flow of 400 m^3/s was assigned at the location of the breach hydrograph.

Table 3 – Summary of Boundary Conditions

Location	Flood-Induced Failure Scenario	Post-Flood Failure Scenarios
Elbow River Upstream Inflow	PMF Hydrograph	30 m^3/s
Bow River Inflow Upstream of Elbow River	2020 m^3/s	400 m^3/s
Bow River Lateral Inflow at Fish Creek	500 m^3/s	n/a
Bow River Lateral Inflow at Fish Creek	80 m^3/s	n/a
Bow River Downstream Normal Depth	0.0022 m/m	0.0022 m/m

4.0 RESULTS AND INUNDATION MAPPING

4.1.1 Flood-Induced Failure of Diversion Structure

Failure of the Diversion Structure Auxiliary Spillway during the IDF event will have minimal impact downstream of the structure. According to breach routing results, such a failure would increase the peak discharge in the Elbow River immediately downstream of the diversion structure from 2770 m^3/s to a peak of 3103 m^3/s for less than 30 minutes. The spike in flow corresponds to approximately a 0.2 m increase in the water surface elevation. By the Highway 22 bridge, which is located approximately 1 km downstream of the Diversion Structure, the increase in water surface elevation due to the breach is less than 0.1 m. Based on these results, inundation mapping would show negligible change to inundation limits and has not been developed. Water surface elevation and discharge hydrographs at locations of interest have been included in Appendix B1.

4.1.2 Post-Flood Failure of Off-Stream Storage Dam

Two post-flood failure scenarios were evaluated for the Off-Stream Storage Dam. With no cascade failure and with a cascade failure of the Glenmore Reservoir Southeast Dyke. Table 4 includes a summary of the arrival time of the start of the breach wave, peak water surface elevations and peak discharges along the Elbow and Bow Rivers resulting from each failure scenario. All listed water surface elevations are headwater elevations.

Table 4 – Summary of Results for Post-Flood Failure of Off-Stream Storage Dam

Location	Arrival Time after Start of Breach (hr:min)	No Cascade Failure		Glenmore Reservoir Southeast Dyke Cascade Failure	
		WSE (m)	Discharge (m^3/s)	WSE (m)	Discharge (m^3/s)
Elbow River at Breach (Station 44,946)	0:00	1180.96	17309	1080.96	17309
Elbow River at Sarcee Bridge (Station 19,779)	2:20	1086.88	10227	1086.88	10227
Glenmore Reservoir Southeast Dyke Overtopping	2:40	1082.47	2445	1082.23	3314
Elbow River at Glenmore Dam (Station 11,417)	2:40	1082.14	4433	1081.93	4188
Elbow River at Elbow Drive Bridge (Station 7,206)	3:00	1059.68	2971[1]	1059.43	2820[1]
Elbow River at 1st St (Patterson) Bridge (Station 2,954)	3:20	1050.68	1688[1]	1050.58	1611[1]
Elbow River at 9th Ave Bridge (Station 287)	3:30	1044.48	2132[1]	1044.48	2063[1]
Bow River at 17th Ave (Cushing) Bridge (Station 44,288)	4:00	1037.86	4131	1037.33	3730
Bow River at Glenmore Trail (Graves) Bridge (Station 37,138)	4:40	1023.76	3648	1023.50	3282
Bow River at Highway 2 Bridge (Station 18,031)	5:50	988.40	4017[2]	988.88	4658[2]
Bow River at Confluence with Highwood River (Station 0)	8:10	952.99	3865	953.43	4608

[1] Discharge for 1D model segments only, does not include flow spread over 2D floodplain

[2] Discharge increases due to flow discharged over Glenmore Reservoir Southeast Dyke re-entering Bow River

According to the Golder frequency discharge study (Reference 24), the 100-year discharge for the Bow River upstream of the confluence with Highwood River is 3,400 m^3/s and downstream of the confluence it is 5,610 m^3/s. The breach routing model terminates at the confluence with the Highwood River. Peak discharges from the breach routing model are less than the 100-year discharge downstream of the confluence indicating that sufficient attenuation has occurred to end the breach analysis.

Inundation limits for each of the failure scenarios were mapped to determine the potential impacts on property and the potential risk to human life downstream of SR1. Appendix B2-B13 presents the maximum inundation extents which result from the post-flood failure scenarios.

5.0 REFERENCES

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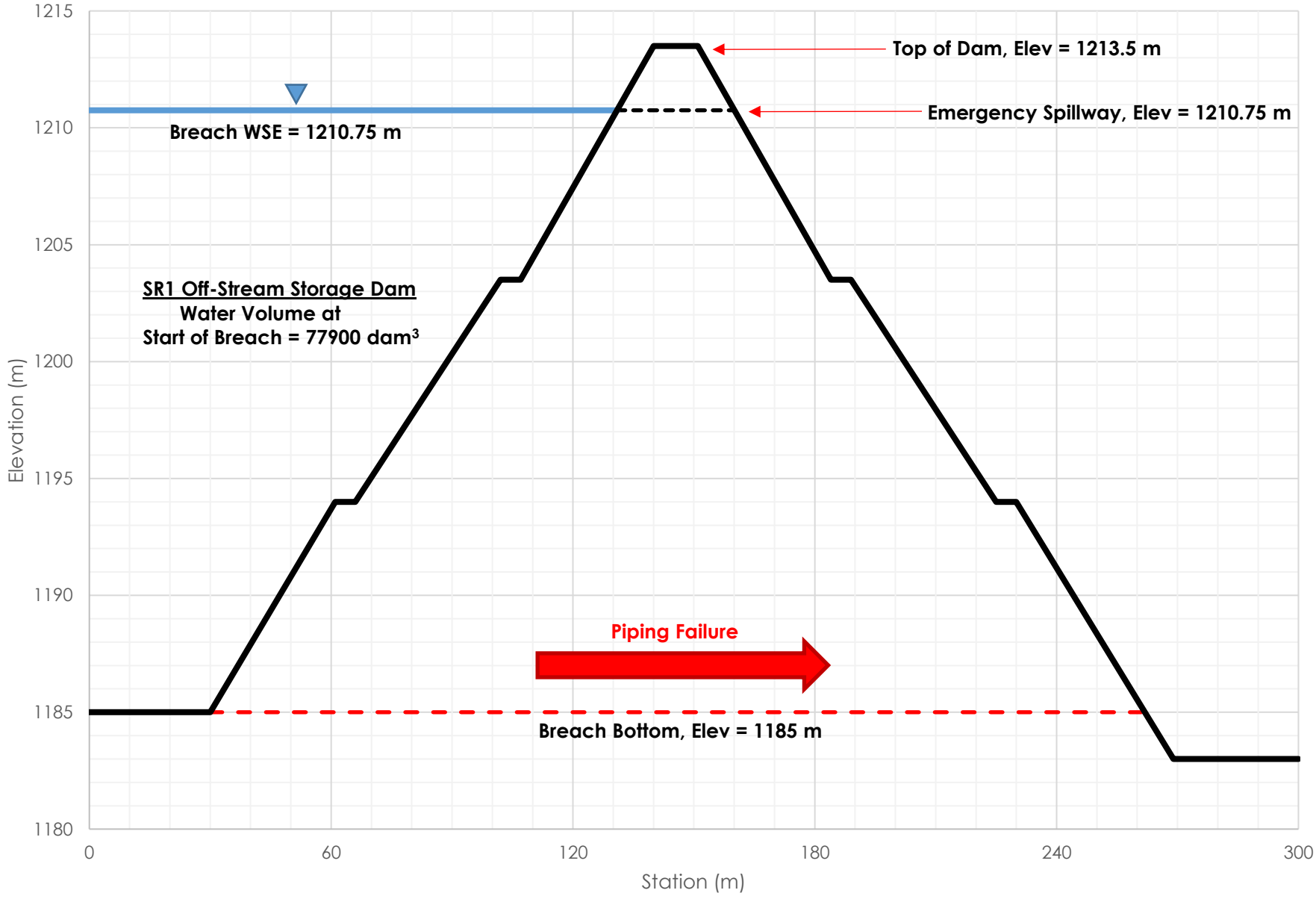
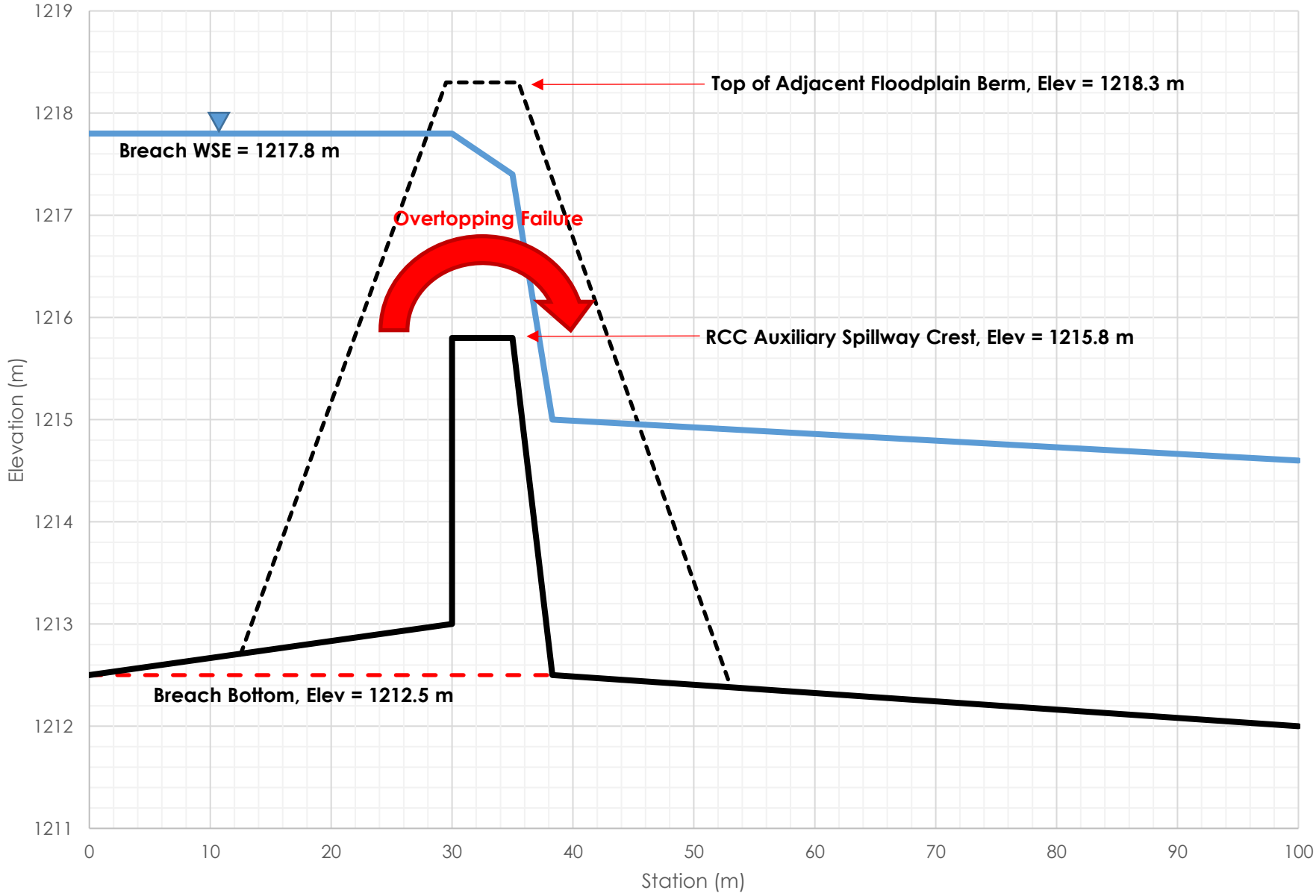
APPENDIX A – HYDROLOGIC AND BREACH DATA

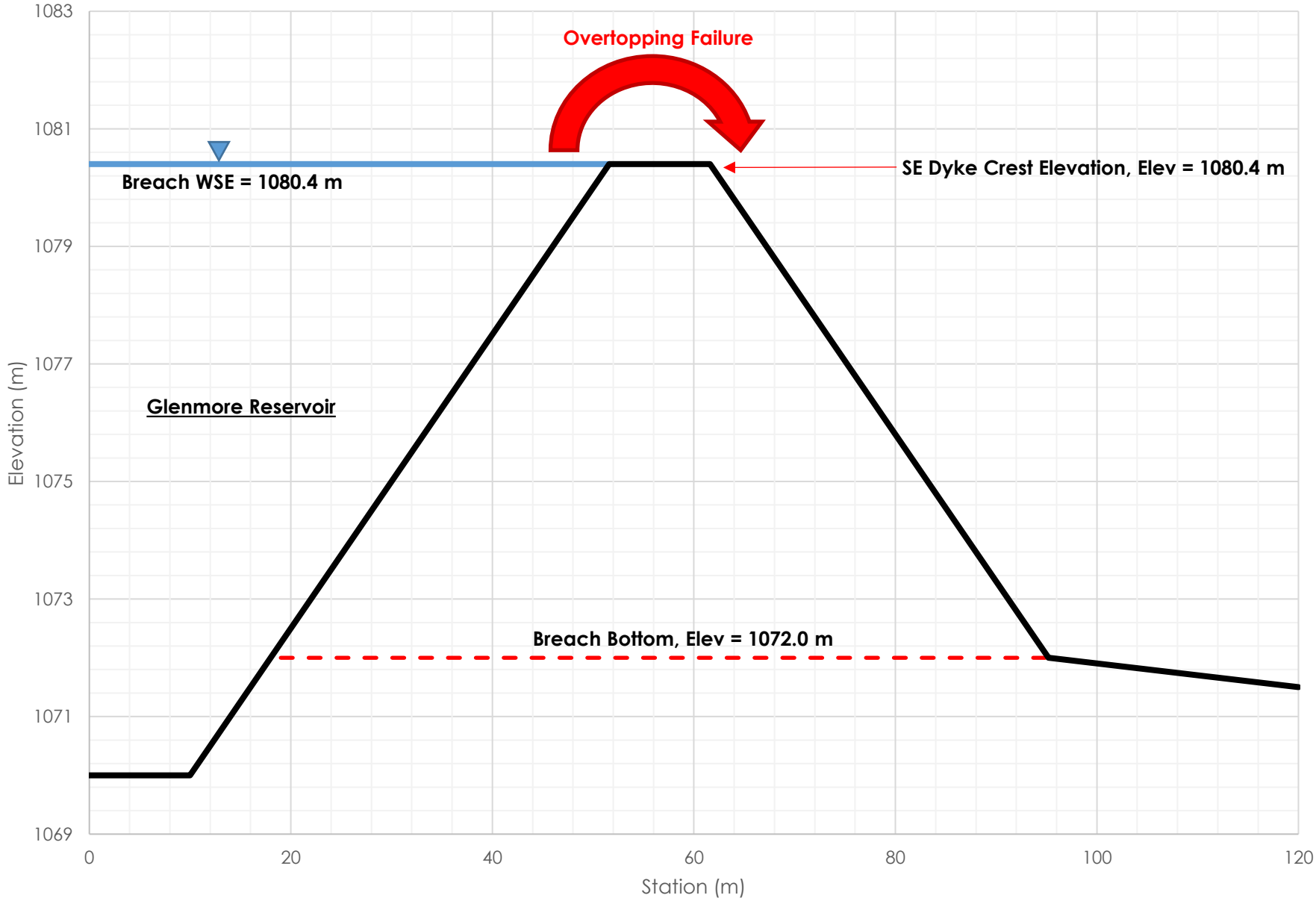
Appendix A1 - Off-Stream Storage Dam Post-Flood Breach Schematic



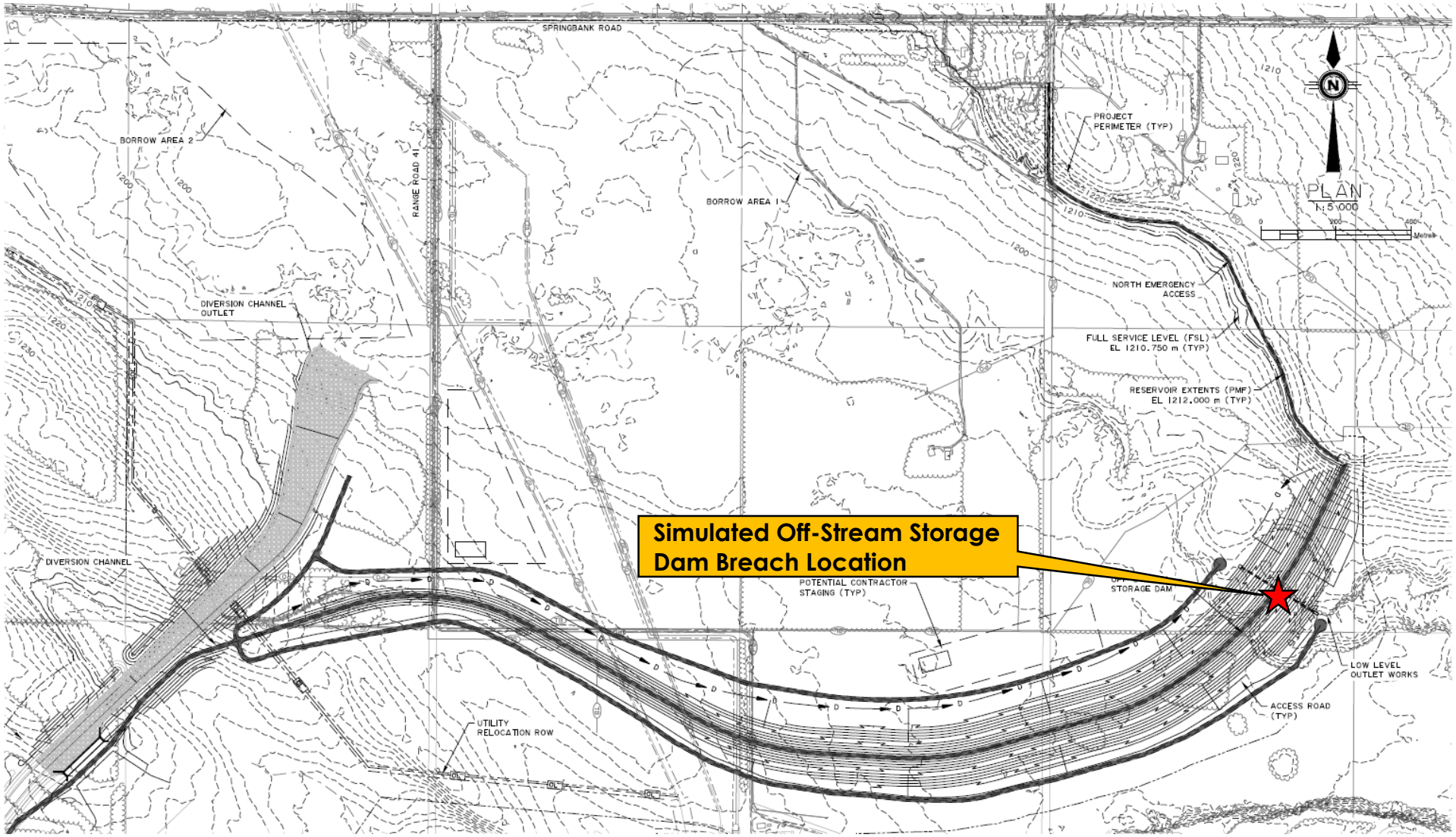
Appendix A2 - Diversion Structure Flood-Induced Breach Schematic



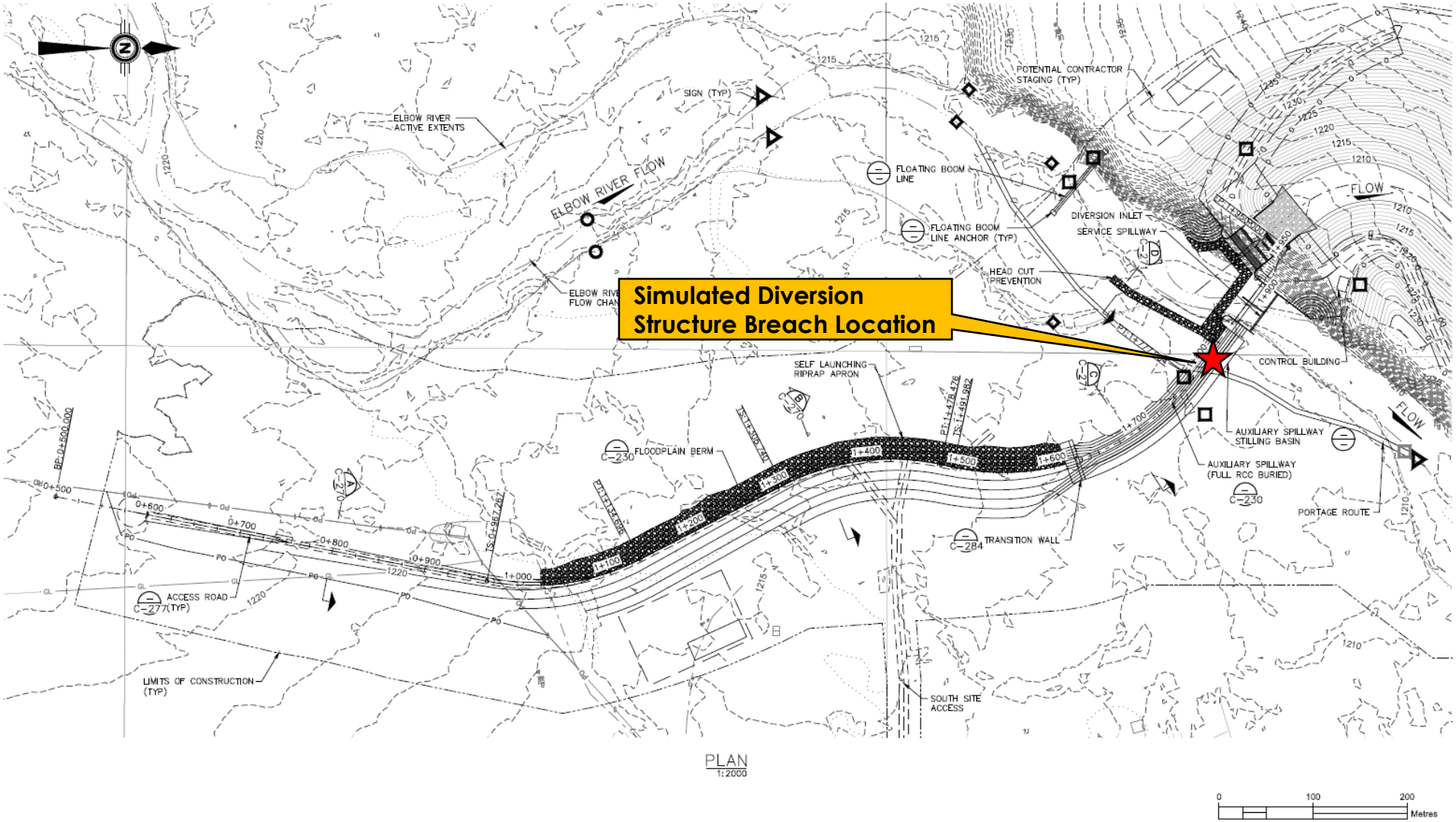
Appendix A3 - Southeast Dyke Post-Flood Cascade Breach Schematic



Appendix A4 – Off-Stream Storage Dam Breach Location



Appendix A5 – Diversion Structure Breach Location



Appendix A6 - Dam Breach Parameter Estimation

Earthen Embankment Breach Parameter Comparative Spreadsheet

Project Data:

Dam: *SR1 Off-Stream Storage Dam, Preliminary Design*

Location: *City of Calgary, Alberta, Canada*

Notes: *Post-flood breach scenario*

Inputs:

		English Units		*SI Units*	
Height of dam	h_d	93.5	feet	28.5	meters
Height of breach	h_b	93.5	feet	28.5	meters
Height/depth of water at breach	h_w	84.5	feet	25.8	meters
Storage	S	63172.0	ac-feet	77921514.6	m^3
Volume of water at breach	V_w	63172.0	ac-feet	77921514.6	m^3
Width of dam at base	W_{base}	765.0	feet	233.2	meters
Width of dam at crest	W_{crest}	33.0	feet	10.1	meters
Estimated breach side slope	Z	1.0		1.0	
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s
Type of Failure		Piping			
Dam has core wall?		Yes			
Erosion resistant embankment?		Yes			

Data Convention:

- User Input Data
- Default calculation, user can change.
- Calculated value.

Average of Calculated Values:

Breach width	B_{AVG}	309.6	feet	94.4	meters
Breach bottom width	B_W	232.4	feet	70.8	meters
Breach formation time	t_f	1.2	hours	1.16	hours
Peak discharge	Q_p	510,141	ft^3/s	14446.1	m^3/s
Breach side slope	Z	0.83		0.83	
Volume of embankment eroded	V_{er}	11560327.9	ft^3	327364.0	m^3
Volume of water discharged	V_o,V_{out}	63172.00	ac-feet	77921514.6	m^3

Estimates of Breach Width & Dimensions

Source Equation	B (m)	B (ft)	Z	V_{er} (m^3)	K_o	$\overline{W}$ (m)	K_c	C_b
1 - Johnson and Illes 1976	49.9	163.6						
2 - Singh and Snorrason 1982, 1984	99.8	327.3						
3 - MacDonald and Langridge-Monopolis 1984	107.2	351.7		371787.0				
4 - MacDonald and Langridge-Monopolis 1984			0.500					
5 - FERC 1987	85.5	280.5						
6 - FERC 1987			0.625					
7 - Froehlich 1987	102.0	334.7			1.0			
8 - Froehlich 1987			1.107			121.6	0.6	
9 - USBR 1988	77.3	253.4						
10 - Von Thun and Gillette 1990			1.000					
11 - Von Thun and Gillette 1990	119.3	391.3						54.9
12 - Froehlich 1995	114.2	374.7			1.0			
13 - Froehlich 1995			0.900					

Appendix A6 - Dam Breach Parameter Estimation

Earthen Embankment Breach Parameter Comparative Spreadsheet

Project Data:

Dam: *SR1 Off-Stream Storage Dam, Preliminary Design*

Location: *City of Calgary, Alberta, Canada*

Notes: *Post-flood breach scenario*

Inputs:

		English Units		*SI Units*	
Height of dam	h_d	93.5	feet	28.5	meters
Height of breach	h_b	93.5	feet	28.5	meters
Height/depth of water at breach	h_w	84.5	feet	25.8	meters
Storage	S	63172.0	ac-feet	77921514.6	m^3
Volume of water at breach	V_w	63172.0	ac-feet	77921514.6	m^3
Width of dam at base	W_{base}	765.0	feet	233.2	meters
Width of dam at crest	W_{crest}	33.0	feet	10.1	meters
Estimated breach side slope	Z	1.0		1.0	
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s
Type of Failure		Piping			
Dam has core wall?		Yes			
Erosion resistant embankment?		Yes			

Data Convention:

- User Input Data
- Default calculation, user can change.
- Calculated value.

Average of Calculated Values:

Breach width	B_{AVG}	309.6	feet	94.4	meters
Breach bottom width	B_W	232.4	feet	70.8	meters
Breach formation time	t_f	1.2	hours	1.16	hours
Peak discharge	Q_p	510,141	ft^3/s	14446.1	m^3/s
Breach side slope	Z	0.83		0.83	
Volume of embankment eroded	V_{er}	11560327.9	ft^3	327364.0	m^3
Volume of water discharged	V_o,V_{out}	63172.00	ac-feet	77921514.6	m^3

Estimates of Failure Time

Source Equation	**t_f** (hours)
14 - Singh and Snorrason 1982, 1984	0.625
15 - MacDonald and Langridge-Monopolis 1984	1.821
16 - FERC 1987	0.550
17 - Froehlich 1987	1.701
18 - USBR 1988	1.038
19 - Von Thun and Gillette 1990	0.765
20 - Von Thun and Gillette 1990	0.916
21 - Von Thun and Gillette 1990	
22 - Von Thun and Gillette 1990	
23 - Froehlich 1995	1.897

Appendix A7 - Dam Breach Parameter Estimation

Earthen Embankment Breach Parameter Comparative Spreadsheet

Project Data:

Dam: *Glenmore Reservoir Southeast Dyke*

Location: *City of Calgary, Alberta, Canada*

Notes: *Post-Flood Cascade breach scenario*

Inputs:

		English Units		*SI Units*	
Height of dam	h_d	27.6	feet	8.4	meters
Height of breach	h_b	27.6	feet	8.4	meters
Height/depth of water at breach	h_w	27.6	feet	8.4	meters
Storage	S	27034.0	ac-feet	33345948.0	m^3
Volume of water at breach	V_w	27034.0	ac-feet	33345948.0	m^3
Width of dam at base	W_{base}	480.0	feet	146.3	meters
Width of dam at crest	W_{crest}	33.0	feet	10.1	meters
Estimated breach side slope	Z	1.0		1.0	
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s
Type of Failure		Overtopping			
Dam has core wall?		Yes			
Erosion resistant embankment?		Yes			

Data Convention:

- User Input Data
- Default calculation, user can change.
- Calculated value.

Average of Calculated Values:

Breach width	B_{AVG}	195.4	feet	59.6	meters
Breach bottom width	B_W	163.4	feet	49.8	meters
Breach formation time	t_f	1.5	hours	1.50	hours
Peak discharge	Q_p	194,453	ft^3/s	5506.5	m^3/s
Breach side slope	Z	1.16		1.16	
Volume of embankment eroded	V_{er}	1382521.3	ft^3	39150.1	m^3
Volume of water discharged	V_o,V_{out}	27034.00	ac-feet	33345948.0	m^3

Estimates of Breach Width & Dimensions

Source Equation	B (m)	B (ft)	Z	V_{er} (m^3)	K_o	$\overline{W}$ (m)	K_c	C_b
1 - Johnson and Illes 1976	14.7	48.2						
2 - Singh and Snorrason 1982, 1984	29.4	96.5						
3 - MacDonald and Langridge-Monopolis 1984	124.5	408.3		81792.4				
4 - MacDonald and Langridge-Monopolis 1984			0.500					
5 - FERC 1987	25.2	82.7						
6 - FERC 1987			0.625					
7 - Froehlich 1987	85.1	279.2			1.4			
8 - Froehlich 1987			2.293			78.2	0.6	
9 - USBR 1988	25.2	82.7						
10 - Von Thun and Gillette 1990			1.000					
11 - Von Thun and Gillette 1990	75.9	249.0						54.9
12 - Froehlich 1995	96.6	317.0			1.4			
13 - Froehlich 1995			1.400					

Appendix A7 - Dam Breach Parameter Estimation

Earthen Embankment Breach Parameter Comparative Spreadsheet

Project Data:

Dam: *Glenmore Reservoir Southeast Dyke*

Location: *City of Calgary, Alberta, Canada*

Notes: *Post-Flood Cascade breach scenario*

Inputs:

		English Units		*SI Units*	
Height of dam	h_d	27.6	feet	8.4	meters
Height of breach	h_b	27.6	feet	8.4	meters
Height/depth of water at breach	h_w	27.6	feet	8.4	meters
Storage	S	27034.0	ac-feet	33345948.0	m^3
Volume of water at breach	V_w	27034.0	ac-feet	33345948.0	m^3
Width of dam at base	W_{base}	480.0	feet	146.3	meters
Width of dam at crest	W_{crest}	33.0	feet	10.1	meters
Estimated breach side slope	Z	1.0		1.0	
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s
Type of Failure		Overtopping			
Dam has core wall?		Yes			
Erosion resistant embankment?		Yes			

Data Convention:

- User Input Data
- Default calculation, user can change.
- Calculated value.

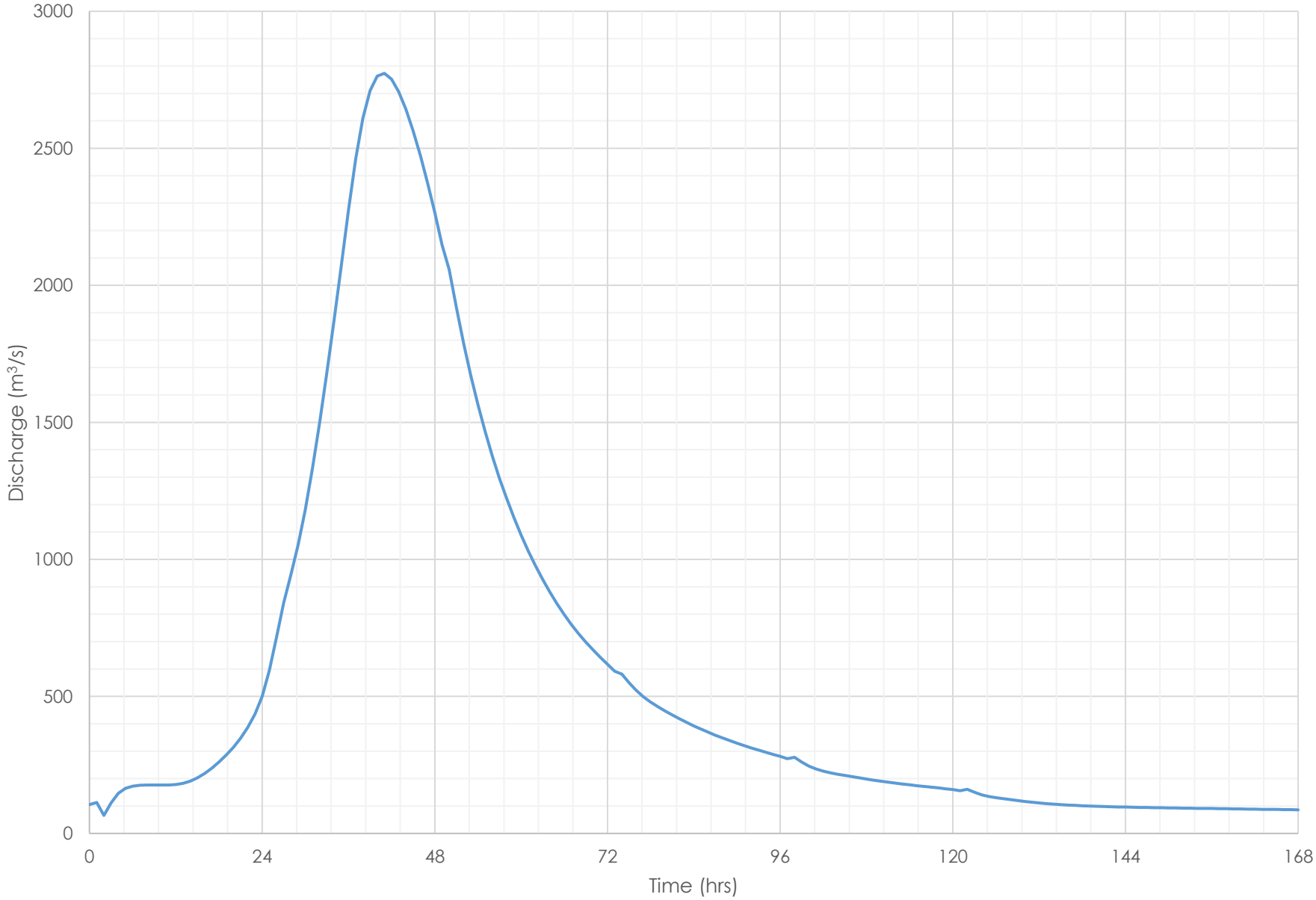
Average of Calculated Values:

Breach width	B_{AVG}	195.4	feet	59.6	meters
Breach bottom width	B_W	163.4	feet	49.8	meters
Breach formation time	t_f	1.5	hours	1.50	hours
Peak discharge	Q_p	194,453	ft^3/s	5506.5	m^3/s
Breach side slope	Z	1.16		1.16	
Volume of embankment eroded	V_{er}	1382521.3	ft^3	39150.1	m^3
Volume of water discharged	V_o,V_{out}	27034.00	ac-feet	33345948.0	m^3

Estimates of Failure Time

Source Equation	**t_f** (hours)
14 - Singh and Snorrason 1982, 1984	0.625
15 - MacDonald and Langridge-Monopolis 1984	0.841
16 - FERC 1987	0.550
17 - Froehlich 1987	3.470
18 - USBR 1988	0.655
19 - Von Thun and Gillette 1990	0.418
20 - Von Thun and Gillette 1990	1.773
21 - Von Thun and Gillette 1990	
22 - Von Thun and Gillette 1990	
23 - Froehlich 1995	3.632

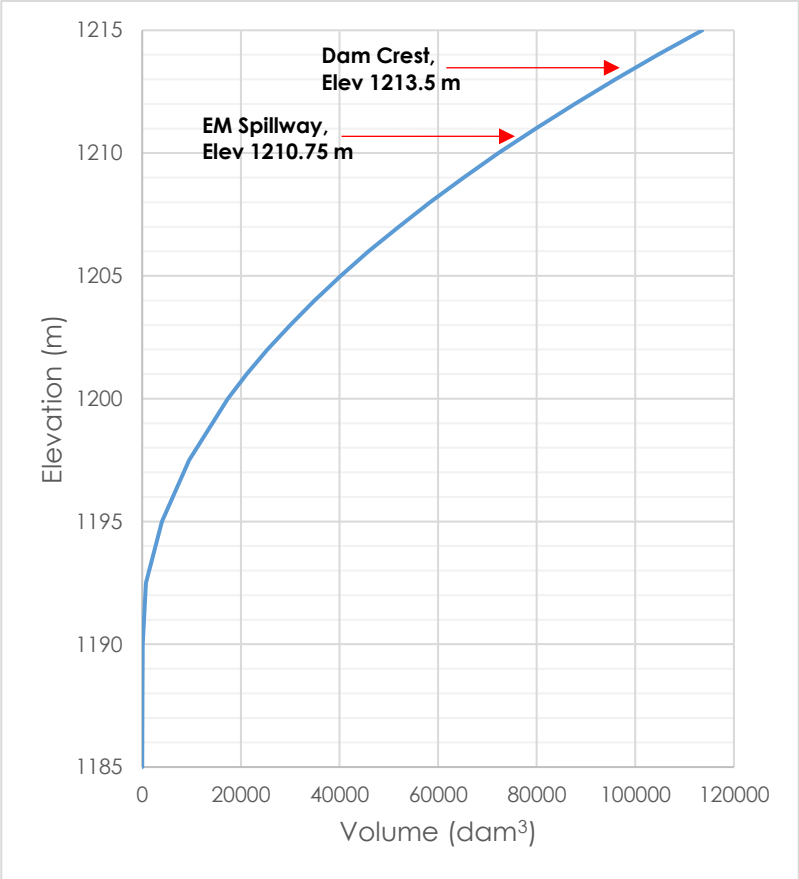
Appendix A8 - PMF Hydrograph Developed by Stantec



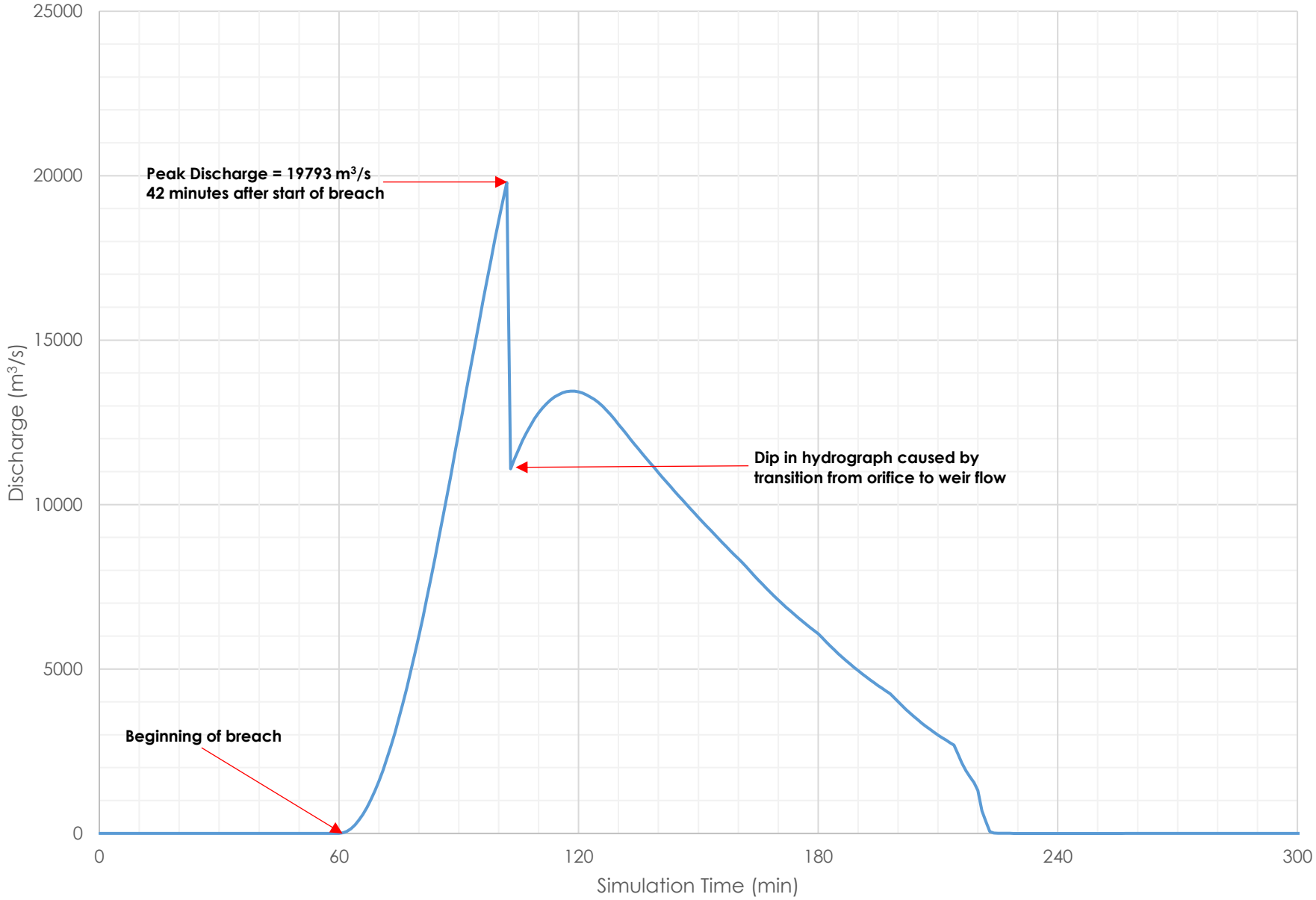
Appendix A9 - Off-Stream Storage Dam Stage-Storage Curve

Developed for Preliminary Design

Elevation (m)	Volume (dam^3)
1185.0	0
1187.5	11
1190.0	104
1192.5	778
1195.0	3994
1197.5	9515
1200.0	17337
1201.0	21175
1202.0	25411
1203.0	30008
1204.0	34957
1205.0	40271
1206.0	45953
1207.0	51999
1208.0	58397
1209.0	65164
1210.0	72292
1211.0	79799
1212.0	87684
1213.0	95952
1214.0	104596
1215.0	113586

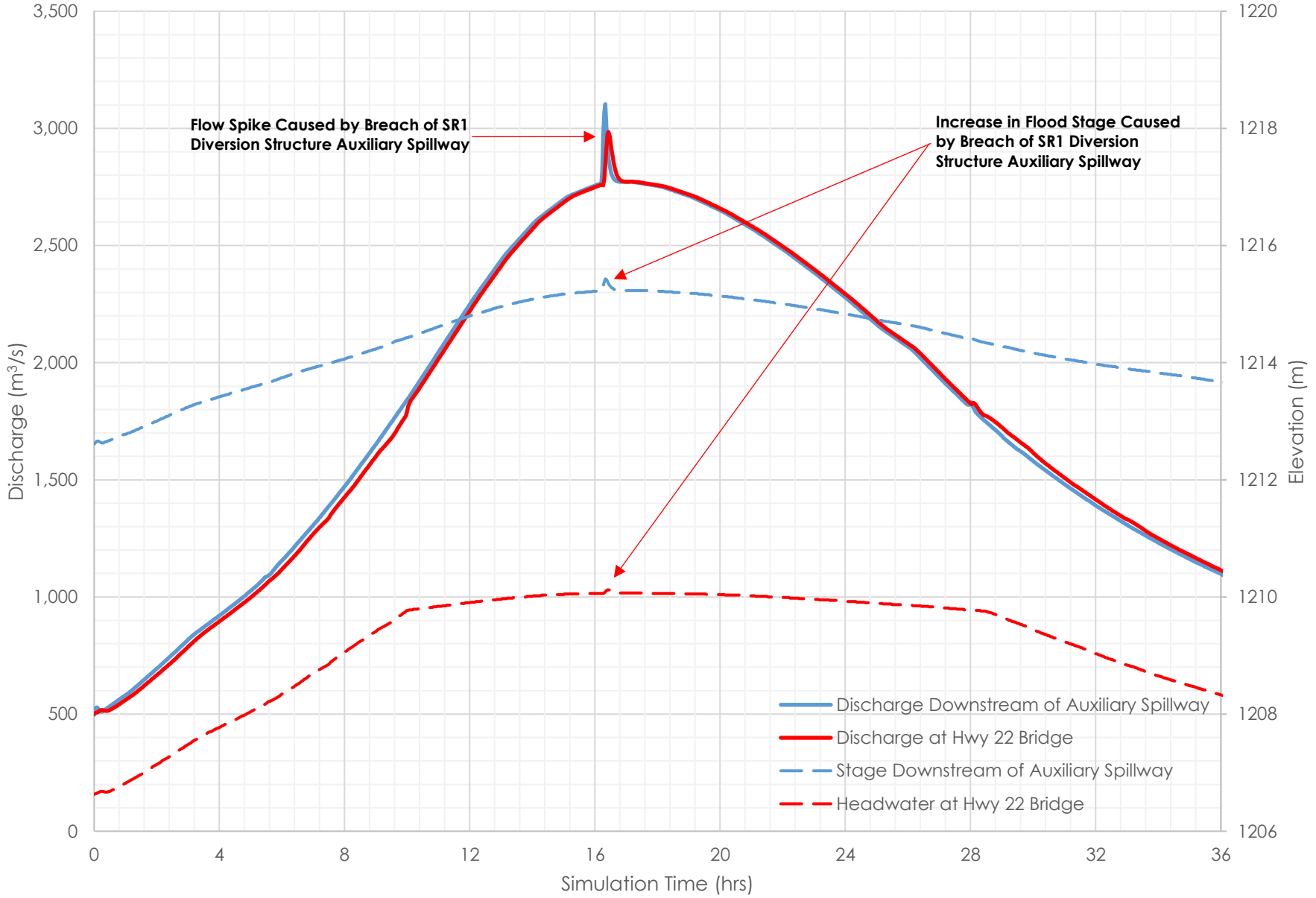


Appendix A10 - Off-Stream Storage Dam Breach Hydrograph from HEC-HMS



APPENDIX B – BREACH ROUTING RESULTS

Appendix B1 - Diversion Structure Flood-Induced Breach Hydrograph Routing



SR1 Diversion Structure

SR1 Off-Stream Storage Dam

Twsp. Road 242

Range Road 43

Range Road 42

Range Road 41

Circle S Est

Circle S Est

51489.00
51654.60
51795.06
52115.69
52655.73
51390.29
51201.83
50890.09
50572.82
50368.02
50255.45
50072.94
49840.07
49499.62
49305.38
49046.96
48594.56
48203.75
48058.27
47761.38
47553.14
46807.35
46392.87
46134.76
45819.06
45474.13
44946.1
44585.04
44323.42
44001.89
43692.29
43423.91
43254.46
43080.62
42827.27
42515.51
42161.58

-35000 -34000 5656000 -33000 -32000 -31000 5658000 -30000 -29000 5659000

5655000 -35000 5654000 -34000 5653000 -33000 -32000 5653000 -31000 -30000 -29000 5655000 -28000 5658000 -27000 5656000

Legend

- Model XS
- River Centerline
- Inundation Extents, No Cascade Failure
- Inundation Extents Southeast Dyke Cascade Failure
- Elevation Contour (5 meter)

0 400 800 Meters

1:20,000 (At original document size of 11x17)

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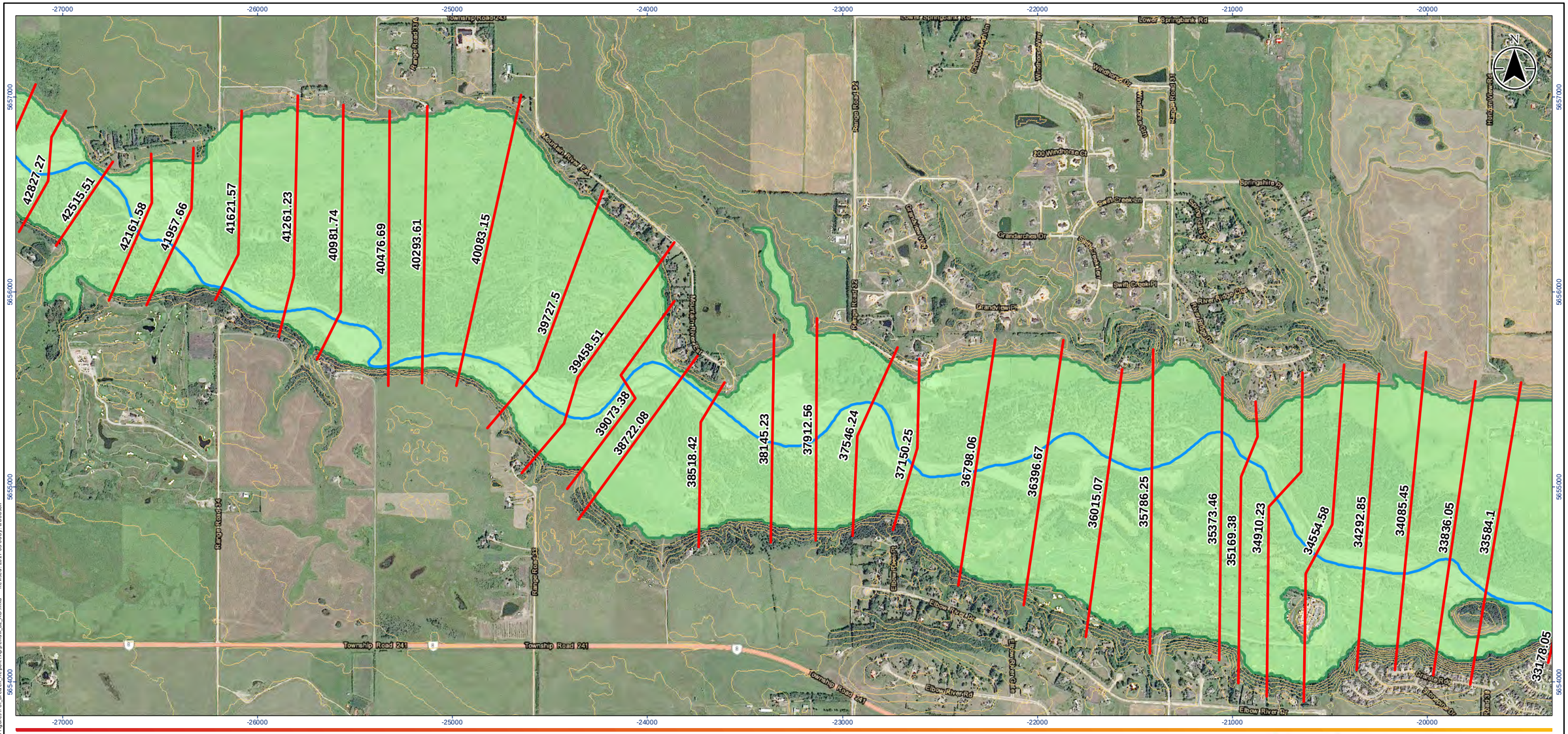
Figure No.
B2

Title
Breach Analysis and Inundation Mapping

Notes

1. Coordinate System: NAD 1983 3TM 114



Legend

- Model XS
- River Centerline
- Inundation Extents, No Cascade Failure
- Inundation Extents Southeast Dyke Cascade Failure
- Elevation Contour (5 meter)

0 400 800 Meters

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Notes

1. Coordinate System: NAD 1983 3TM 114

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Figure No.
B3

Title
Breach Analysis and Inundation Mapping

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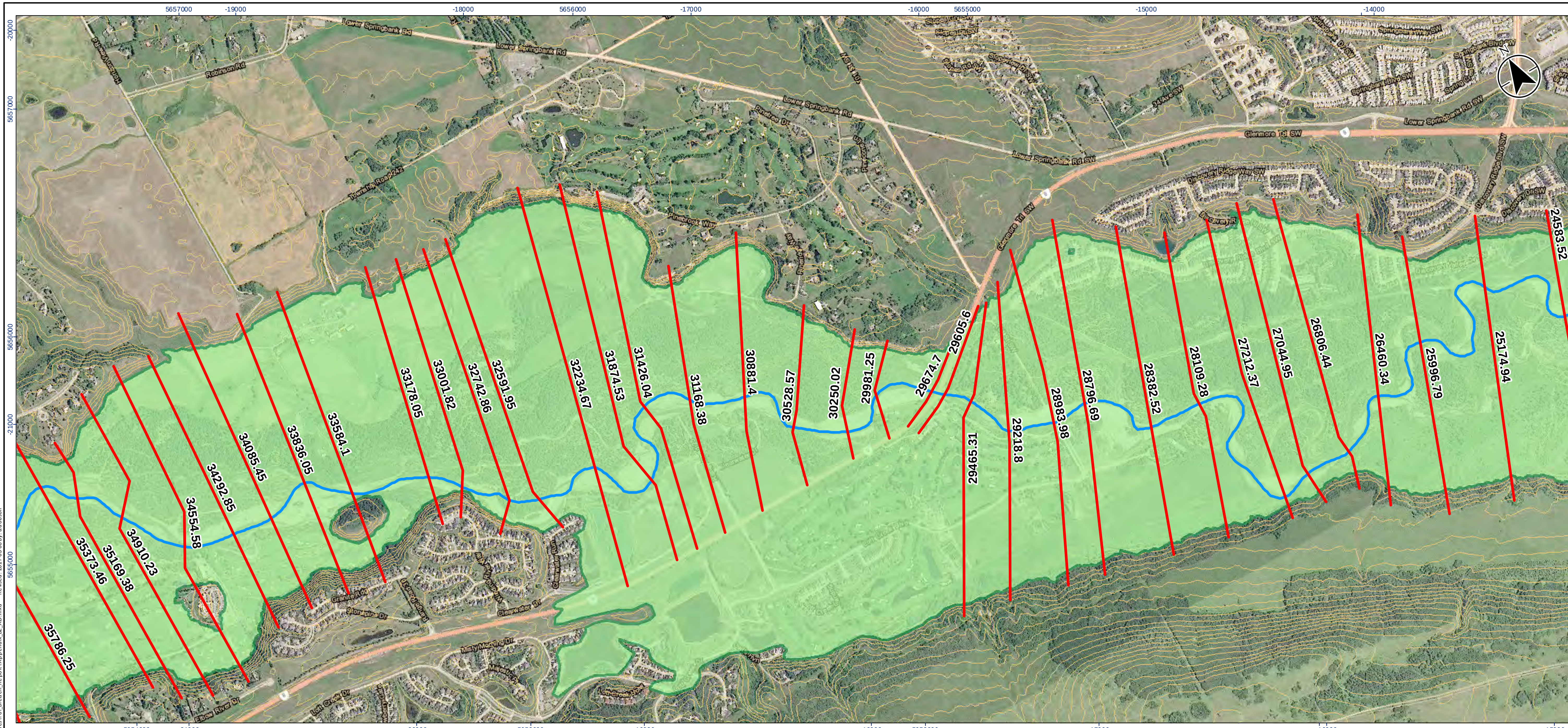

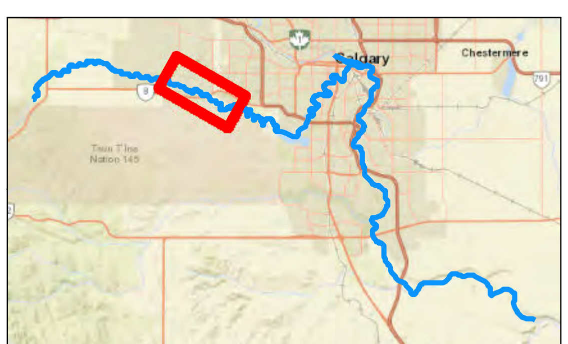

Legend

- Model XS
- River Centerline
- Inundation Extents, No Cascade Failure
- Inundation Extents Southeast Dyke Cascade Failure
- Elevation Contour (5 meter)

0 400 800 Meters

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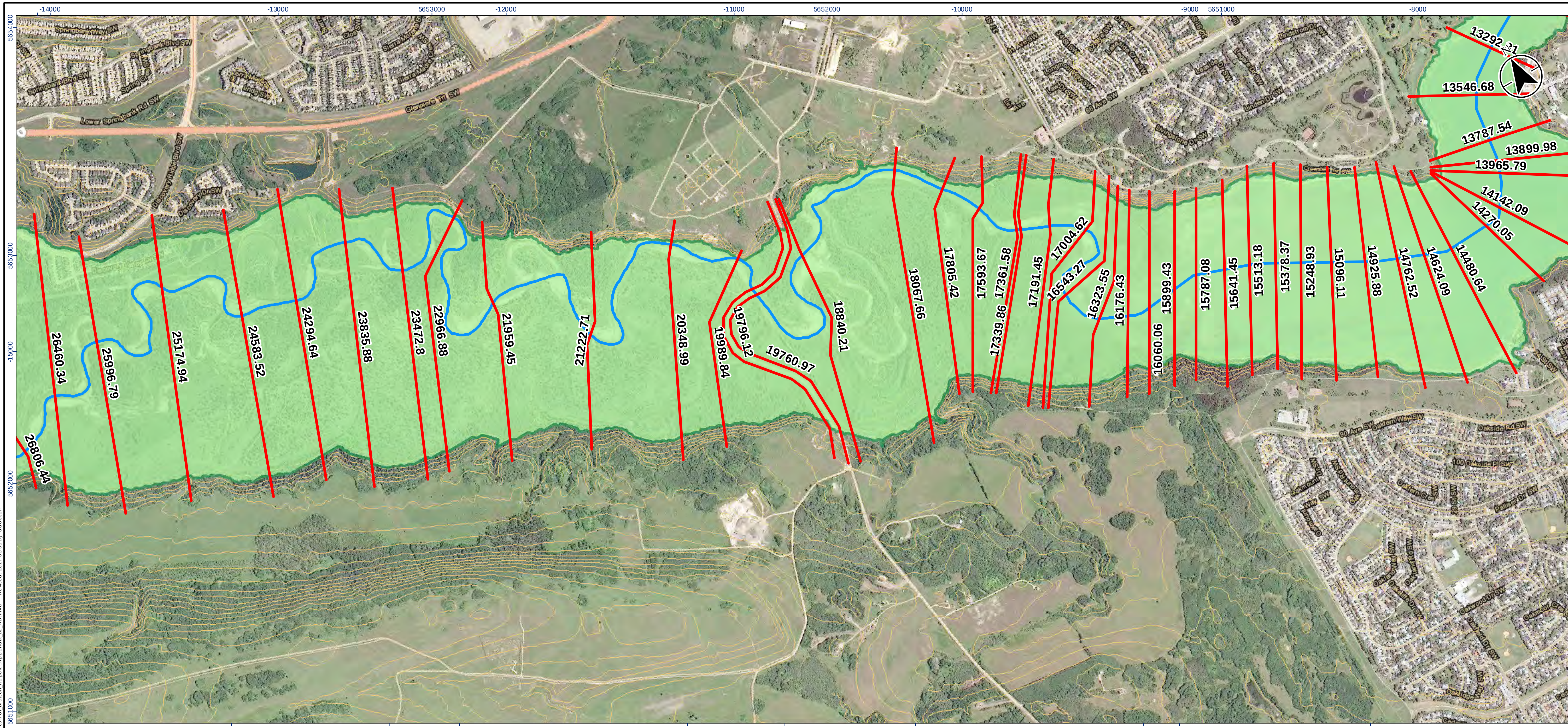
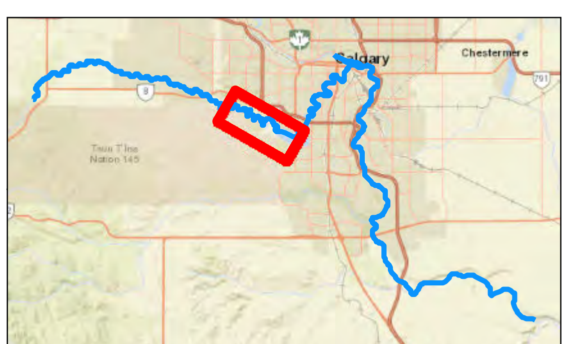
Figure No.
B4

Title
Breach Analysis and Inundation Mapping

Notes

1. Coordinate System: NAD 1983 3TM 114





Legend

- Model XS
- River Centerline
- Inundation Extents, No Cascade Failure
- Inundation Extents Southeast Dyke Cascade Failure
- Elevation Contour (5 meter)

0 400 800 Meters

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Figure No.
B5

Title
Breach Analysis and Inundation Mapping

Notes

1. Coordinate System: NAD 1983 3TM 114

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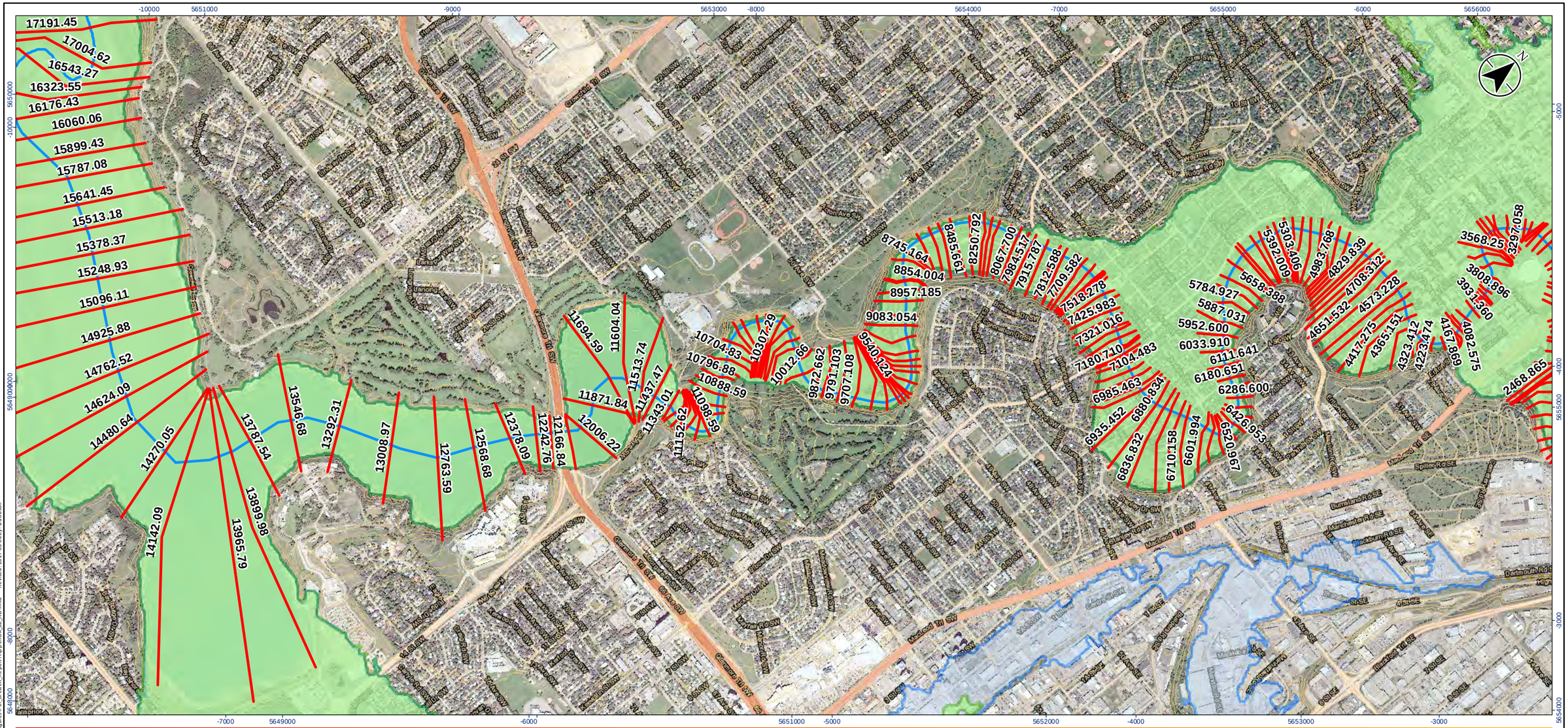

Notes

1. Coordinate System: NAD 1983 3TM 114

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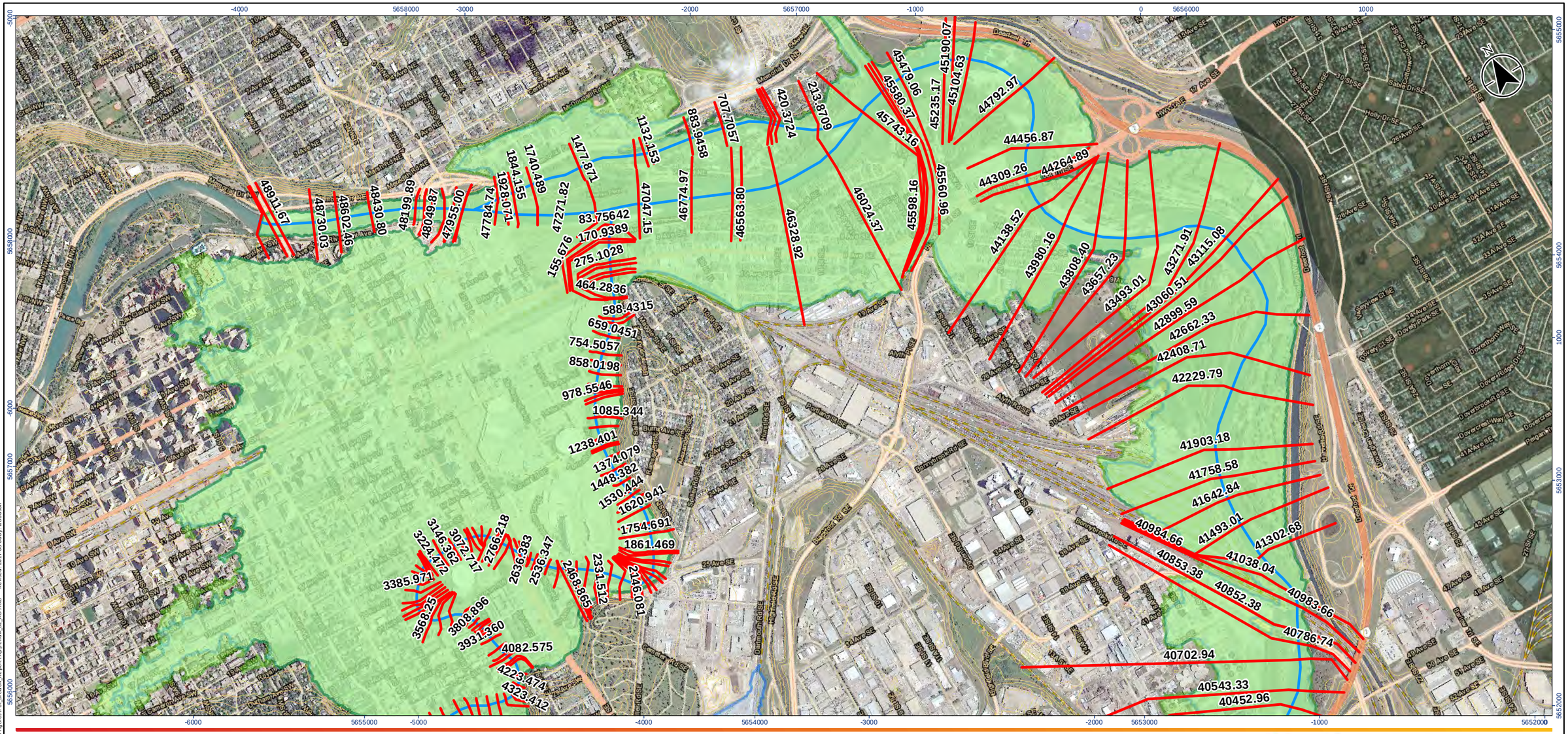
Springbank Off-Stream Reservoir (SR1)

Figure No.
B6

Title
Breach Analysis and Inundation Mapping



Notes

1. Coordinate System: NAD 1983 3TM 114

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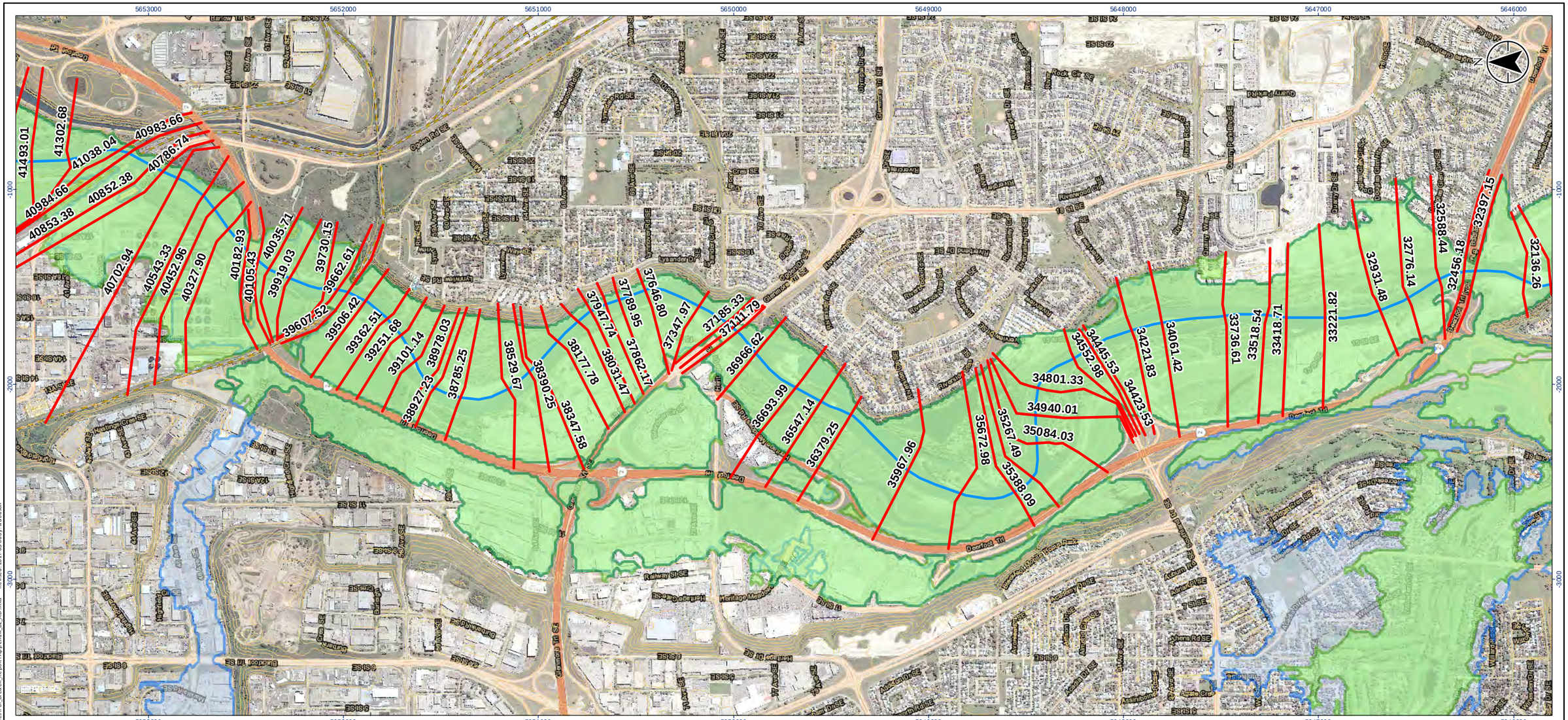
Alberta Transportation
Springbank Off-Stream Reservoir (SR1)

Figure No.
B7

Title
Breach Analysis and Inundation Mapping



Legend

- Model XS
- River Centerline
- Inundation Extents, No Cascade Failure
- Inundation Extents Southeast Dyke Cascade Failure
- Elevation Contour (5 meter)

0 400 800 Meters

1:20,000 (At original document size of 11x17)

Notes

1. Coordinate System: NAD 1983 3TM 114

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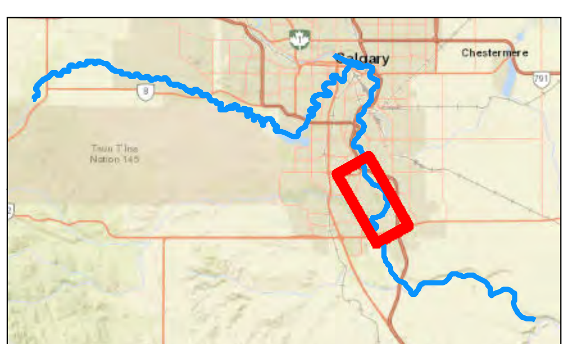
Springbank Off-Stream Reservoir (SR1)

Figure No.
B8

Title
Breach Analysis and Inundation Mapping



Legend

- Model XS
- River Centerline
- Inundation Extents, No Cascade Failure
- Inundation Extents Southeast Dyke Cascade Failure
- Elevation Contour (5 meter)

0 400 800 Meters

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Springbank Off-Stream Reservoir (SR1)

Figure No.
B9

Title
Breach Analysis and Inundation Mapping

Notes

1. Coordinate System: NAD 1983 3TM 114

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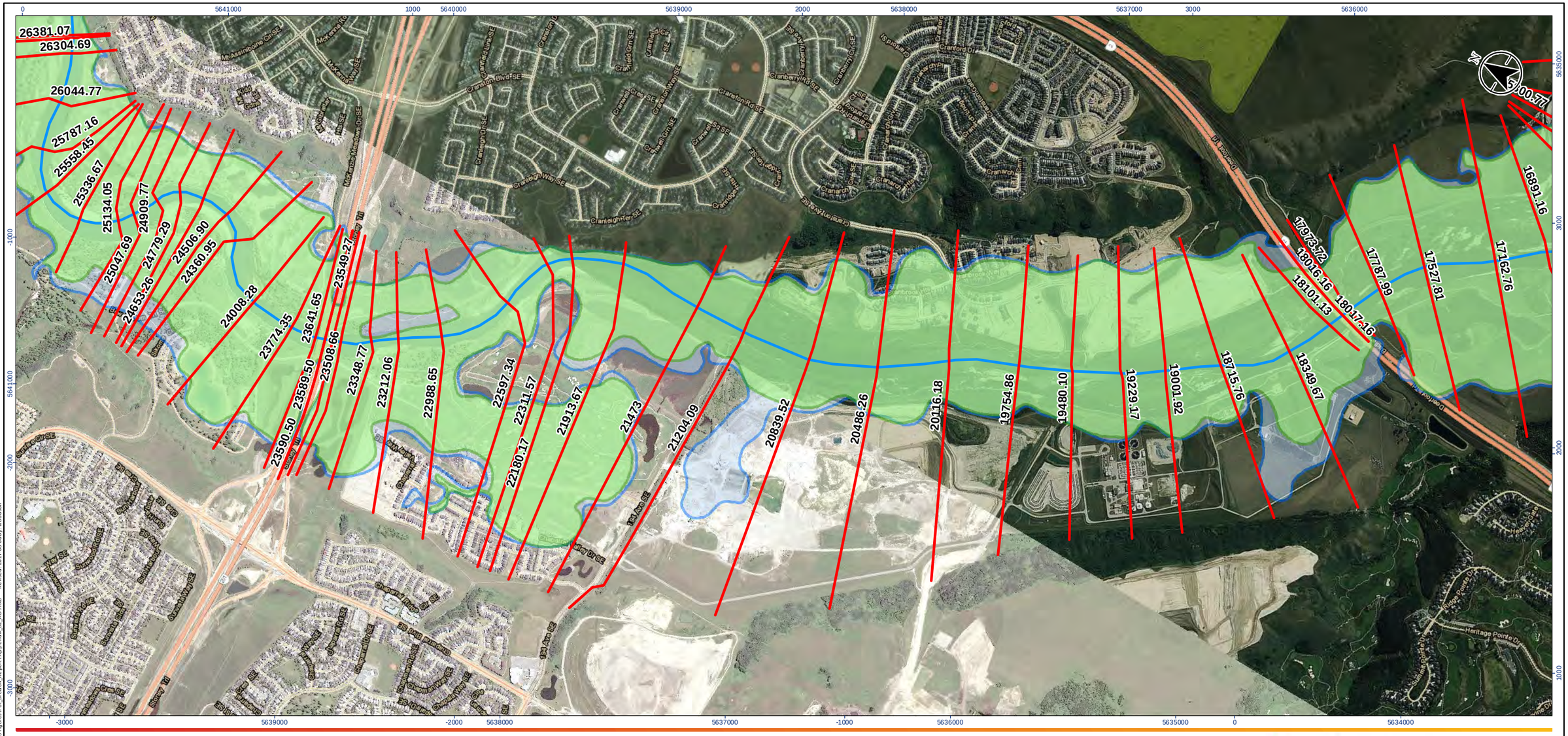

Legend

- Model XS
- River Centerline
- Inundation Extents, No Cascade Failure
- Inundation Extents Southeast Dyke Cascade Failure
- Elevation Contour (5 meter)

0 400 800 Meters

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Notes

1. Coordinate System: NAD 1983 3TM 114

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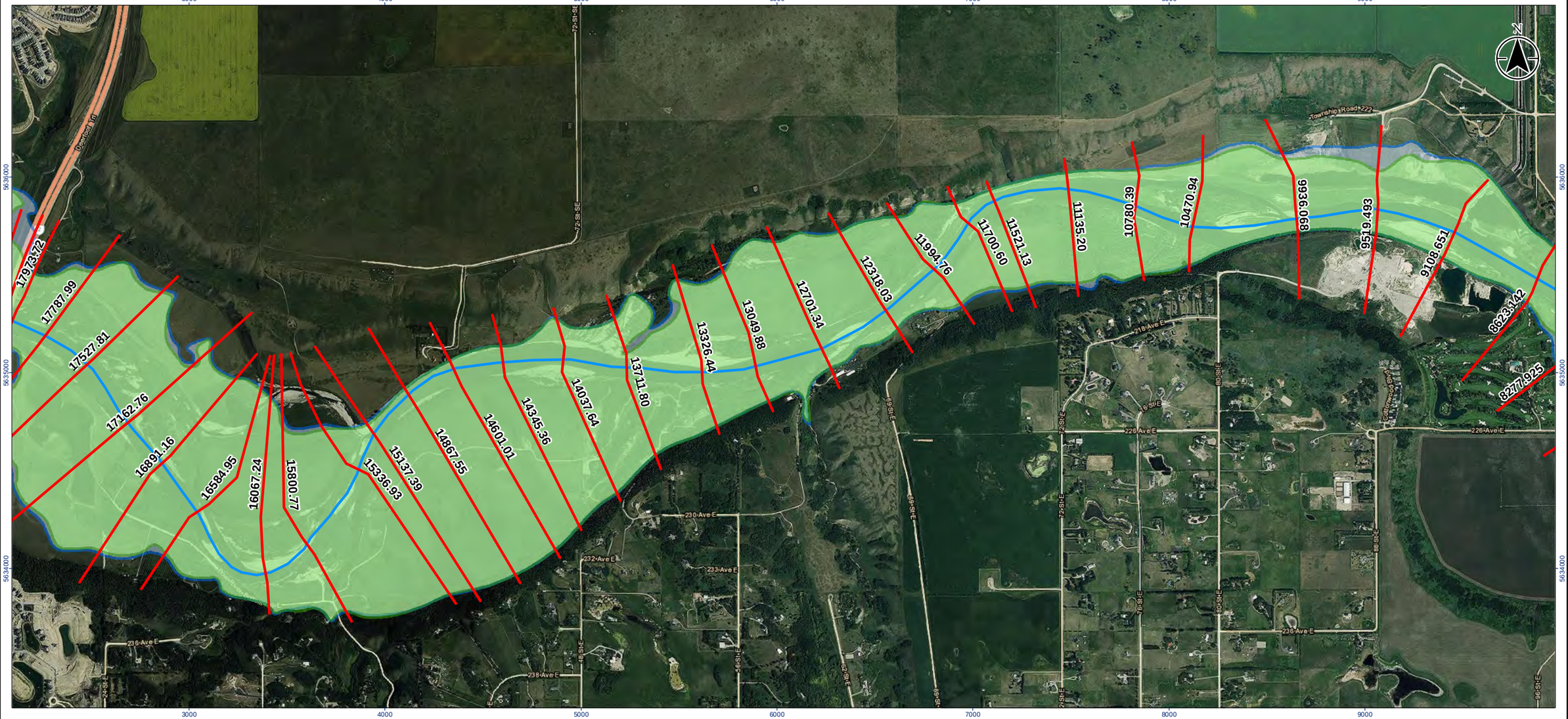
Alberta Transportation
Springbank Off-Stream Reservoir (SR1)

Figure No.
B10

Title
Breach Analysis and Inundation Mapping



Legend

- Model XS
- River Centerline
- Inundation Extents, No Cascade Failure
- Inundation Extents Southeast Dyke Cascade Failure
- Elevation Contour (5 meter)

0 400 800 Meters

1:20,000 (At original document size of 11x17)

Notes

1. Coordinate System: NAD 1983 3TM 114

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Figure No.
B11

Title
Breach Analysis and Inundation Mapping

Legend

- Model XS
- River Centerline
- Inundation Extents, No Cascade Failure
- Inundation Extents Southeast Dyke Cascade Failure
- Elevation Contour (5 meter)

Notes

1. Coordinate System: NAD 1983 3TM 114

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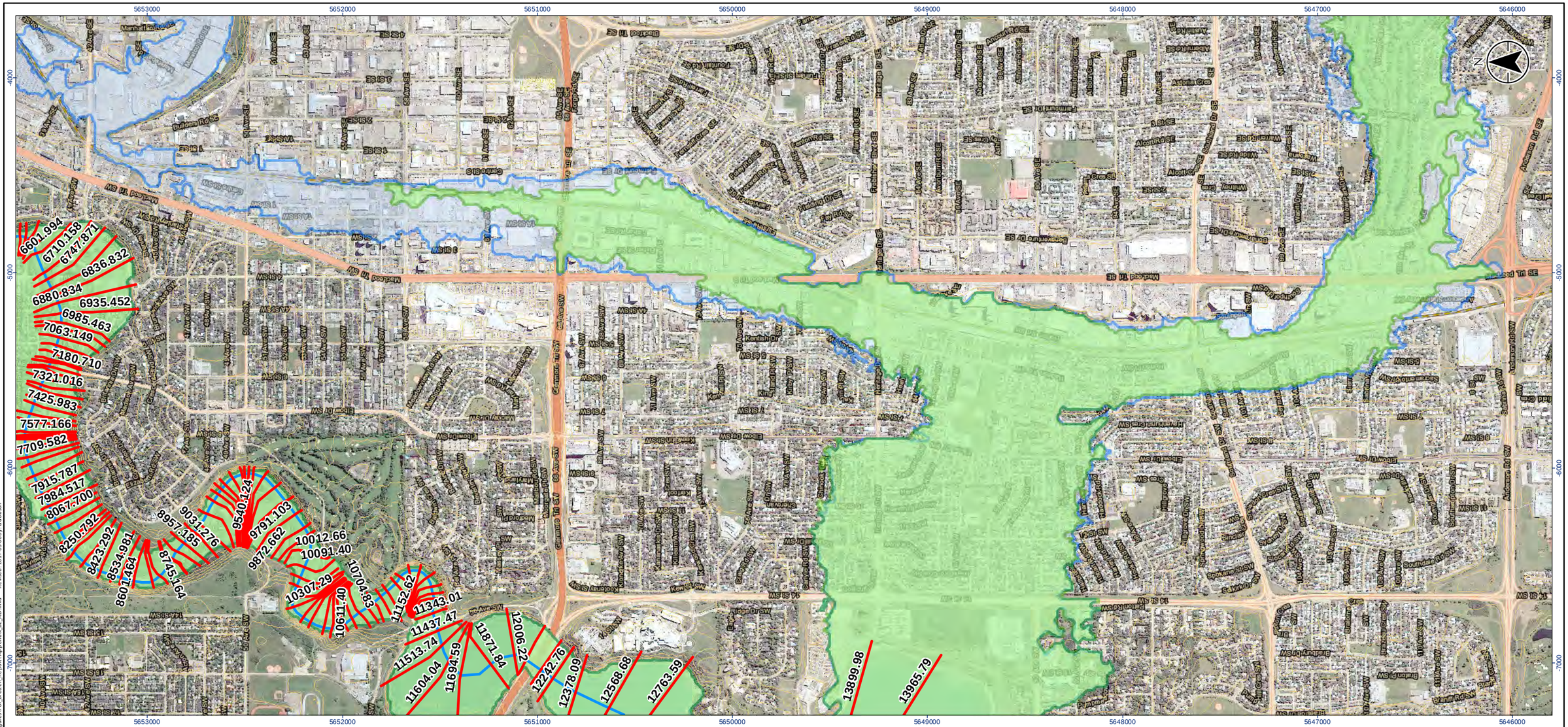
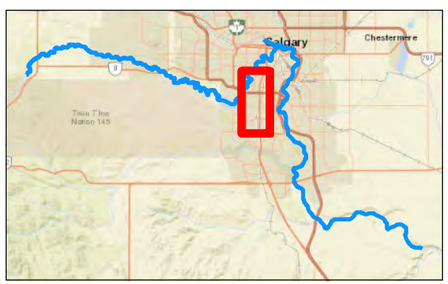
Springbank Off-Stream Reservoir (SR1)

Figure No.
B12

Title
Breach Analysis and Inundation Mapping





Legend

- Model XS
- River Centerline
- Inundation Extents, No Cascade Failure
- Inundation Extents Southeast Dyke Cascade Failure
- Elevation Contour (5 meter)

0 400 800 Meters

1:20,000 (At original document size of 11x17)

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Client/Project
Alberta Transportation
Springbank Off-Stream Reservoir (SR1)

Figure No.
B13

Title
Breach Analysis and Inundation Mapping

Notes

1. Coordinate System: NAD 1983 3TM 114