Knife River Alternatives Analysis Report

Mercer County, North Dakota

SWC Project #1404
August 2018

North Dakota
State Water Commission

Knife River Alternative Analysis Report

Beulah, North Dakota, Mercer County

SWC Project #1404
North Dakota State Water Commission
900 East Boulevard Ave.
Bismarck, ND 58505-0850

Prepared for:
Mercer County Water Resource District

August 2018

Prepared by:

Chris Korkowski

Chris Korkowski, E.I.T.
Water Resource Engineer

Under the direct supervision of:

REGISTERED PROFESSIONAL ENGINEER
LAURA C. ACKERMAN
PE-7861
DATE 8/17/2018
NORTH DAKOTA

Laura C Ackerman

Laura Ackerman, P.E.
Investigations Section Chief

Table of Contents

List of Tables

List of Figures

Appendices

1. Introduction

1.1 Purpose

This report documents the alternatives analyzed for reducing flood risk along the Knife River at Beulah, ND. The alternatives were created as part of a Section 22 Planning Assistance to States study agreement between the U.S. Army Corps of Engineers (Omaha District) and the Mercer County Water Resource District (District), and pursuant to an investigation agreement between the District and the North Dakota State Water Commission (SWC). The purpose of the Section 22 study is to investigate the flood risk management alternatives for the communities along the Knife River.

The purpose of this report is to analyze impacts on water surface elevations based on developed alternatives for Beulah, ND. Alternatives analyzed as part of this report include levee alignments, removing restrictions, and creation of overflow conveyance channels. This report does not include an examination of upstream storage alternatives, as this methodology was screened out of consideration in the Knife River Hydrology Report that was examined as part of the Section 22 study.

This report includes electronic appendices A, B, C, D, and E which provide more information on levee alternatives, conveyance alternatives, overflow conveyance channel alternatives, the hydraulic model used to evaluate each alternative, and the Beulah Structure Survey, respectively.

1.2 Site Location

The Knife River reach included in the alternative analysis (**Figure 1**) is located in Mercer County, near the City of Beulah, ND. The figure illustrates the cross sections used in the hydraulic model and includes the cross section IDs.

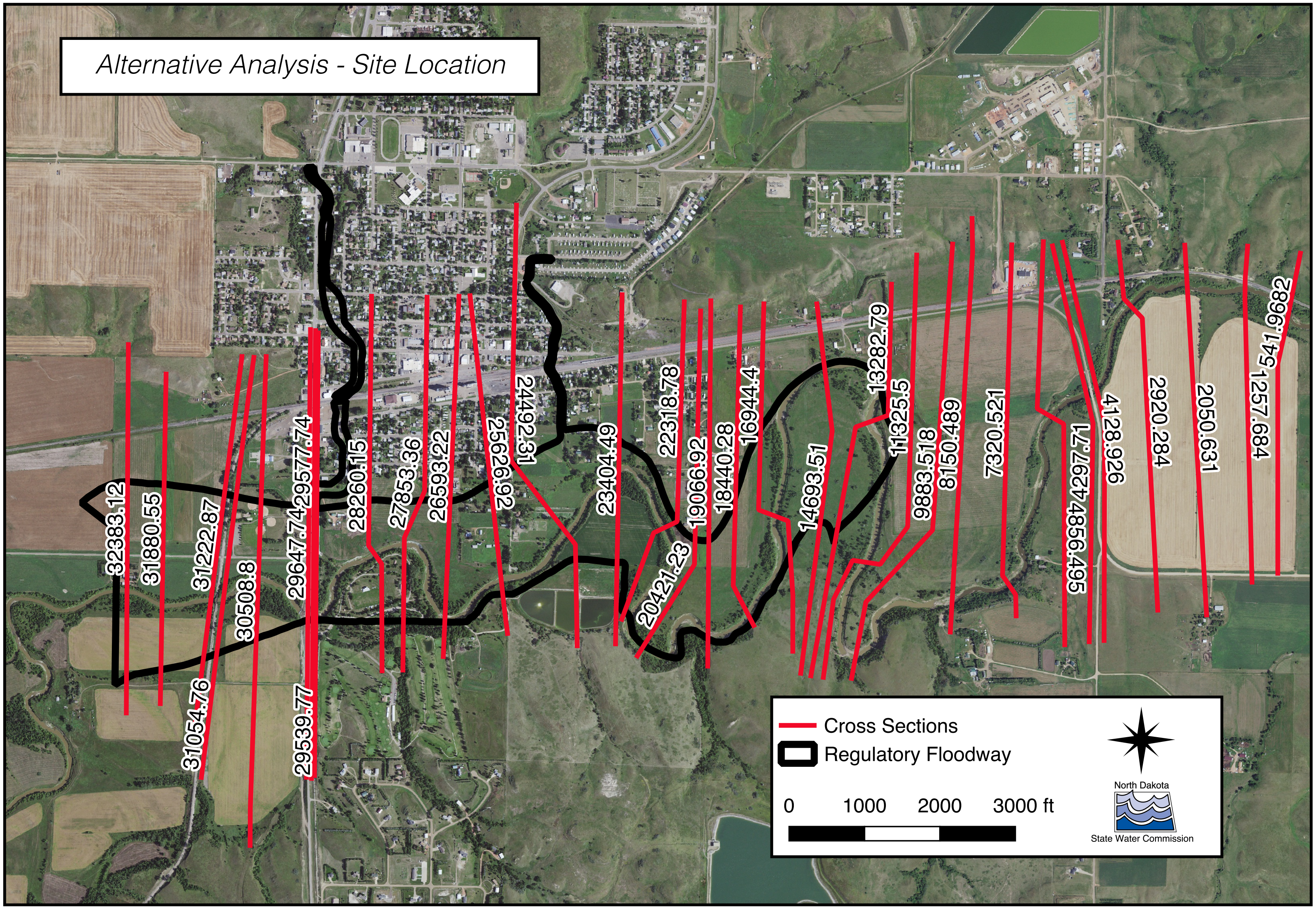

Figure 1. Knife River reach included in the alternative analysis.

2. Levee Alignments

As part of the Section 22 agreement, three options for temporary levee configuration were identified by the SWC, each containing two to three levees. Temporary emergency levees were evaluated because of interest from the City of Beulah after the 2009 flood event. They were favorably viewed due to their lack of continuous maintenance, but the potential to build permanent structures was discussed. For this reason, closure structure locations were identified in case the community wants to pursue a Section 205 agreement with the Omaha District to further design permanent protection.

As part of emergency flood protection, temporary emergency levees require a permit from the Office of the State Engineer. A description of the permitting requirements for temporary flood measures is described in a letter from the North Dakota Office of the State Engineer (Appendix A). Levee Option A provides the most protection, but presents the most challenges with floodway restrictions, demolition of structures, and private property encroachment. Levee Option B provides moderate protection and is more easily constructed. Levee Option C is mainly located along roads and alleyways and provides the least amount of protection and is the most easily constructed. Each levee option footprint could be reduced by decreasing the amount of freeboard, consulting a geotechnical engineer on the side slopes of the levee, and by placing HESCO barriers on top of the levees. These options were not utilized in the evaluation of the levees to allow screening based on a similar set of criteria. Each levee option was screened using the same criteria, listed below.

- 3 feet of freeboard for the 100-year event, excluding the tieback section of the levee
- 10-foot top width
- 3-horizontal to 1-vertical side slopes
- Protect as many structures as possible
- No encroachment on the regulatory floodway

All three options require two levees (Main Levee and East Levee) to cross the railroad tracks in order to provide 3 feet of freeboard. Summaries for each option are provided in **Table 1**.

The City of Beulah has two sizeable tributaries, East Tributary and West Tributary, that cut through the floodplain and enter the Knife River. Both of these tributaries have a regulatory floodway that continue until they meet the Knife River's floodway. Because of this, a continuous levee along the Knife River cannot be constructed and options have been broken into two or three levees. Levees along West Tributary include a tieback feature to protect against flows along the tributary. Tieback features were not included on East Tributary due to the flows being controlled by a dry dam located upstream of the City of Beulah. The tieback for West Tributary was conservatively estimated based on inundation mapping completed using the two-dimensional hydraulic model developed for the "West Tributary, Preliminary Findings" report (North Dakota State Water Commission, 2017).

Temporary emergency levee alignments for the City of Beulah were determined using 1-ft high resolution aerial photography from the Department of Emergency Services (DES), 1-m Light Detection and Ranging Data (LiDAR), and a one-dimensional hydraulic model of the Knife River, which was created as part of this study. The goal of the levee alignments was to protect as many structures as possible during the 100-year flood event, without encroachment into the Federal Emergency Management Agency's (FEMA) regulatory floodway. The 2015 FEMA Flood Insurance Study (FIS) 100-year flood event of 39,000 cfs was used to evaluate the levee alignments. FEMA's 100-year regulatory flow was utilized over the 100-year flow produced from this study because it is greater in magnitude and provides more conservative results. Many homes are within or near the regulatory floodway, and protection of these homes with a levee is infeasible.

Table 1. Summary table for evaluated levee options.

Levee Name	Length (ft)	Max Height (ft)	Average Height (ft)	Max Width (ft)	Average Width (ft)	Volume (cy)	Clearing and Grubbing (acres)	Plastic Sheeting Area (SY)	Approximate Homes/Businesses Protected	Non-Dwelling Structures Demolished	Potential Floodway Conflict	Constructability
Levee Option A												
West Ring Levee	2,100	8.2	4.9	59	39.5	12,000	0.5	4,316	7	1	Yes	Most Difficult
Main Levee A (Most Protection)	6,700	15.3	6.2	101.4	47	59,000	5.5	16,829	204	10	Yes	Most Difficult
East Levee A (Most Protection)	7,200	12.3	5.7	84	44	53,000	4.5	16,820	62	4	Yes	Most Difficult
Levee Option B												
Main Levee B (Medium Protection)	7,900	10.9	5.6	75	44	57,000	1.7	18,178	169	0	No	More Difficult
East Levee B (Medium Protection)	3,040	9.6	6.4	68	49	26,500	2.5	7,849	29	0	No	More Difficult
Levee Option C												
Main Levee C (Less Protection)	6,333	11.1	5.4	76	39	44,500	0.7	14,127	155	0	No	Less Difficult
East Levee C (Less Protection)	2,450	8.4	5.7	60	44	18,000	0.5	5,723	23	0	No	Less Difficult

- *The heights for Table 1 were determined using the 100-year event plus three feet of freeboard.*
- *The widths for Table 1 were determined using a 10-foot top width and 3-horizontal to 1-vertical side slopes.*
- *The volumes for Table 1 were determined using the information above and the LiDAR profile, a detailed output of these computations is provided in a spreadsheet in* ***Appendix A****.*
- *The total acreage of each footprint provided in Table 1 was determined using the spreadsheet available in* ***Appendix A****.*

2.1 Levee Option A

Figure 2 illustrates the alignment of Levee Option A, which includes the West Ring Levee, Main Levee A, and East Levee A. Detailed maps of the levees are provided in **Appendix A**. Maps included in Appendix A do not include the 3 ft tall tie back levee to the east of West Tributary. This option provides the most protection but presents the most challenges regarding floodway encroachments, obtaining easements from land owners, and demolishing structures. Two homes located on Chaffee Row closest to East Tributary are located so close to the floodway that a traditional levee footprint (3 ft freeboard, 10 ft top width, 3 to 1 side slopes) could not be constructed. Levee protection could likely still be provided in this area by using HESCO or sandbagging efforts. Additionally, approximately 15 garages or sheds would need to be removed along with considerable clearing and grubbing of trees.

Levee protection requires pumping stations to facilitate interior drainage, as illustrated in **Figure 3**. Levee Option A would require two major pump stations with capacities of 2,500 and 700 GPM (gallons per minute) and potentially six minor pump stations (100, 160, 180, 190, 200, and 240 GPM).

Figures 4 and **5** illustrate the water surface profiles along Main Levee A and East Levee A, respectively. A figure was not included for the West Ring Levee due to the alignment being designed to a single elevation. It was designed to a single elevation due to the relatively short distance between the upstream and downstream end of the levee. **Table 2** provides the water surface impacts resulting from Levee Option A (positive values signifying an increase in water surface and negative values meaning a decrease). **Table 2** displays some negative values, which are likely due to the levee constricting the flow area, increasing water surfaces along and upstream of the levee, while decreasing water surfaces downstream.

For the purpose of future planning, **Figure 6** illustrates locations for potential road and railroad closure structures for Levee Option A. The layout was designed to be temporary, but given the constraints (river, structures, and regulatory floodway) potential permanent levees would need to maintain access at these locations. The closure structures illustrated in **Figure 6** could also be used for Option B or C if these alignments were deemed more desirable for permanent works.

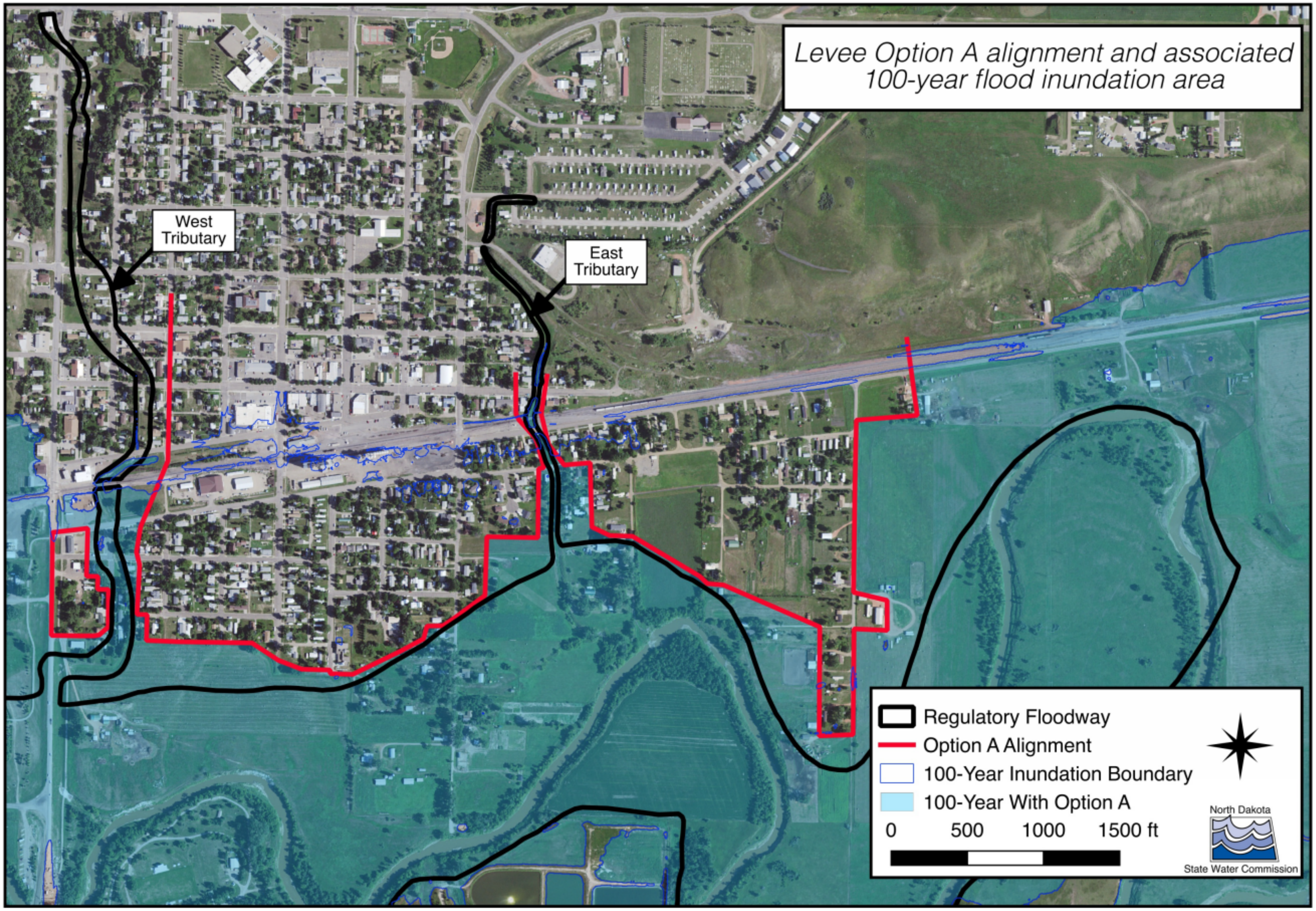

Figure 2. Levee Option A alignment and associated 100-year flood inundation area.

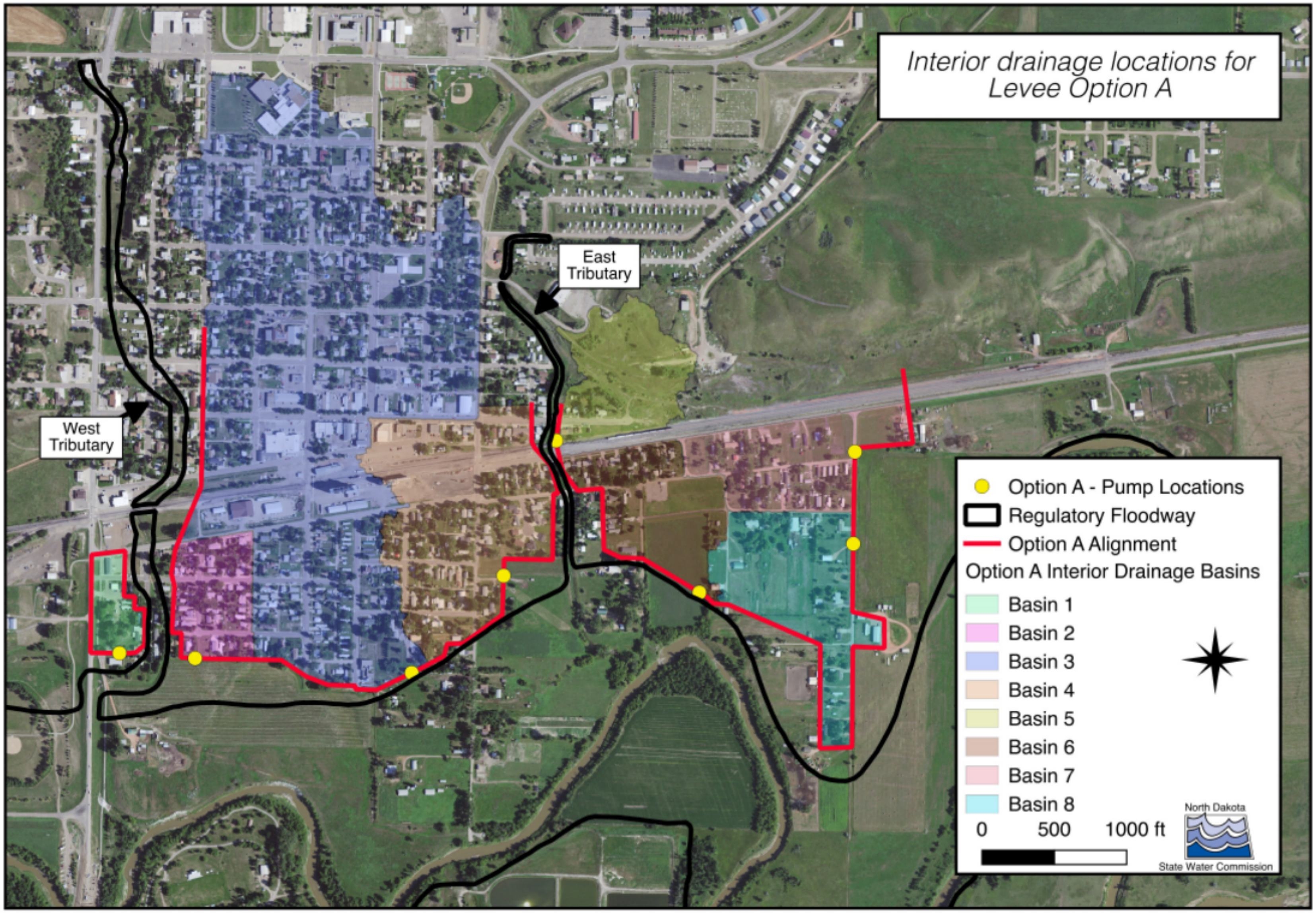

Figure 3. Interior drainage locations for Levee Option A.

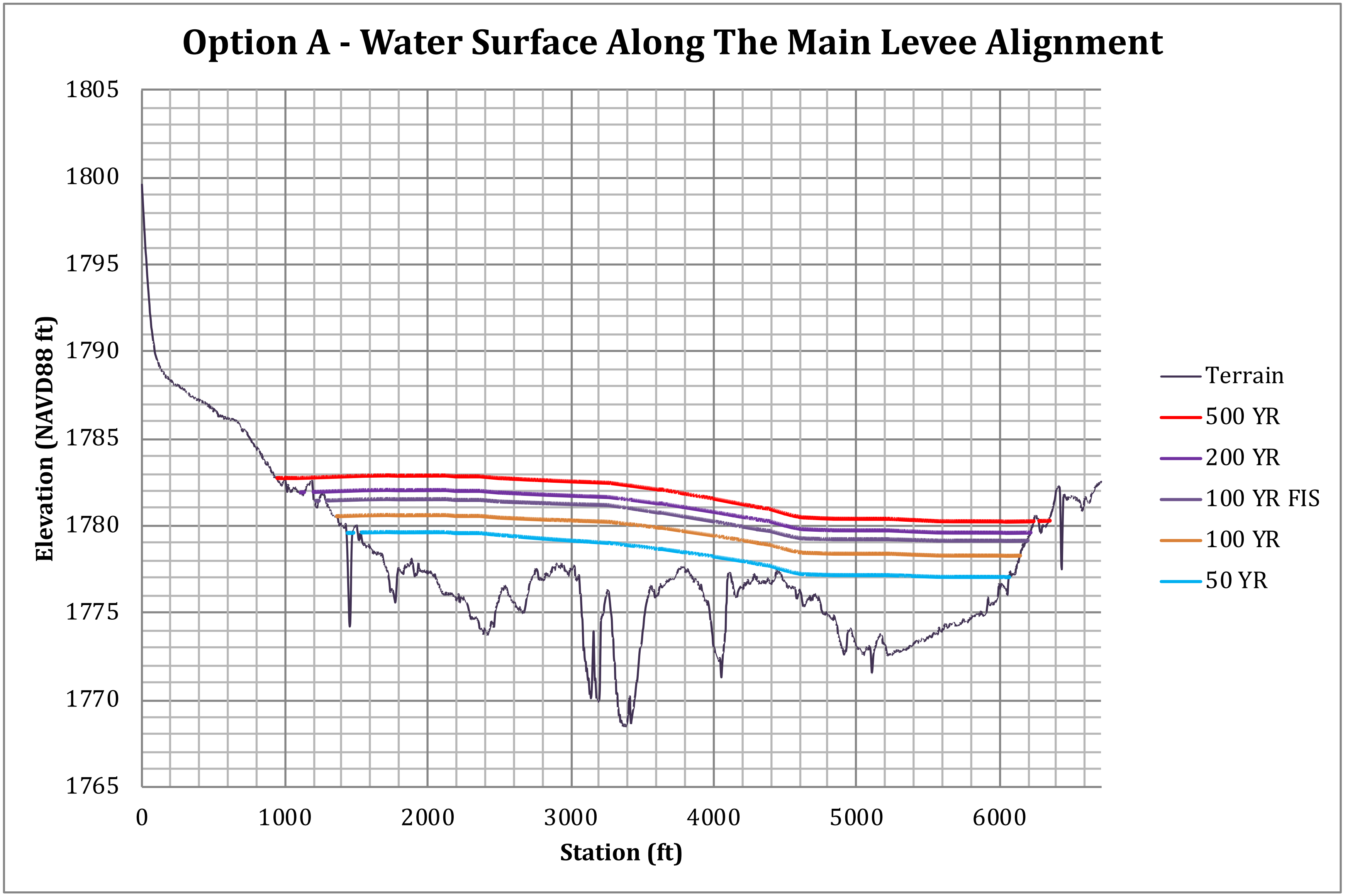

Figure 4. Water surface elevations along the alignment for Main Levee A.

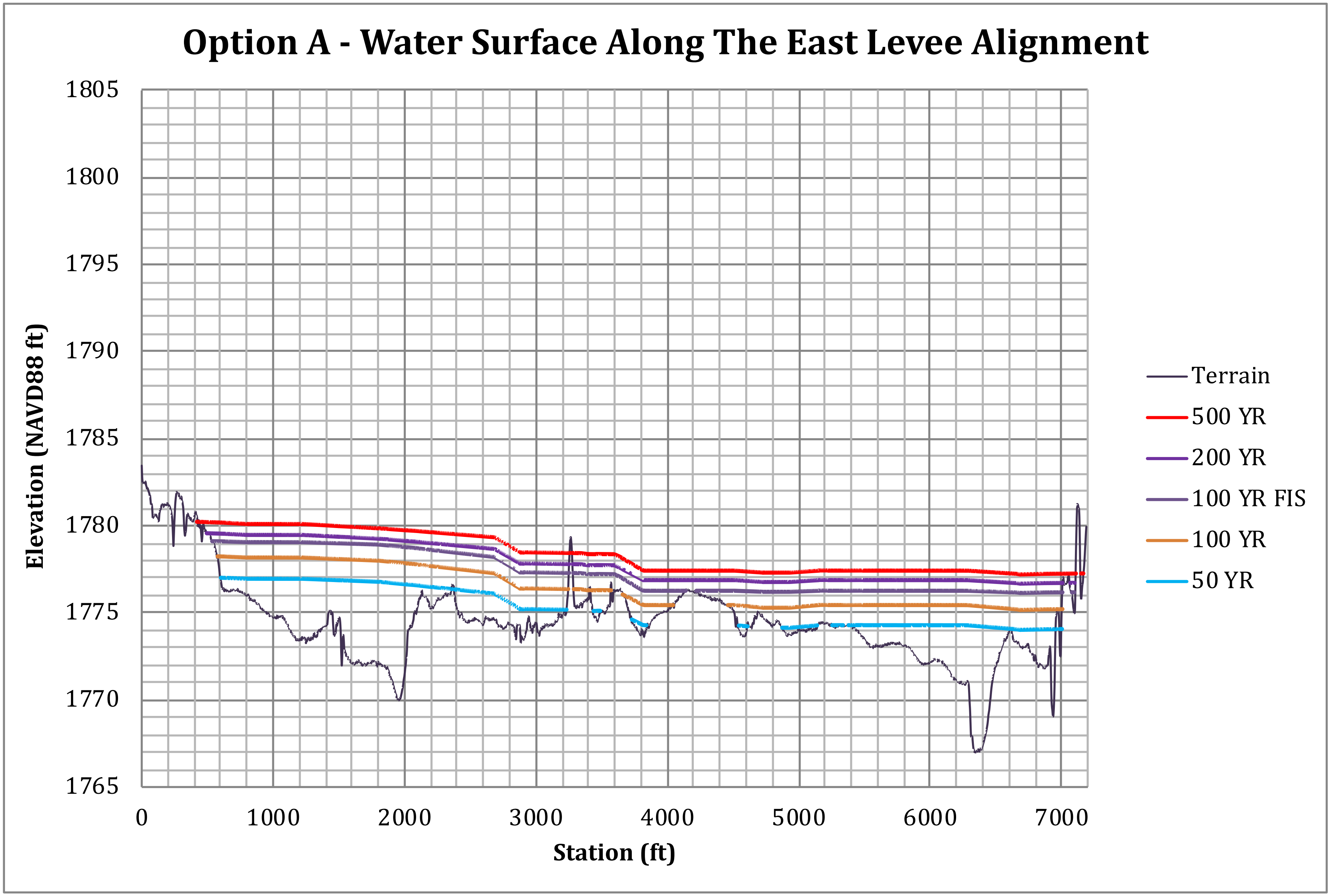

Figure 5. Water surface elevations along the alignment for East Levee A.

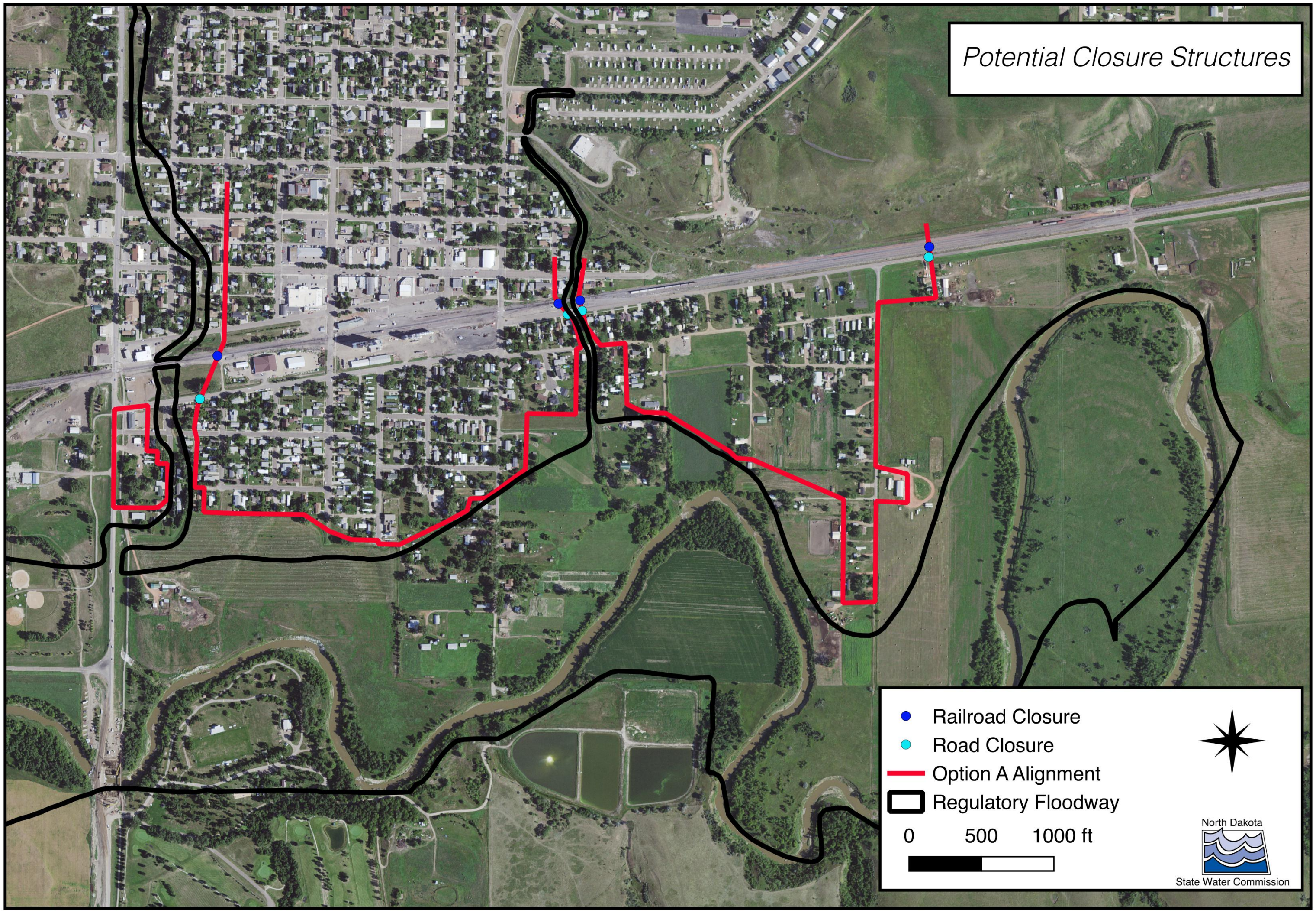

Figure 6. Locations for potential closure structures for Levee Option A.

Table 2. Water surface impacts at cross sections resulting from Levee Option A alternative.

Cross Section ID	50 YR	100 YR	100 YR FIS	200 YR	500 YR
	(ft)	(ft)	(ft)	(ft)	(ft)
32383.12	0.09	0.06	0.09	0.42	0.52
31880.55	0.09	0.06	0.1	0.45	0.54
31222.87	0.09	0.07	0.1	0.47	0.57
31138.23	Mult Open	Mult Open	Mult Open	Mult Open	Mult Open
31054.76	0.09	0.07	0.13	0.55	0.64
30508.8	0.12	0.09	0.18	0.64	0.82
29647.74	0.2	0.12	0.36	0.9	1.14
29612.74	Bridge	Bridge	Bridge	Bridge	Bridge
29577.74	-0.09	-0.07	0.43	0.58	0.68
29539.77	0.02	0.16	0.4	0.57	0.67
28260.15	0.03	0.18	0.38	0.57	0.67
27853.36	0.12	0.19	0.37	0.56	0.67
26593.22	0.14	0.16	0.31	0.52	0.63
25626.92	0.19	0.18	0.31	0.52	0.63
24492.31	0.27	0.39	0.94	0.63	0.75
23404.49	0.27	0.4	0.74	0.64	0.78
22318.78	0.08	0.12	0.51	0.55	0.71
20421.23	0	0	-0.02	0.22	0.31
19066.92	0	0	0.03	-0.03	-0.04
18440.28	0.01	0	0	0.01	0
16944.4	0.01	0.01	0	0	0
14693.51	0	0	0	0	0

2.2 Levee Option B

Figure 7 illustrates the alignment of Levee Option B, which includes Main Levee B and East Levee B. This option provides less protection than Levee Option A, but avoids demolition of structures and lowers the maximum height of the levees by shifting them northward. By locating the levees along roads or grasslands, they are more constructible, and easements are likely easier to obtain. The two homes located on Chaffee Row closest to East Tributary would still be protected by using HESCO or sandbagging efforts.

Pumping stations for interior drainage would be required on the dry side of the levee, as illustrated in **Figure 8**. Levee Option B would require two major pump stations with capacities of 2500 and 530 GPM and two minor pump stations with capacities of 100 and 170 GPM.

Figures 9 and **10** illustrate the water surface profile along Main Levee B and East Levee B, respectively. **Table 3** provides the water surface impacts resulting from Levee Option B (positive values signifying an increase in water surface and negative values meaning a decrease). **Table 3** displays some negative values, which are likely due to the levee constricting the flow area, increasing water surfaces along and upstream of the levee, while decreasing water surfaces downstream.

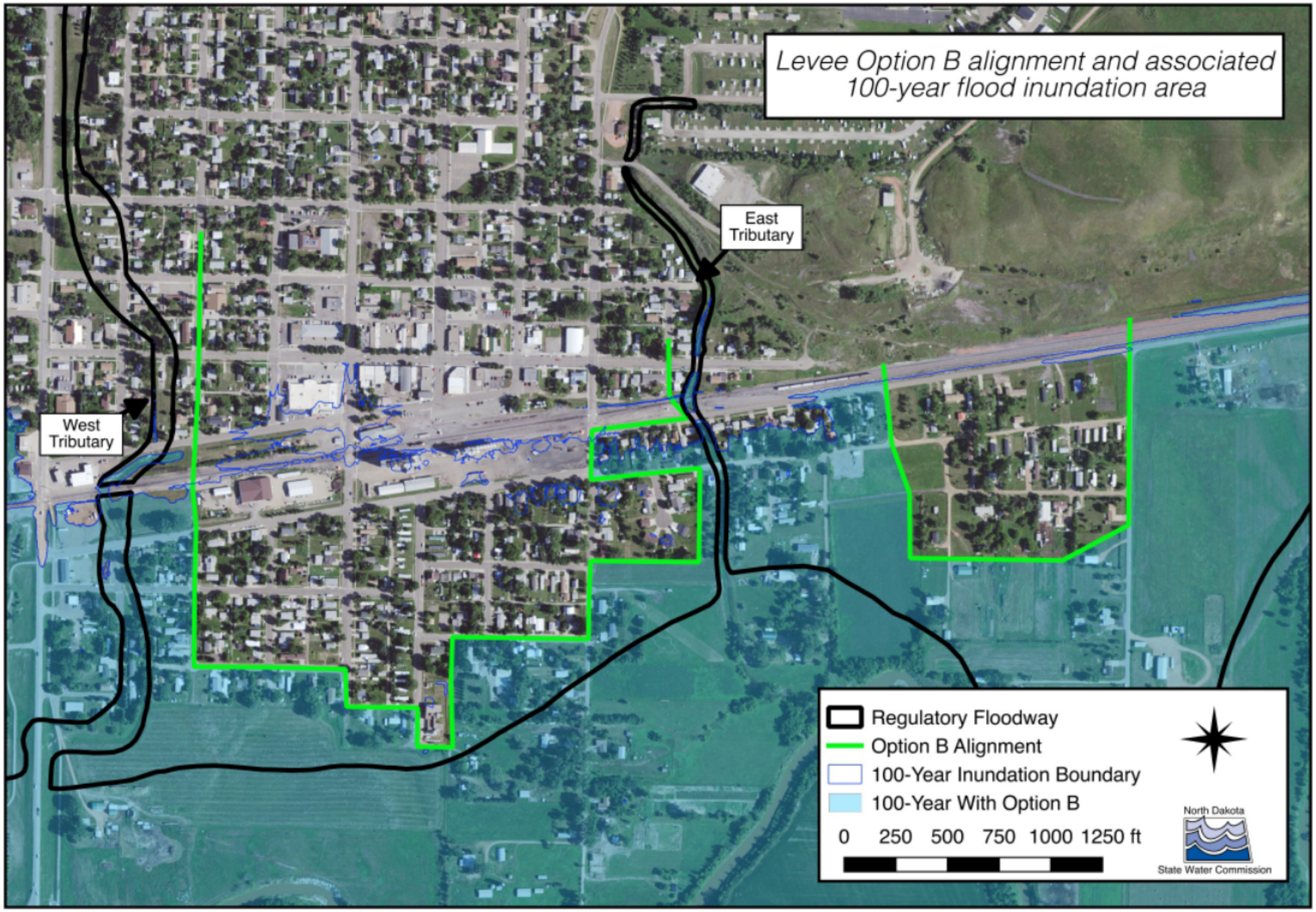

Figure 7. Levee Option B alignment and associated 100-year flood inundation area.

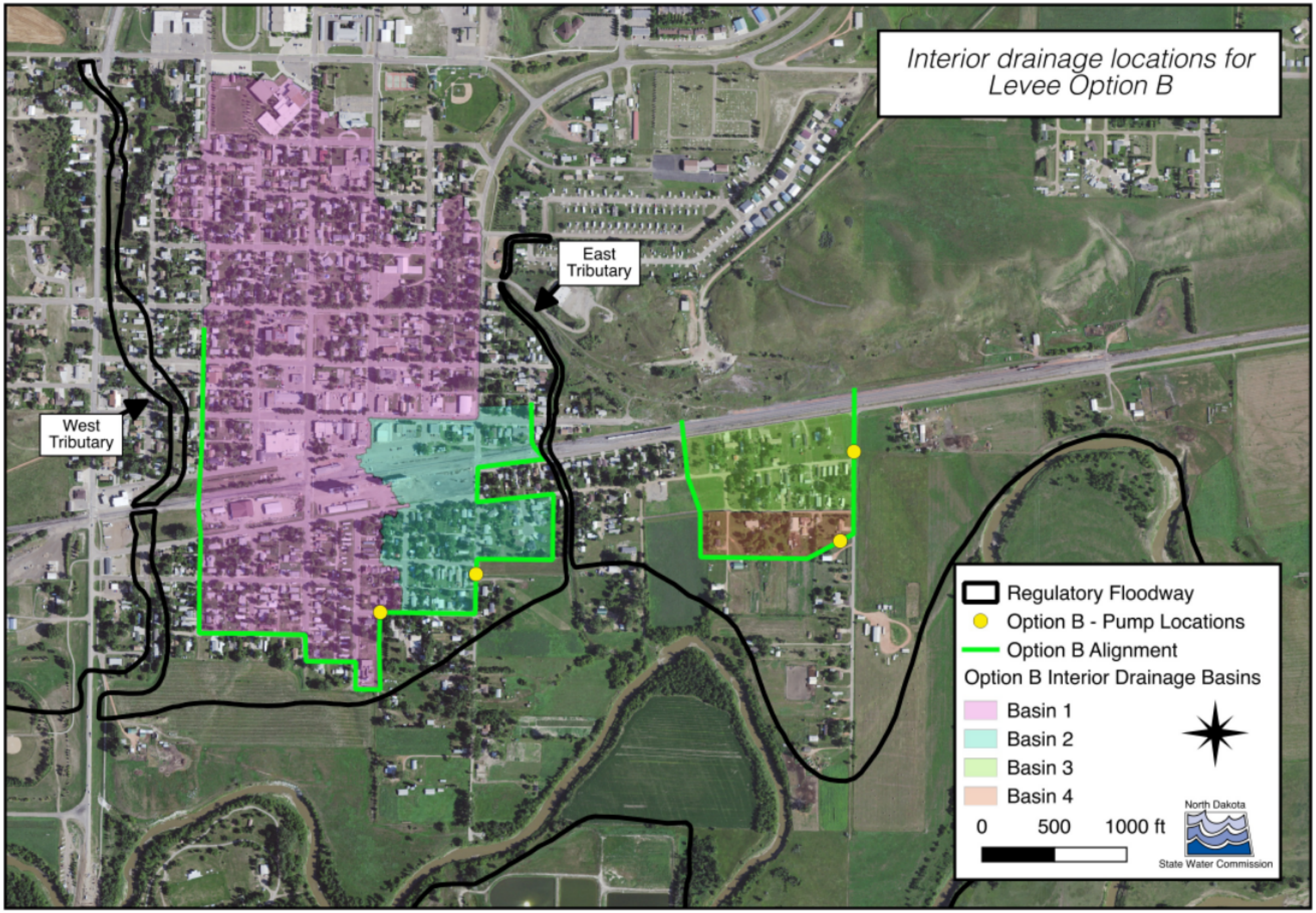

Figure 8. Interior drainage locations for Levee Option B.

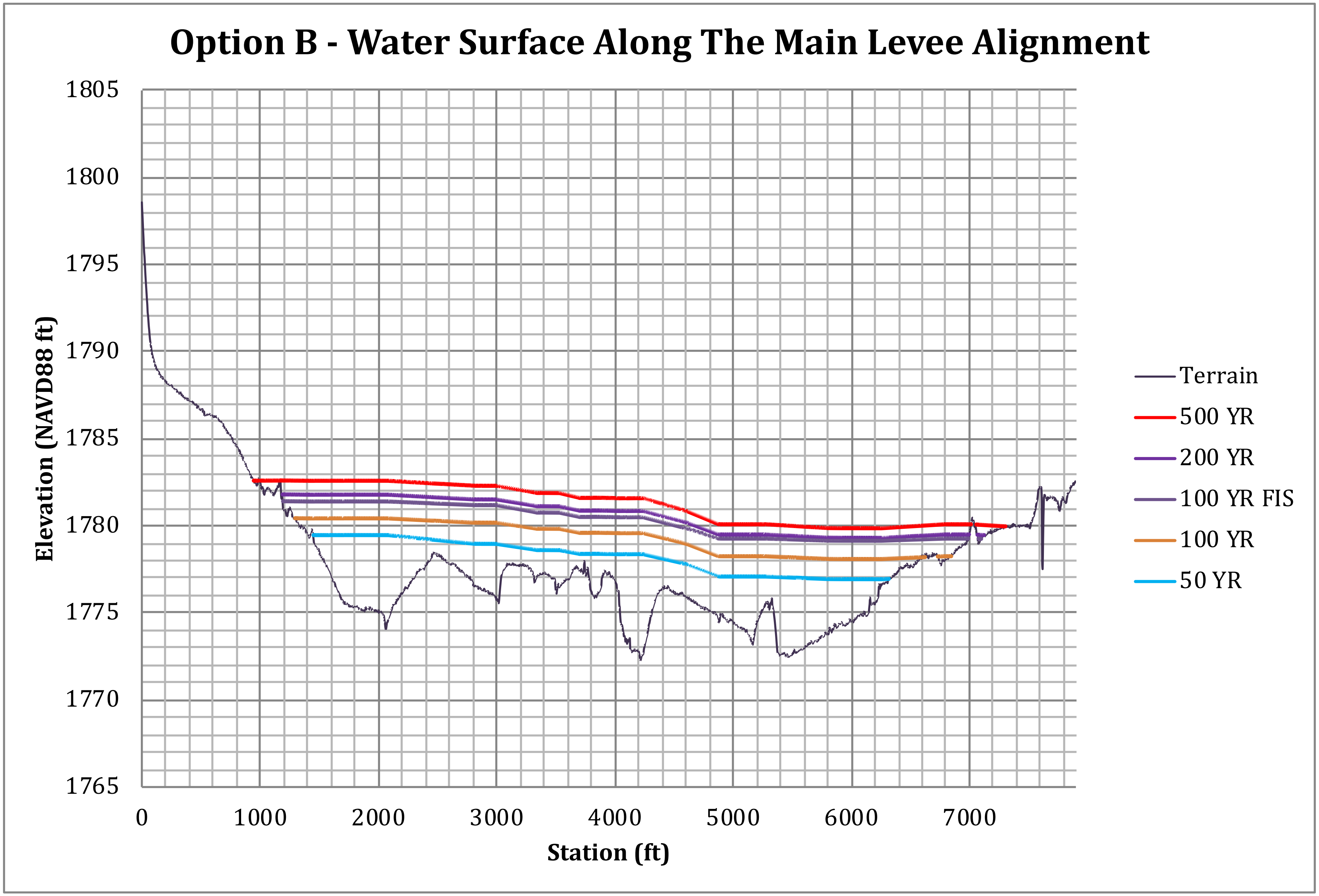

Figure 9. Water surface elevations along the alignment for Main Levee B.

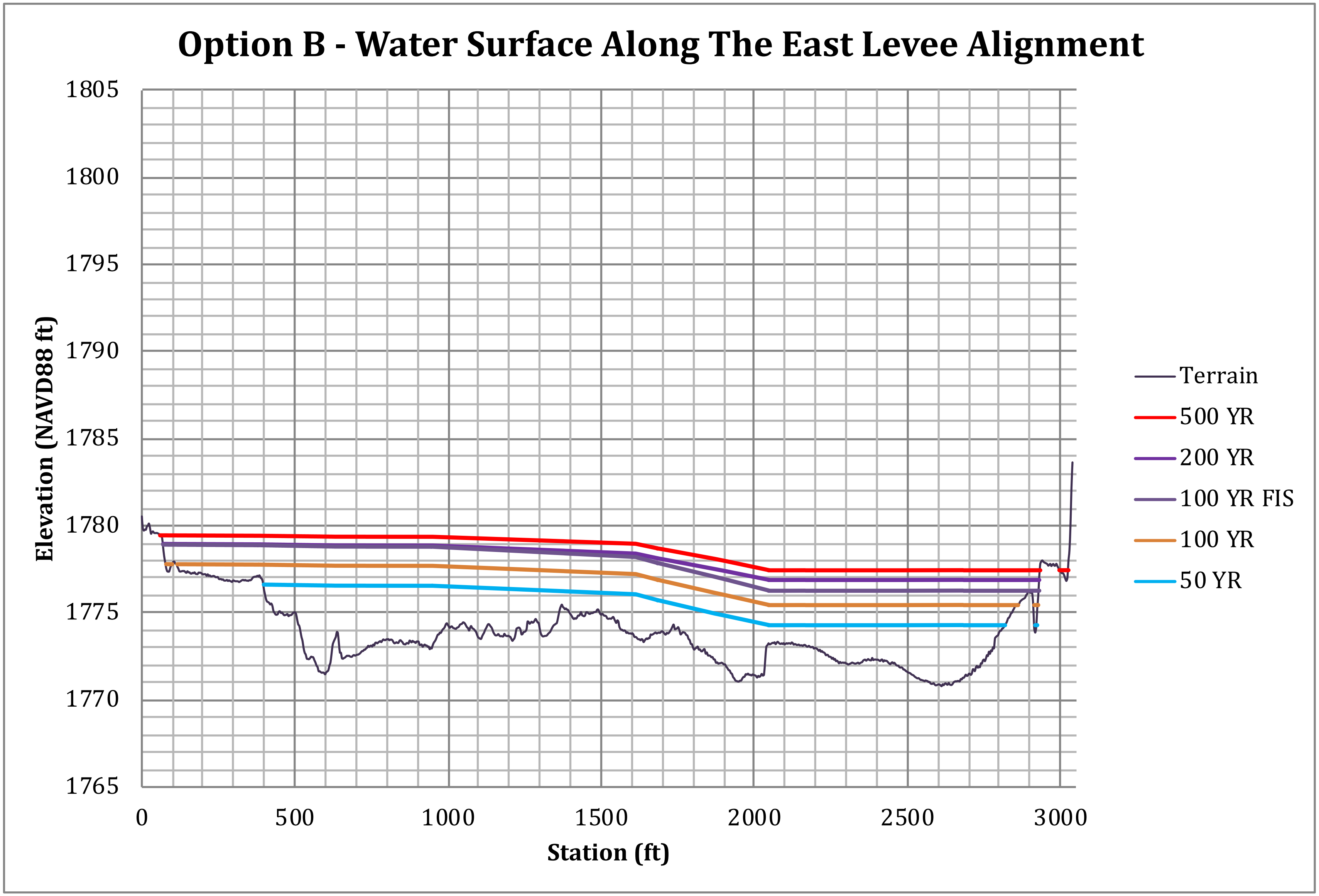

Figure 10. Water surface elevations along the alignment for East Levee B.

Table 3. Water surface impacts at cross sections resulting from Levee Option B alternative.

Cross Section ID	50 YR	100 YR	100 YR FIS	200 YR	500 YR
	(ft)	(ft)	(ft)	(ft)	(ft)
32383.12	0.01	-0.04	0.09	0.06	0.12
31880.55	0.01	-0.03	0.1	0.07	0.12
31222.87	0	-0.04	0.1	0.07	0.13
31138.23	Mult Open	Mult Open	Mult Open	Mult Open	Mult Open
31054.76	0	-0.04	0.13	0.08	0.15
30508.8	0	-0.05	0.18	0.1	0.2
29647.74	0.01	-0.05	0.36	0.17	0.29
29612.74	Bridge	Bridge	Bridge	Bridge	Bridge
29577.74	0.01	-0.03	0.43	0.5	0.58
29539.77	0.01	0.11	0.4	0.46	0.54
28260.15	0.01	0.13	0.38	0.45	0.51
27853.36	0.06	0.14	0.37	0.42	0.5
26593.22	0.07	0.1	0.31	0.36	0.43
25626.92	0.1	0.08	0.31	0.3	0.35
24492.31	0.15	0.2	0.94	0.33	0.37
23404.49	0.14	0.2	0.74	0.34	0.37
22318.78	0.05	0.07	0.51	0.28	0.34
20421.23	0	0	-0.02	0.15	0.18
19066.92	0	0	0.03	-0.02	-0.02
18440.28	0.01	0	0	0	0
16944.4	0.01	0.01	0	0	0
14693.51	0	0	0	0	0

2.3 Levee Option C

Figure 11 illustrates the alignment of Levee Option C, which includes Main Levee C and East Levee C. This option provides the least amount of protection, but avoids demolition of structures and requires the least amount of fill. Most of the levees are located on roads or grasslands, minimizing the need for easements.

Pumping stations for interior drainage would be required on the dry side of the levee, as illustrated in **Figure 12**. Levee Option C would require one major pump station with a capacity of 2500 GPM and two minor pump stations with capacities of 200 and 300 GPM.

Figures 13 and **14** illustrate the water surface profile along Main Levee C and East Levee C, respectively. **Table 4** provides the water surface impacts resulting from Levee Option C (positive values signifying an increase in water surface and negative values meaning a decrease). **Table 4** displays some negative values, which is likely due to the levee constricting the flow area, increasing water surfaces along and upstream of the levee, while decreasing water surfaces downstream.

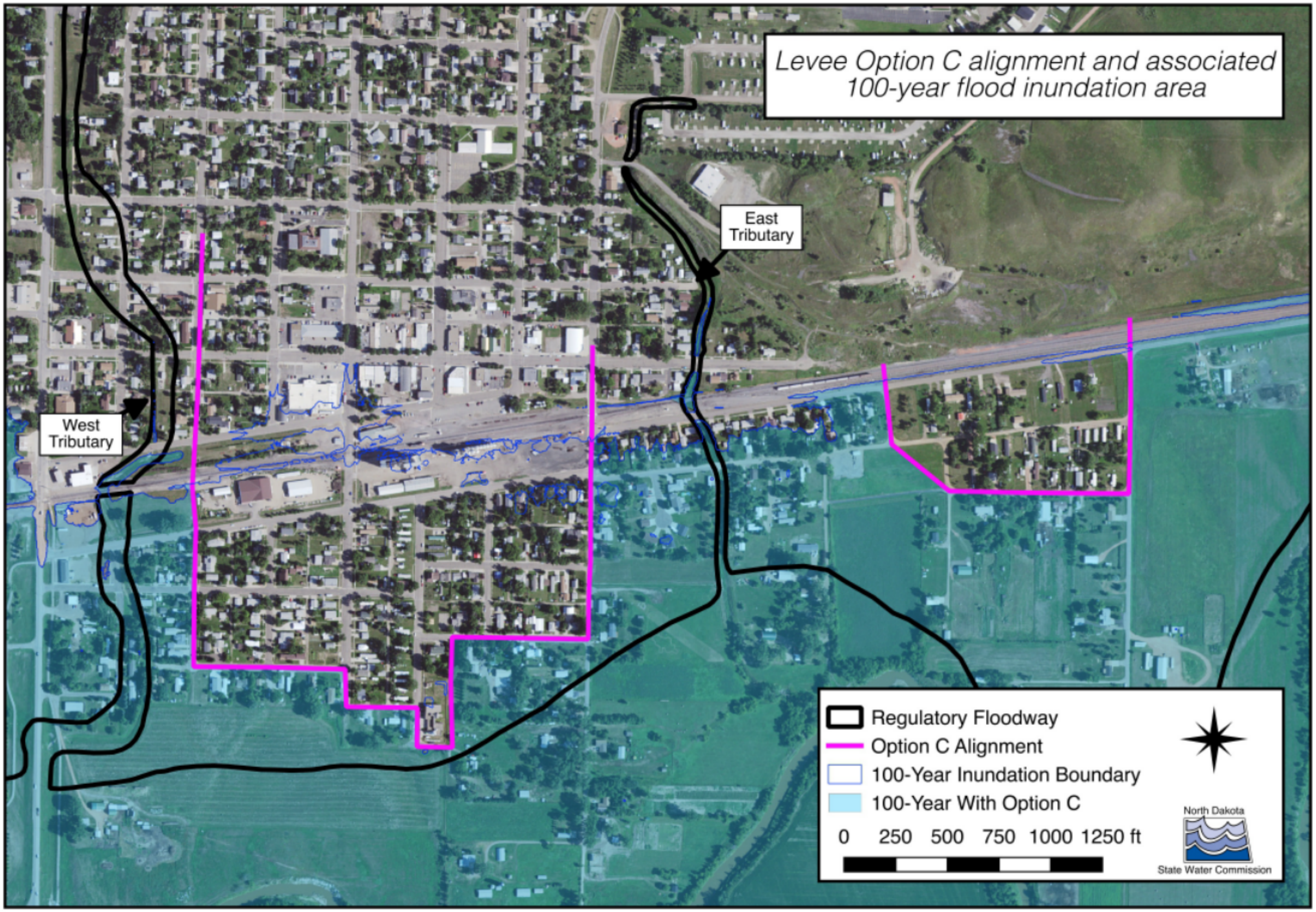

Figure 11. Levee Option C alignment and associated 100-year flood inundation area.

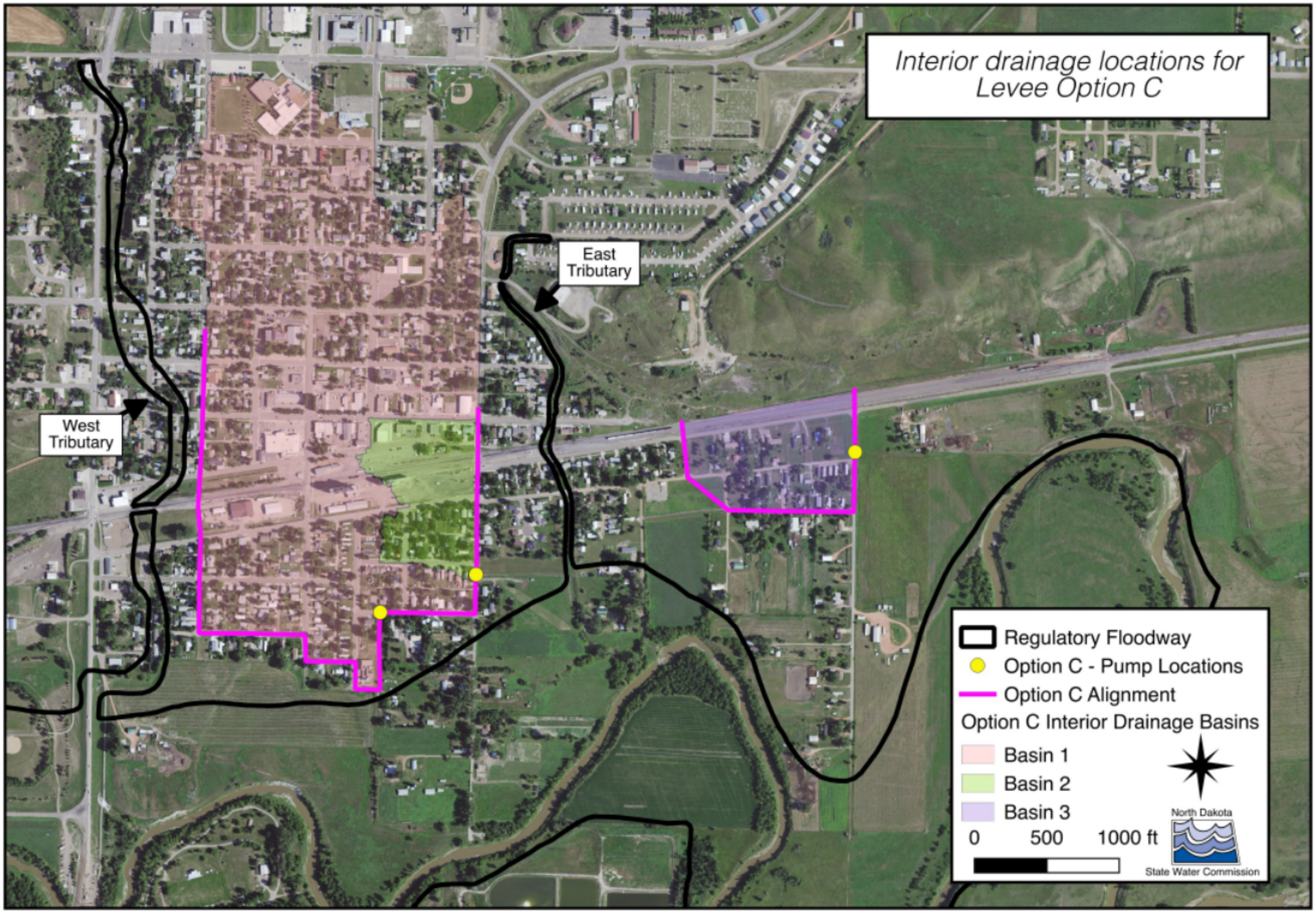

Figure 12. Interior drainage locations for Levee Option C.

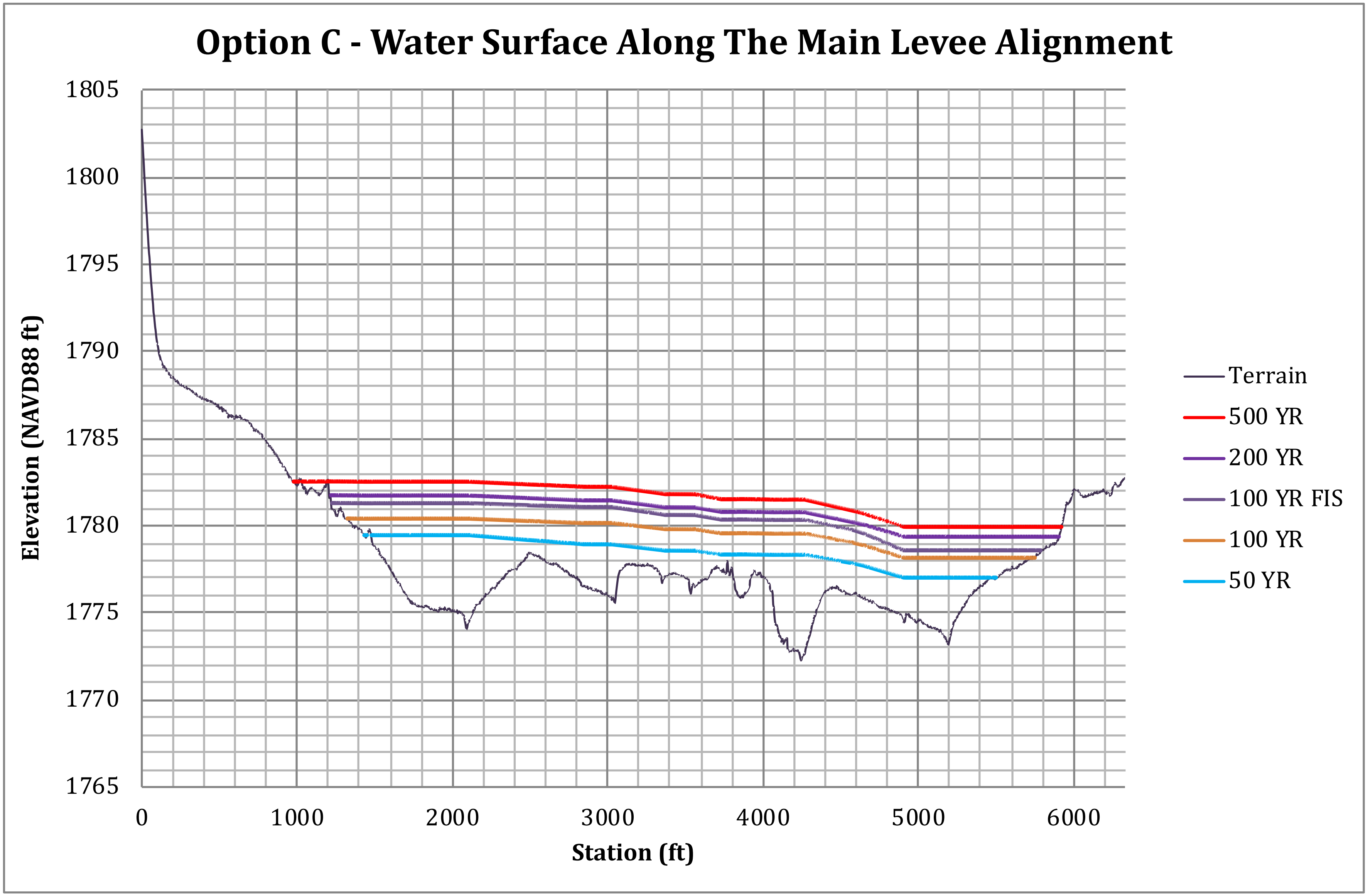

Figure 13. Water surface elevations along the alignment for Main Levee C.

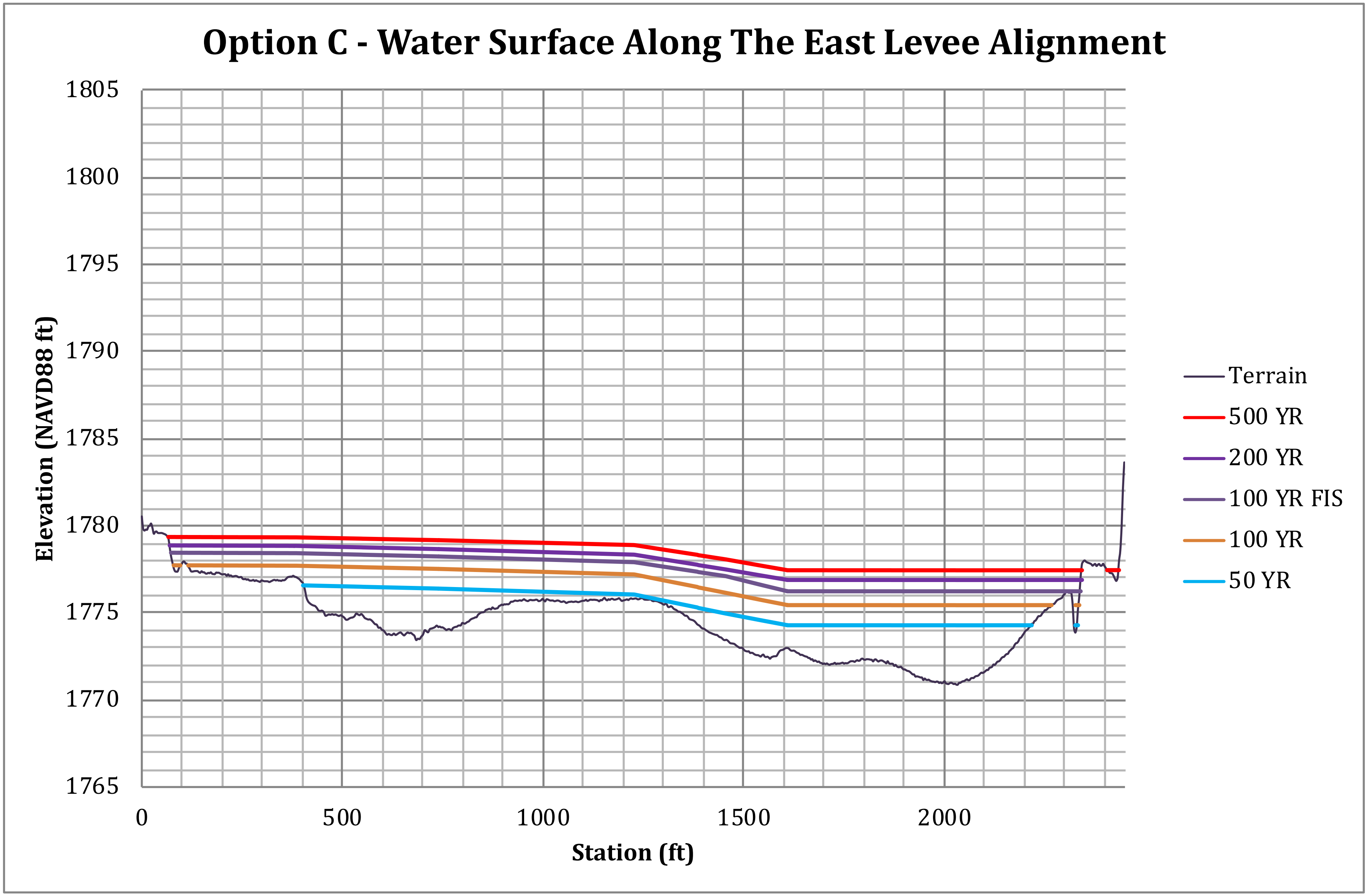

Figure 14. Water surface elevations along the alignment for East Levee C.

Table 4. Water surface impacts at cross sections resulting from Levee Option C alternative.

Cross Section ID	50 YR	100 YR	100 YR FIS	200 YR	500 YR
	(ft)	(ft)	(ft)	(ft)	(ft)
32383.12	0.01	-0.03	0	0.05	0.11
31880.55	0.01	-0.03	0	0.06	0.11
31222.87	0	-0.03	0	0.06	0.12
31138.23	Mult Open	Mult Open	Mult Open	Mult Open	Mult Open
31054.76	0	-0.04	0	0.07	0.14
30508.8	0	-0.05	0	0.09	0.19
29647.74	0.01	-0.05	0	0.15	0.26
29612.74	Bridge	Bridge	Bridge	Bridge	Bridge
29577.74	0.01	-0.02	0.45	0.46	0.53
29539.77	0.01	0.1	0.32	0.42	0.49
28260.15	0.01	0.12	0.27	0.4	0.46
27853.36	0.04	0.12	0.26	0.37	0.44
26593.22	0.04	0.08	0.17	0.3	0.37
25626.92	0.06	0.04	0.12	0.22	0.25
24492.31	0.08	0.11	0.26	0.2	0.22
23404.49	0.1	0.14	0.28	0.26	0.28
22318.78	0.04	0.05	0.21	0.22	0.27
20421.23	0	0	0.01	0.12	0.15
19066.92	0	0	0	-0.02	-0.02
18440.28	0.01	0	0	0	0
16944.4	0.01	0	0	0	0
14693.51	0	0	0	0	0

3. Conveyance Alternatives

As part of the alternatives analysis, restrictions to the floodplain were examined. Flow restrictions are areas that restrict the flow of water within the floodplain. These can create stage increases upstream, and for this reason, their removal to increase conveyance was examined.

Conveyance alternatives were examined using LiDAR, a hydraulic model (**Appendix D**), and structure survey (**Appendix E**). Conveyance alternatives looked at removing restrictions, while trying to avoid impacts to structures within the floodplain. Three separate conveyance alternatives were identified as part of this analysis.

3.1 Lagoon Restriction 1

The first restriction evaluated was the sanitary lagoon on the right overbank of the Knife River. Removing this feature would require its relocation to an area that would not affect water surfaces in the floodplain. **Figure 15** illustrates the location of the sanitary lagoon as well as other features located in the area. **Figure 16** illustrates the same features as **Figure 15** but the aerial photography has been replaced by a digital elevation model (DEM).

Hydraulic cross sections 24492.31 and 23404.49 were modified to examine Lagoon Restriction 1 alternative. The modification of these cross sections is illustrated in **Figures 17** and **18**. **Table 5** provides the impact of removing the sanitary lagoon from the Knife River floodplain.

An estimate of cut volume for Lagoon Restriction 1 was not included as part of this study due to uncertainty in the volume of the lagoon and appurtenant features.

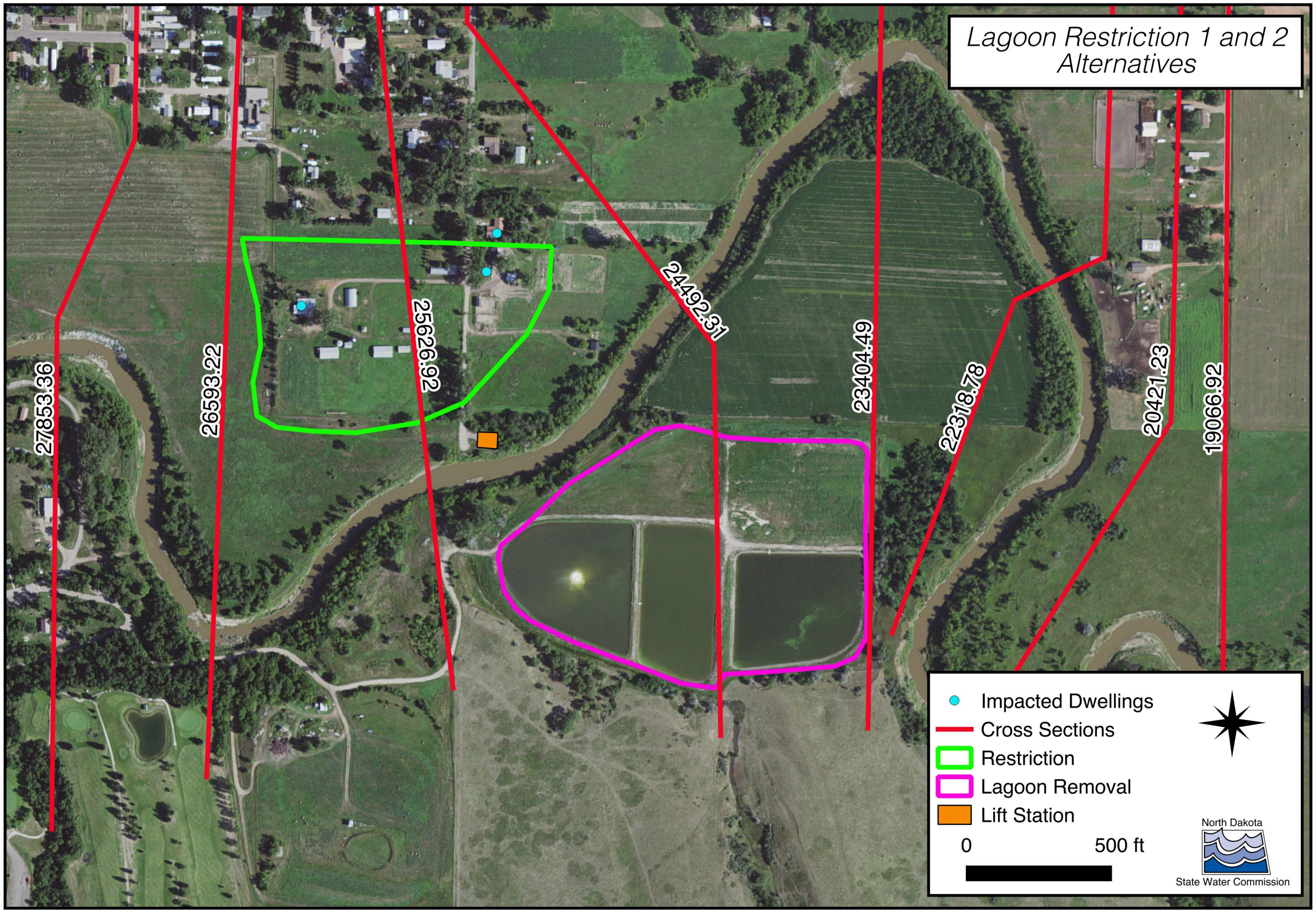

Figure 15. Location of features included in Lagoon Restriction 1 and 2 alternatives.

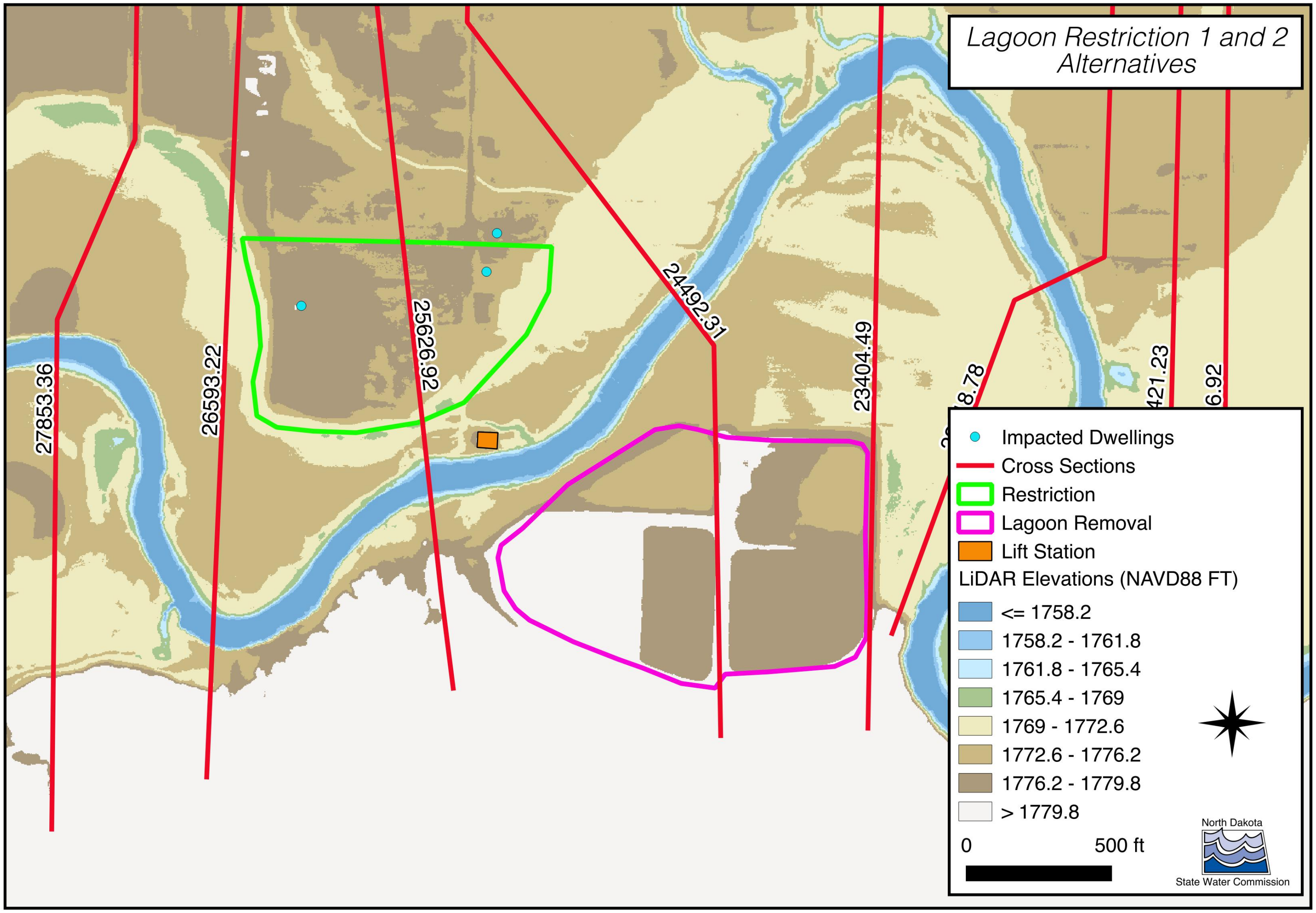

Figure 16. Topography map showing the location of features included in Lagoon Restriction 1 and 2 alternatives.

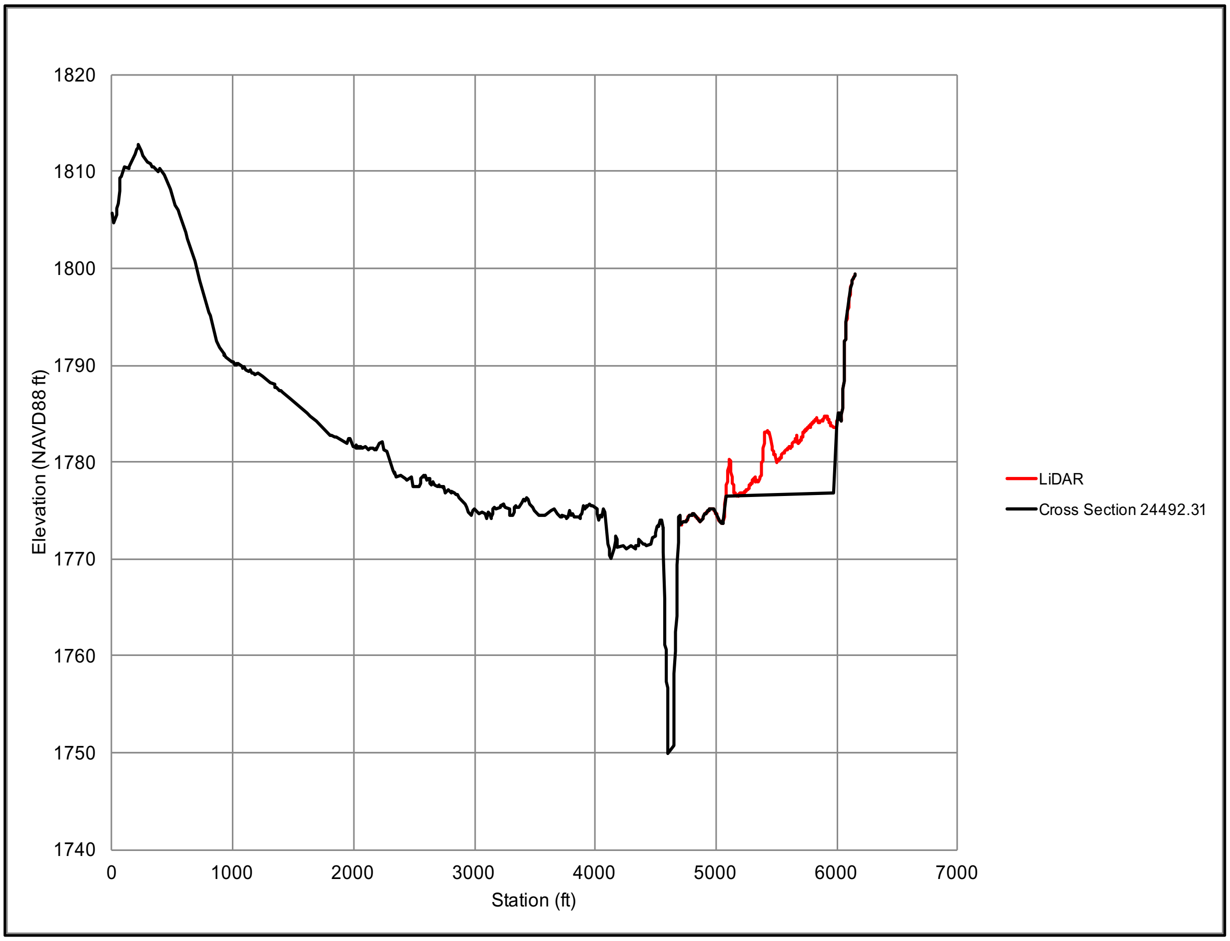

Figure 17. Modified hydraulic cross section 24492.31 for Lagoon Restriction 1 alternative.

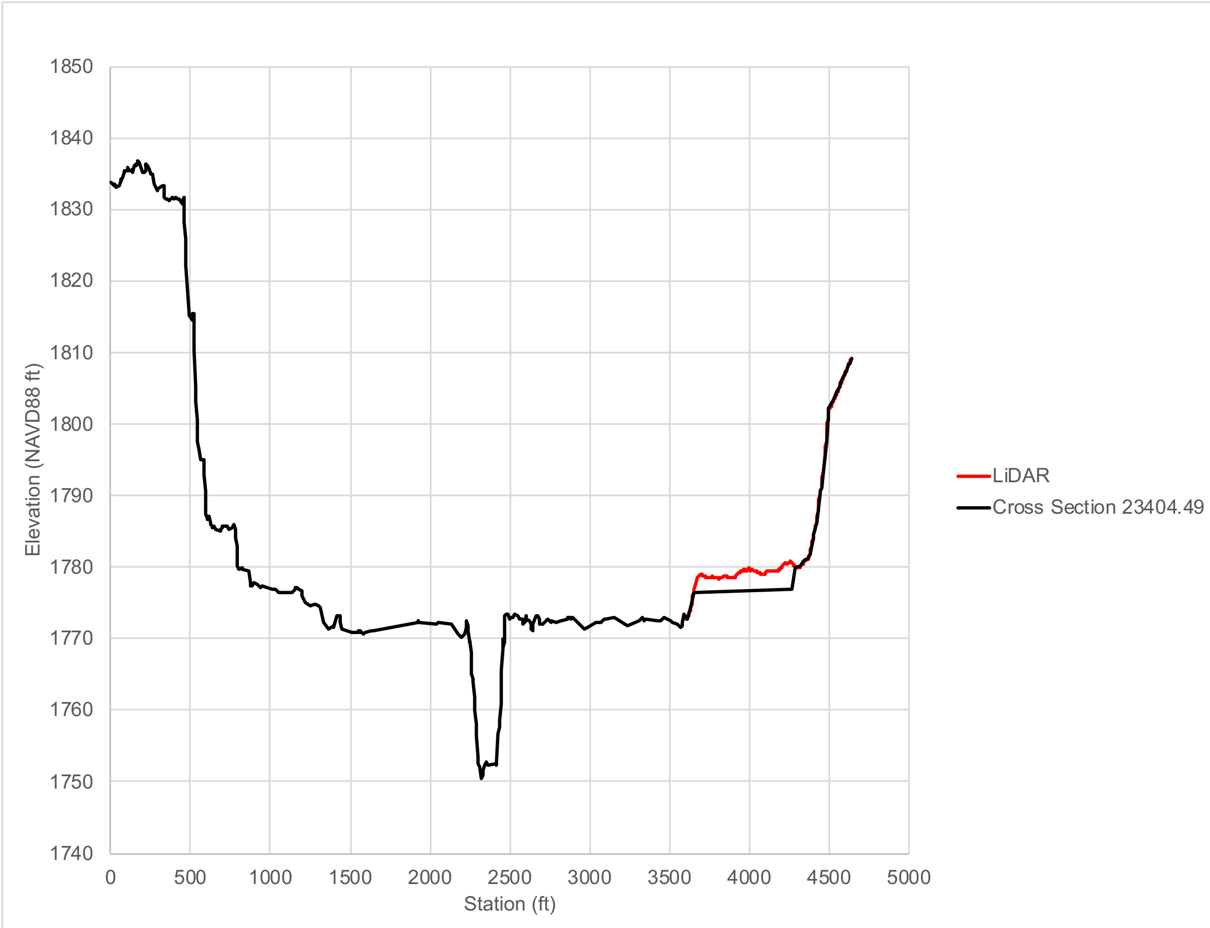

Figure 18. Modified hydraulic cross section 23404.49 for Lagoon Restriction 1 alternative.

Table 5. Water surface impacts at cross sections resulting from Lagoon Restriction 1 alternative.

Cross Section ID	50 YR (ft)	100 YR (ft)	100 YR FIS (ft)	200 YR (ft)	500 YR (ft)
32383.12	-0.01	0	0	-0.01	-0.03
31880.55	-0.01	0.01	0	0	-0.03
31222.87	-0.02	0.01	-0.01	-0.01	-0.03
31138.23	Mult Open	Mult Open	Mult Open	Mult Open	Mult Open
31054.76	-0.01	0	0	-0.01	-0.03
30508.8	-0.02	0.01	-0.01	-0.01	-0.05
29647.74	-0.03	0.02	-0.02	-0.02	-0.08
29612.74	Bridge	Bridge	Bridge	Bridge	Bridge
29577.74	-0.04	-0.03	0.02	-0.08	-0.31
29539.77	-0.03	-0.02	0.01	-0.07	-0.28
28260.15	-0.04	-0.04	-0.11	-0.1	-0.37
27853.36	-0.07	-0.04	-0.08	-0.11	-0.41
26593.22	-0.09	-0.06	-0.09	-0.13	-0.47
25626.92	-0.11	-0.14	-0.15	-0.19	-0.22
24492.31	-0.2	-0.14	-0.09	-0.17	-0.11
23404.49	-0.24	-0.2	-0.16	-0.21	-0.09
22318.78	-0.1	-0.08	-0.01	-0.07	-0.03
20421.23	-0.04	0	0	0	0

3.2 Lagoon Restriction 2

After examining the removal of the lagoon in the previous alternative, it alone was deemed to have little benefit in reducing the water surface in the City of Beulah. For this reason, the second restriction alternative evaluated includes the actions of Lagoon Restriction 1 alternative in addition to removal of a restriction on the left overbank of the Knife River just upstream of the sanitary lagoon (as illustrated in **Figures 15 and 16**). This alternative removes the entire constriction at this location of the river, which causes a greater reduction in water surface on the Knife River. This alternative also requires the relocation of a lift station (as illustrated in **Figures 15** and **16**). Three dwellings identified from the structure survey (**Appendix E**) near the restriction would also have to be moved with this alternative.

Cross sections 25626.92, 24492.31, and 23404.49 were modified to examine Lagoon Restriction 2 alternative. The modification of these cross sections is illustrated in **Figures 19, 20,** and **21**. **Table 6** provides the impact of removing the sanitary lagoon and upstream restriction from the Knife River floodplain.

A cut volume estimate was determined for removal of material as part of Lagoon Restriction 2 (**Appendix B**). The cut volume was estimated by creating cross sections for the region to be removed and using the end area method to calculate total cut. The total cut volume for Lagoon Restriction 2 alternative is approximately 145,500 cubic yards, which does not include the removal of the sanitary lagoon.

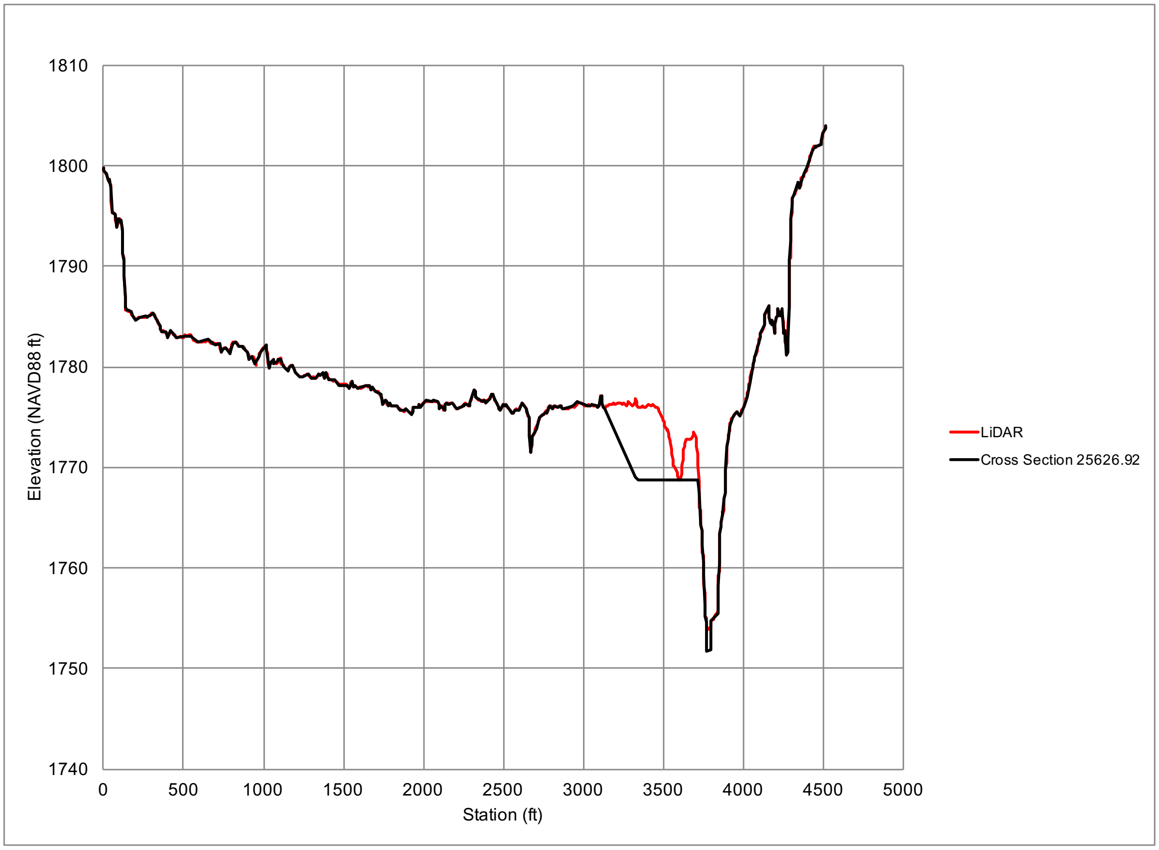

Figure 19. Modified hydraulic cross section 25626.92 for Lagoon Restriction 2 alternative.

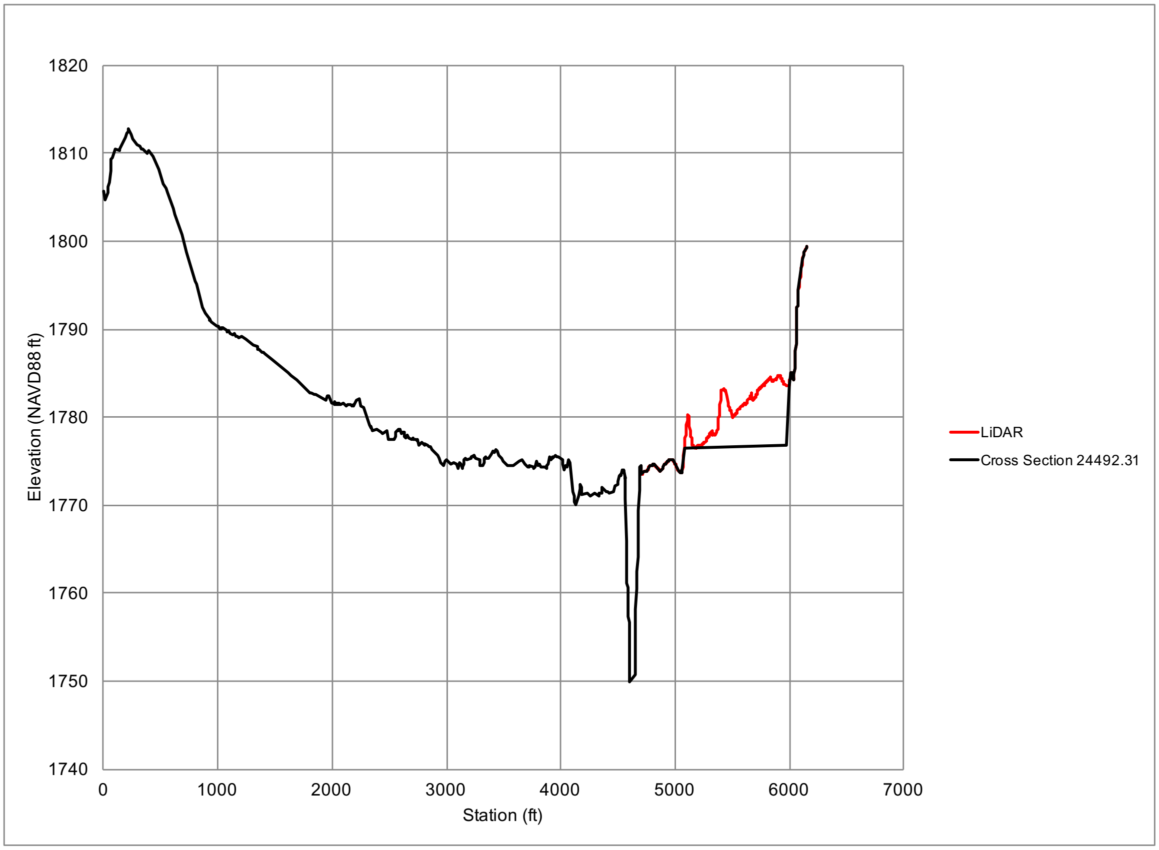

Figure 20. Modified hydraulic cross section 24492.31 for Lagoon Restriction 2 alternative.

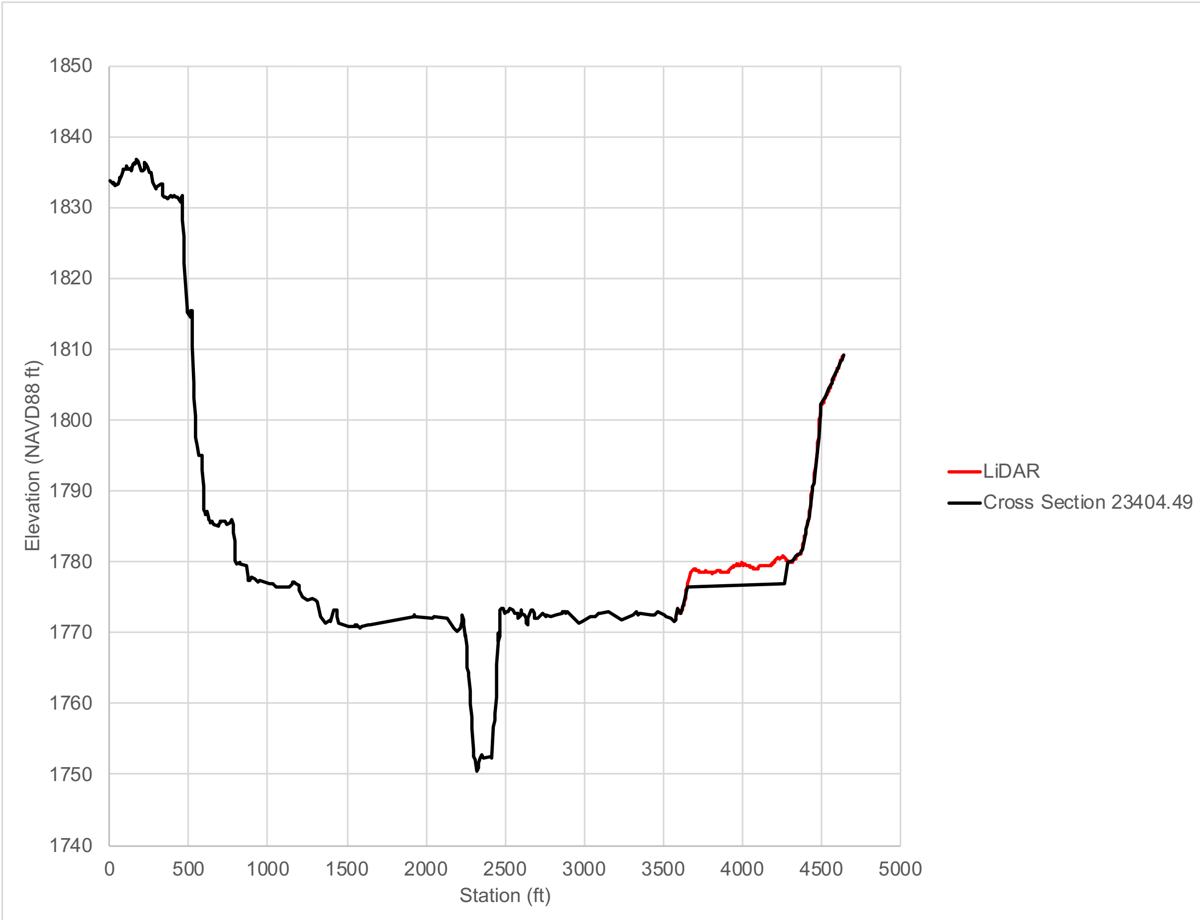

Figure 21. Modified hydraulic cross section 23404.49 for Lagoon Restriction 2 alternative.

Table 6. Water surface impacts at cross sections resulting from Lagoon Restriction 2 alternative.

Cross Section ID	50 YR (ft)	100 YR (ft)	100 YR FIS (ft)	200 YR (ft)	500 YR (ft)
32383.12	-0.02	0.03	0	-0.02	-0.03
31880.55	-0.02	0.03	0	-0.02	-0.03
31222.87	-0.13	0.03	0	-0.03	-0.03
31138.23	Mult Open	Mult Open	Mult Open	Mult Open	Mult Open
31054.76	-0.08	0.03	0	-0.02	-0.03
30508.8	-0.1	0.05	0	-0.03	-0.05
29647.74	-0.14	0.06	-0.01	-0.04	-0.08
29612.74	Bridge	Bridge	Bridge	Bridge	Bridge
29577.74	-0.31	0.02	-0.2	-0.14	-0.31
29539.77	-0.21	-0.12	-0.13	-0.14	-0.28
28260.15	-0.29	-0.23	-0.3	-0.36	-0.37
27853.36	-0.38	-0.31	-0.29	-0.4	-0.41
26593.22	-0.47	-0.44	-0.55	-0.47	-0.47
25626.92	-0.1	-0.13	-0.16	-0.23	-0.22
24492.31	-0.2	-0.14	-0.09	-0.18	-0.11
23404.49	-0.24	-0.2	-0.16	-0.21	-0.09
22318.78	-0.1	-0.08	-0.01	-0.07	-0.03
20421.23	-0.04	0	0	0	0

3.3 County Road 20 Restriction

The third restriction alternative evaluated was removal of a restriction just downstream of the County Road 20 Bridge. **Figure 22** illustrates the location of the restriction as well as other features located in the area. **Figure 23** illustrates the same features as **Figure 22** but the aerial photography has been replaced by a DEM.

Cross sections 1257.684 and 541.9682 were modified to examine this alternative, as illustrated in **Figures 24** and **25**. **Table 7** provides the impact of removing the restriction.

A cut volume estimate was determined for removal of material as part of this alternative (**Appendix B**). The cut volume was estimated by creating cross sections for the region to be removed and using the end area method to calculate total cut. The total volume for the County Road 20 Restriction Alternative is approximately 263,000 cubic yards.

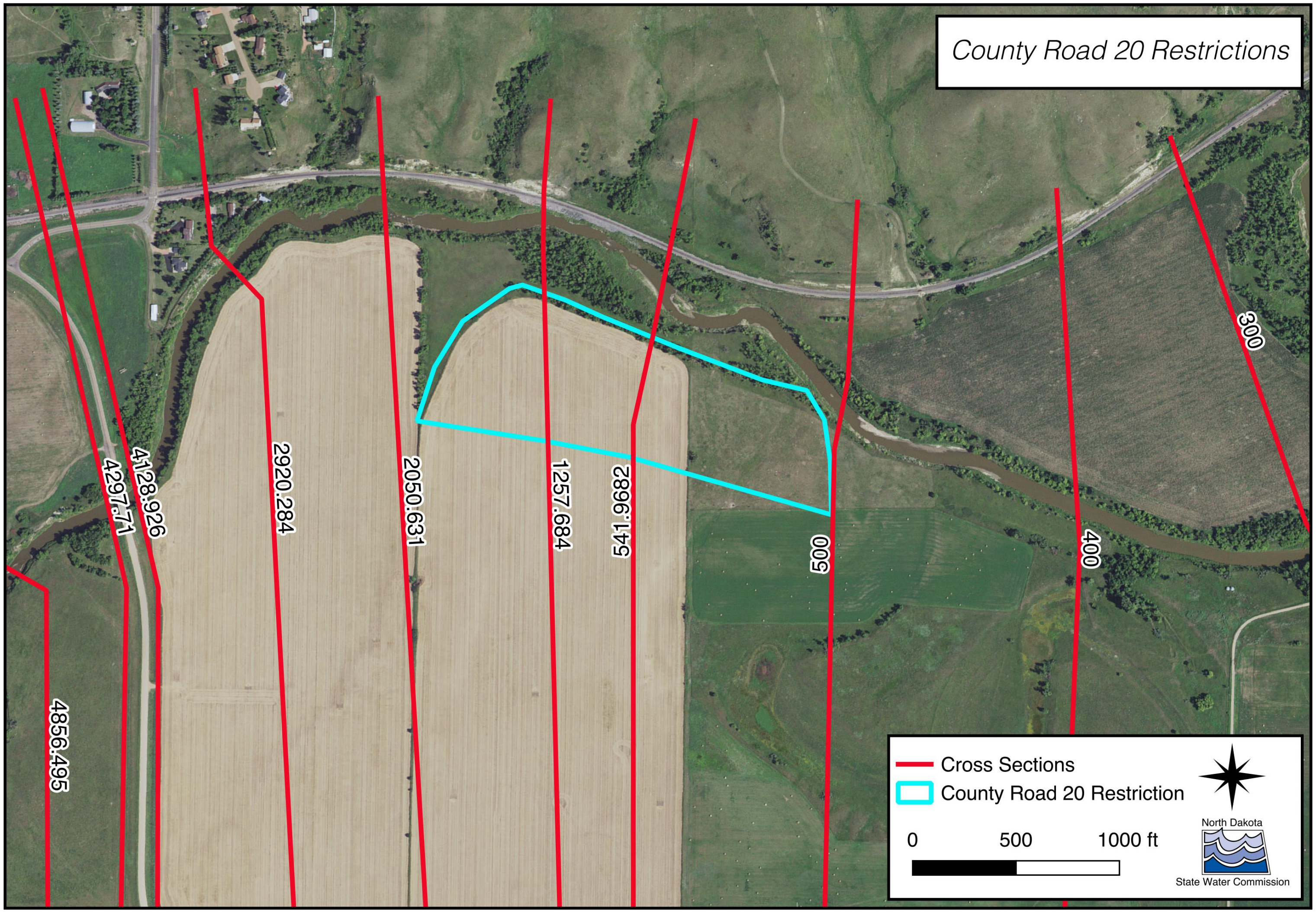

Figure 22. Location of features included in County Road 20 Restriction alternative.

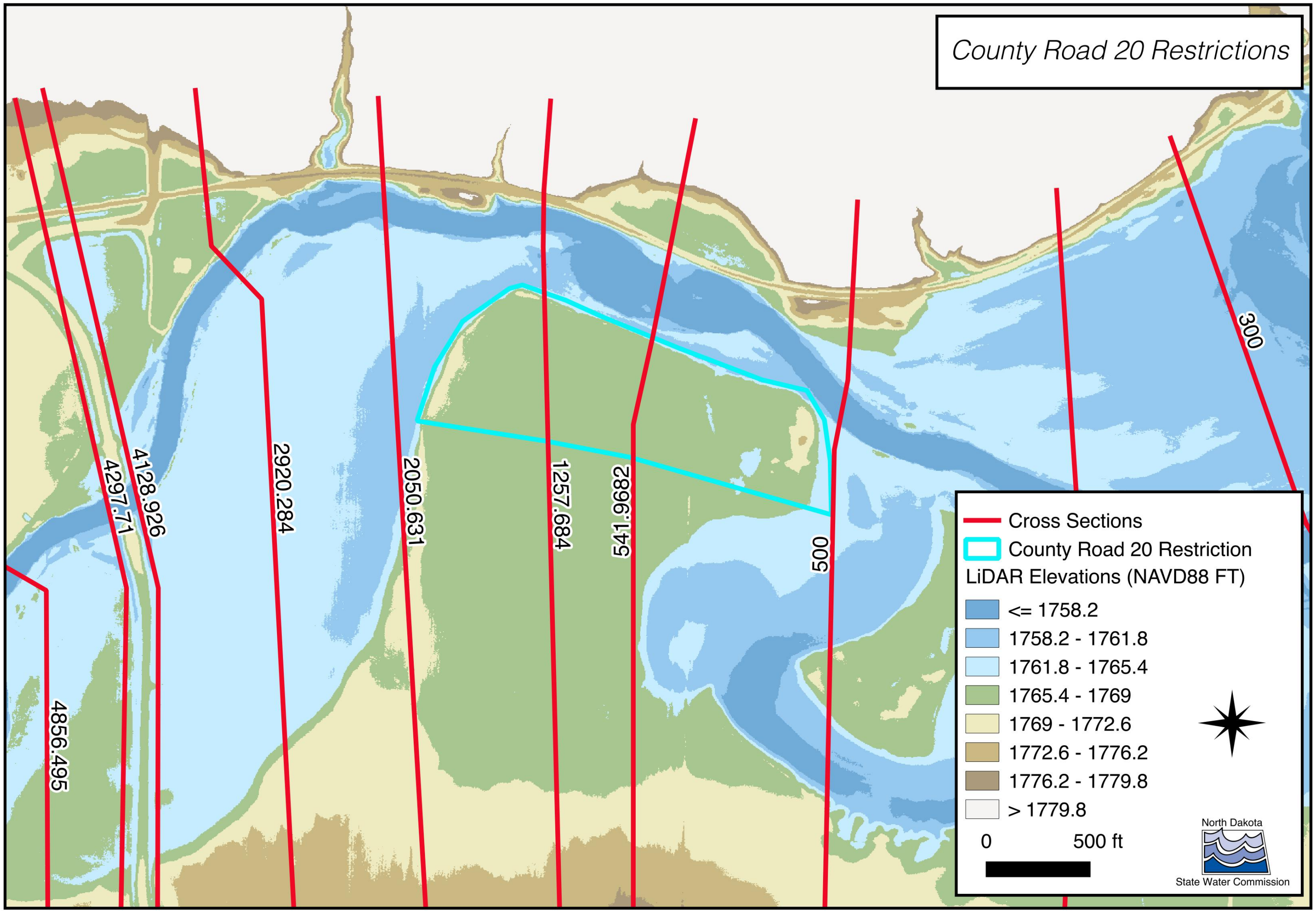

Figure 23. Topography map showing the locations of features included in County Road 20 Restriction alternative.

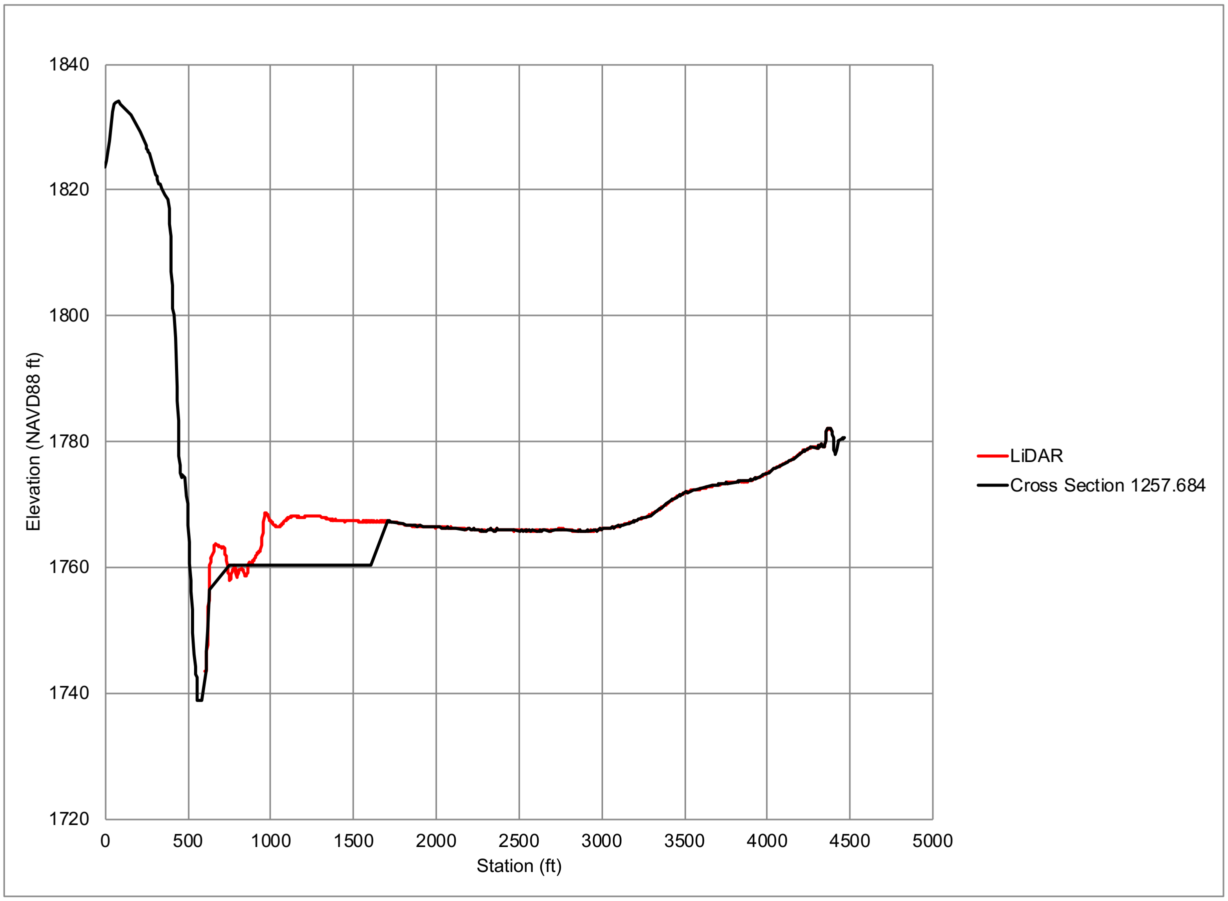

Figure 24. Modified hydraulic cross section 1257.684 for County Road 20 Restriction alternative.

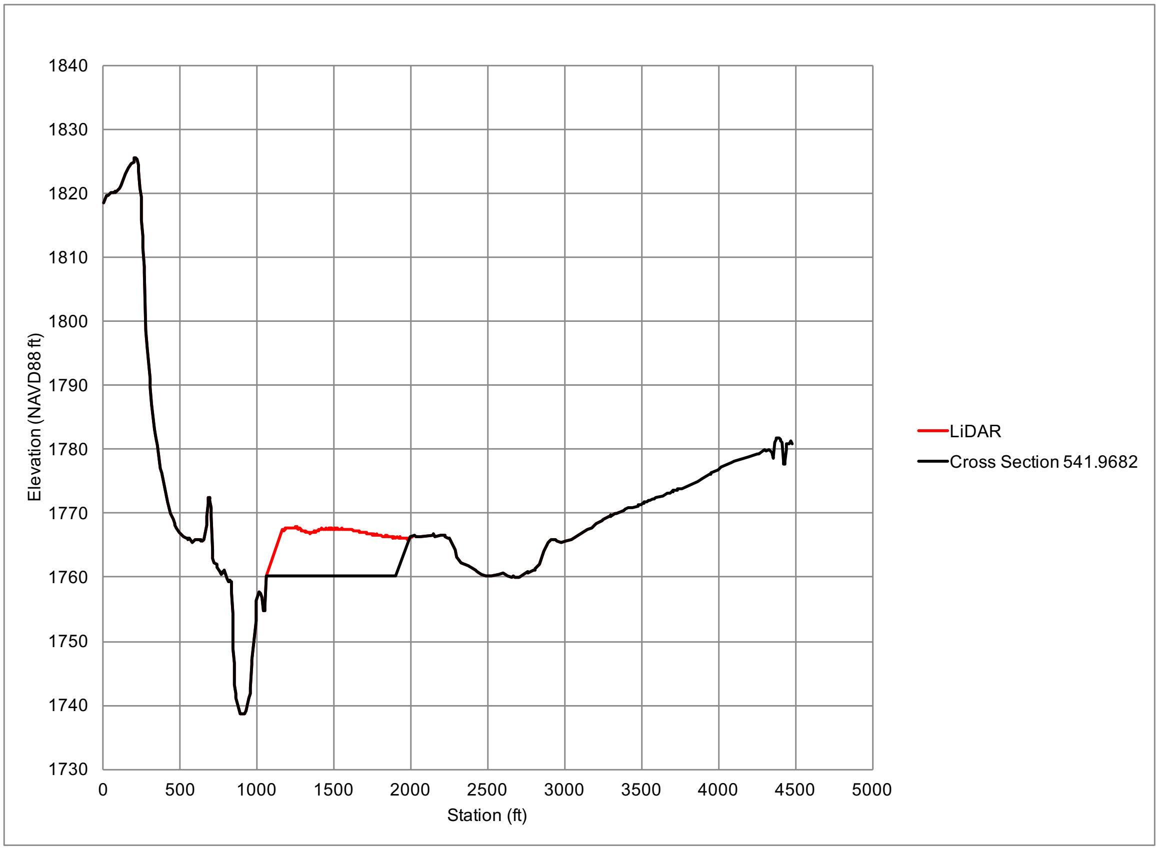

Figure 25. Modified hydraulic cross section 541.9682 for County Road 20 Restriction alternative.

Table 7. Water surface impacts at cross sections resulting from County Road 20 Restriction alternative.

Cross Section ID	50 YR (ft)	100 YR (ft)	100 YR FIS (ft)	200 YR (ft)	500 YR (ft)
29539.77	0	0	0	0	0
28260.15	0	0	-0.01	0	0
27853.36	-0.01	0	-0.01	0	0
26593.22	-0.01	0	0	0	0
25626.92	-0.01	0	-0.01	-0.01	0
24492.31	-0.02	0.01	-0.02	-0.01	0
23404.49	-0.02	0	-0.02	-0.02	0
22318.78	-0.03	0.01	-0.02	-0.01	0
20421.23	-0.06	0.01	-0.03	-0.03	0
19066.92	-0.09	0.02	-0.05	-0.06	-0.01
18440.28	-0.09	0.03	-0.05	-0.05	-0.01
16944.4	-0.11	0.04	-0.06	-0.07	0
14693.51	-0.15	0.05	-0.07	-0.08	0
13282.79	-0.19	0.06	-0.08	-0.1	-0.01
11325.5	-0.25	0.1	-0.11	-0.13	-0.01
9883.518	-0.28	0.11	-0.12	-0.15	0.09
8150.489	-0.32	0.11	-0.16	-0.2	-0.06
7320.521	-0.36	0.09	-0.17	-0.22	-0.08
4856.495	-0.88	-0.76	-0.34	-0.32	-0.17
4297.71	-1.12	-0.92	-0.36	-0.42	-0.19
4220.677	Mult Open	Mult Open	Mult Open	Mult Open	Mult Open
4128.926	-0.55	-0.77	-0.44	-0.42	-0.2
2920.284	-0.81	-1.03	-0.59	-0.56	-0.45
2050.631	-0.8	-1.02	-0.61	-0.64	-0.57
1257.684	-0.2	-0.24	-0.06	-0.19	-0.22
541.9682	-0.07	-0.01	0.11	0.05	0.02
500	0.07	0.02	0.01	0.03	0
400	0.04	0	0.01	0.03	0
300	0.06	0	0.02	0.02	0
200	0.12	0	0.03	0.04	0
100	0.19	0.09	0.06	0.05	0
95	0.44	0.52	0.25	0.35	0.16
94	Lat Struct	Lat Struct	Lat Struct	Lat Struct	Lat Struct
90	0.8	1.05	1.43	0.66	0.3
87	Lat Struct	Lat Struct	Lat Struct	Lat Struct	Lat Struct
85	0.68	1.69	1.45	1.14	0.17
80	0.32	0.7	0.29	0.42	0.07
77	Lat Struct	Lat Struct	Lat Struct	Lat Struct	Lat Struct
75	0.02	0.05	0.08	0.17	0.04
70	-0.02	-0.04	0	0.03	0.01
65	-0.02	-0.04	0	0.03	0.01
60	-0.02	-0.04	0	0.04	0.01

4. Overflow Conveyance Channel Alternatives

As part of the alternatives analysis, potential overflow conveyance channel alternatives were examined using LiDAR and a hydraulic model (**Appendix D**) developed as part of this study. The overflow channels were roughly estimated in the hydraulic model by editing the cross-section geometry. This approach allows for the total modeled conveyance of the overflow channel to be calculated, but the correct flow path length is not captured in the hydraulic model. In order to correctly model the effects of an overflow channel, a two-dimensional hydraulic model would need to be created; however, the cost and time necessary to adequately model the conveyance channels were deemed to be too great compared to the benefits that would be gained. For this reason the methodology utilized was selected to complete the study. Overbank roughness coefficients were kept the same as the existing conditions model because it was assumed that the overflow channel would maintain normal land use when it is not operating.

One overflow conveyance channel alignment was examined with two separate trapezoidal channel sizes. Each channel size was evaluated as a separate alternative. **Figure 26** illustrates the channel invert profile for both alternatives and **Figure 27** illustrates the alignment centerline used for each alternative. Overflow Conveyance Channel 1 and 2 alternatives (OC1 and OC2) were simulated as 30-ft and 200-ft bottom width trapezoidal channels, respectively. Inverts for the overflow channel were selected so that the channel would begin operation at approximately the 2-year event, in order to optimize the channel's benefits. **Table 8** provides a summary of each alternative. Cut volumes for each alternative were determined by assuming the pre-construction centerline profile elevation of the alignment was the top of bank elevation for each side of the trapezoidal channel. Based on the floodplain geometry in this area, it was assumed to be an appropriate assumption for preliminary earthwork volumes.

Figures 28 and **29** illustrate the footprint of OC1 and OC2, while **Tables 9** and **10** provide the modeled water surface impacts resulting from each alternative.

Table 8. Summary of overflow conveyance channel alternatives.

Alternative	Bottom Width (ft)	Side Slope	Upstream Invert (NAVD88 ft)	Downstream Invert (NAVD88 ft)	Total Volume (cu yd)
OC1	30	1:10	1,765.00	1,755.00	125,000
OC2	200	1:10	1,765.00	1,755.00	465,000

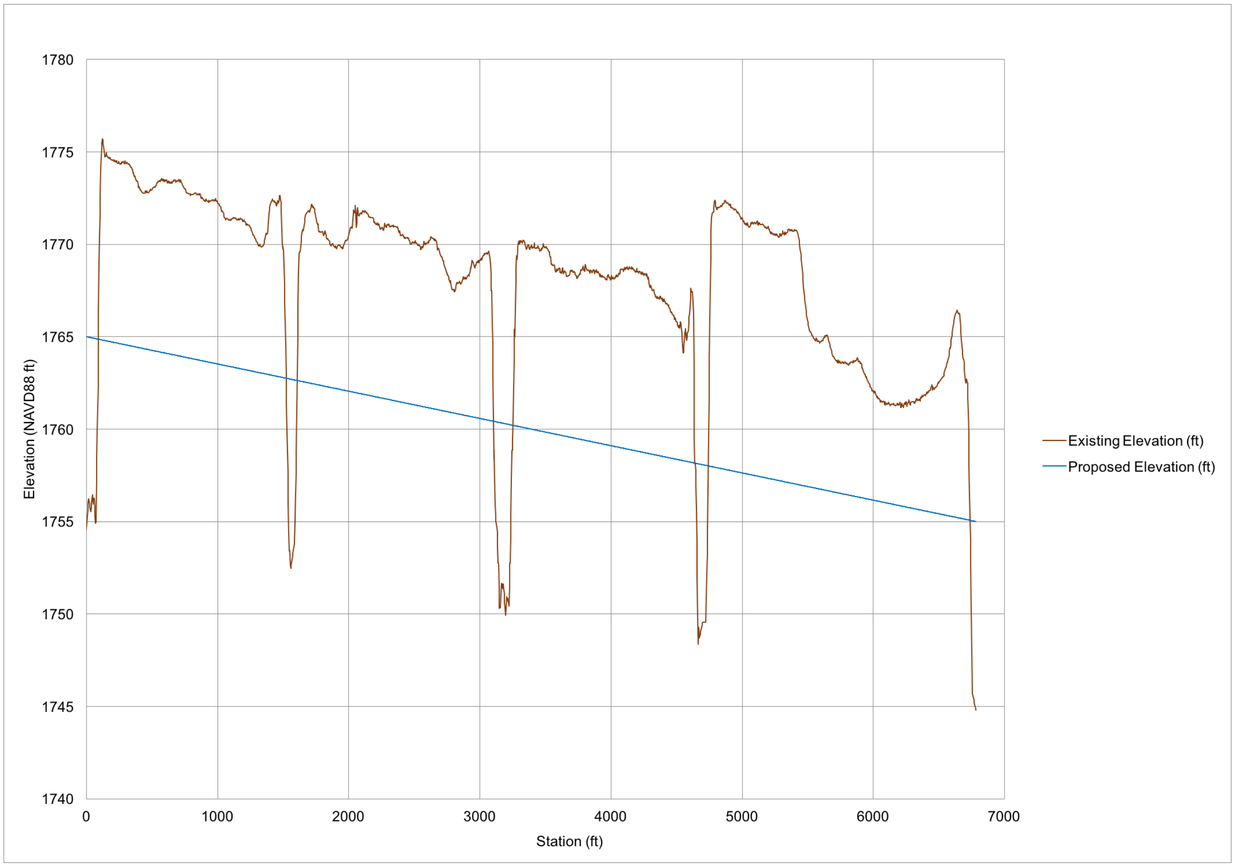

Figure 26. Channel invert profile for both overflow conveyance channel alternatives.

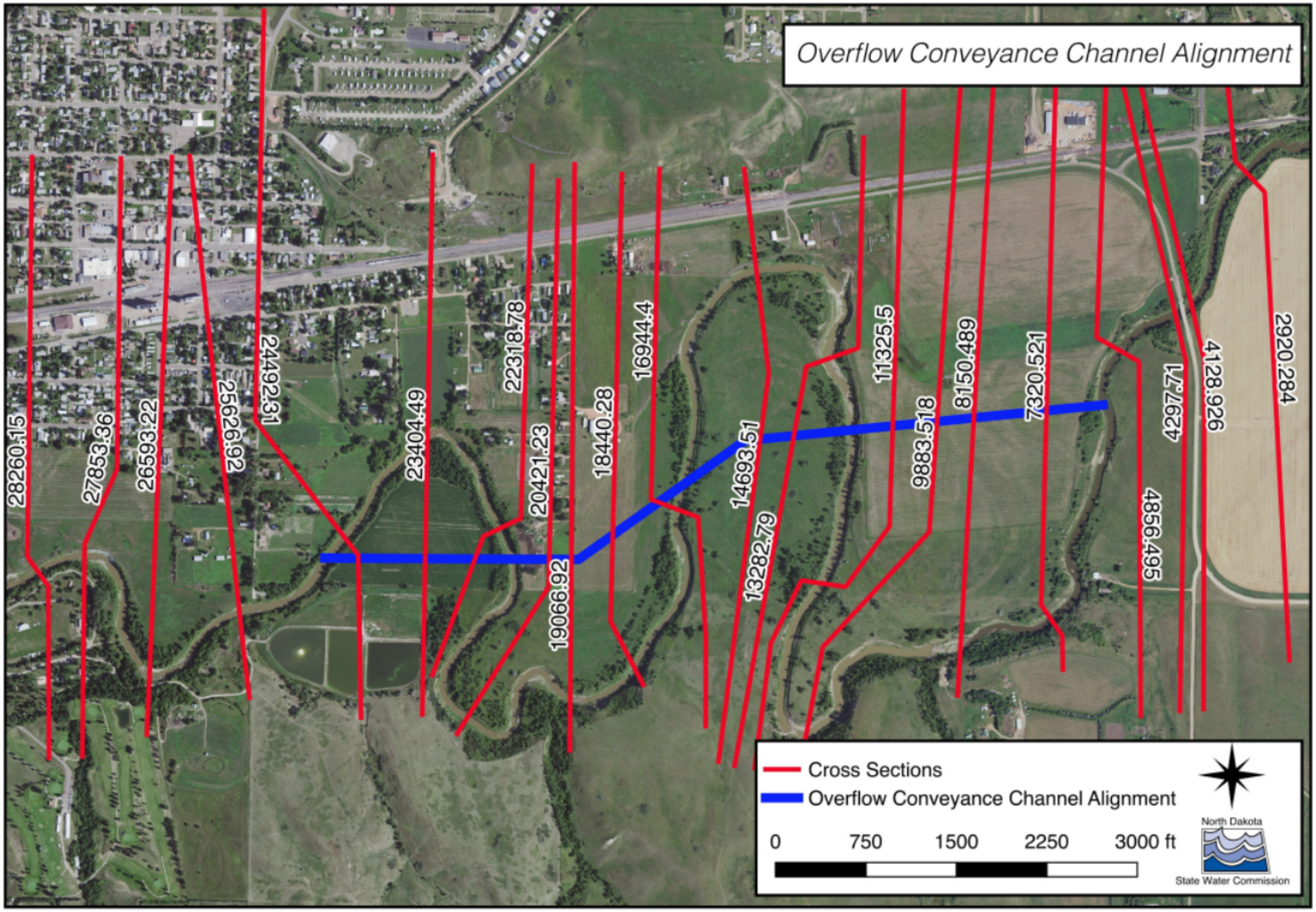

Figure 27. Centerline alignment for both overflow conveyance channel alternatives.

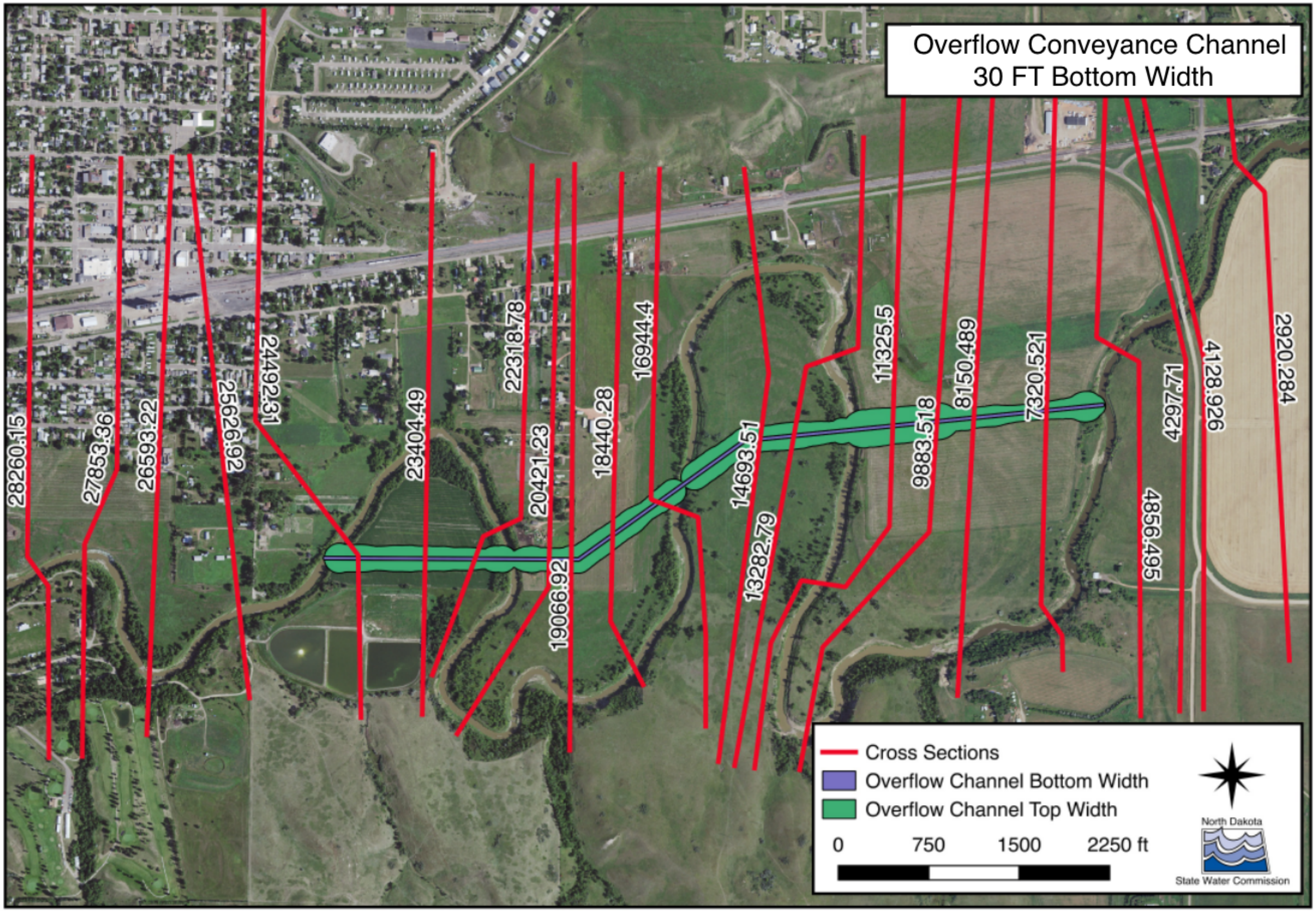

Figure 28. Footprint of OC1.

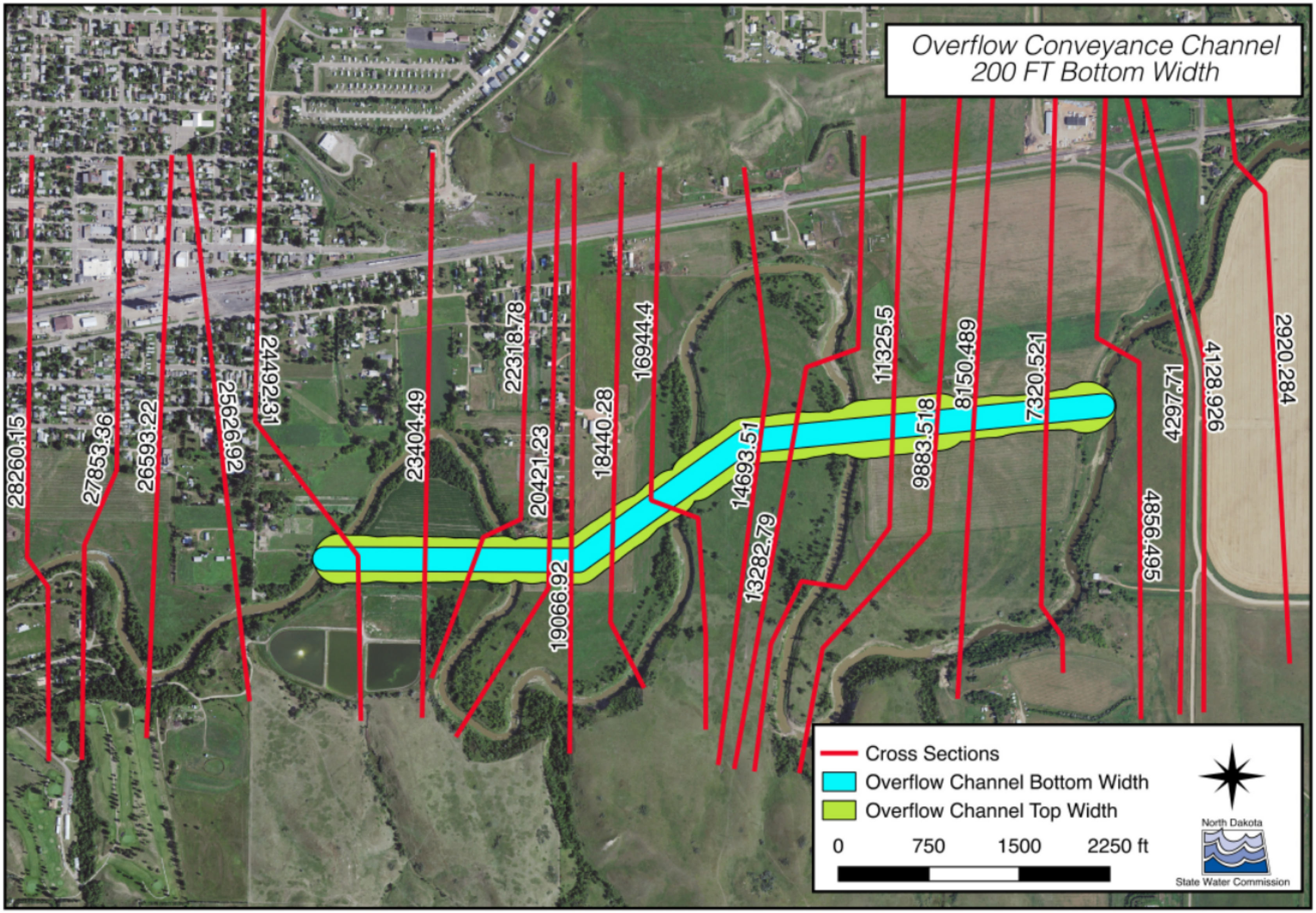

Figure 29. Footprint of OC2.

Table 9. Water surface impacts at cross sections resulting from OC1.

Cross Section ID	50 YR (ft)	100 YR (ft)	100 YR FIS (ft)	200 YR (ft)	500 YR (ft)
32383.12	-0.01	0.02	0	-0.02	-0.02
31880.55	-0.01	0.03	0	-0.01	-0.02
31222.87	-0.13	0.03	0.01	-0.02	-0.02
31138.23	Mult Open	Mult Open	Mult Open	Mult Open	Mult Open
31054.76	-0.07	0.03	0.01	-0.02	-0.02
30508.8	-0.09	0.03	0.01	-0.02	-0.03
29647.74	-0.12	0.05	0.03	-0.04	-0.05
29612.74	Bridge	Bridge	Bridge	Bridge	Bridge
29577.74	-0.27	0	-0.05	-0.14	-0.18
29539.77	-0.18	-0.1	-0.03	-0.14	-0.16
28260.15	-0.25	-0.17	-0.04	-0.18	-0.21
27853.36	-0.33	-0.22	-0.05	-0.2	-0.23
26593.22	-0.41	-0.3	-0.26	-0.24	-0.26
25626.92	-0.53	-0.58	-1.05	-0.38	-0.39
24492.31	-0.37	-0.42	-0.58	-0.29	-0.27
23404.49	-0.44	-0.49	-0.6	-0.29	-0.25
22318.78	-0.55	-0.55	-0.63	-0.28	-0.33
20421.23	-0.71	-0.63	-0.43	-0.48	-0.43
19066.92	-0.72	-0.61	-0.25	-0.68	-0.5
18440.28	-0.76	-0.63	-0.25	-0.7	-0.52
16944.4	-0.87	-0.68	-0.27	-0.78	-0.55
14693.51	-1.04	-0.82	-0.26	-0.86	-0.58
13282.79	-1.16	-0.95	-0.18	-1.01	-0.63
11325.5	-0.86	-0.88	-0.12	-1.17	-0.65
9883.518	-0.88	-0.84	-0.12	-1.12	-0.44
8150.489	-0.6	-0.37	-0.02	-0.33	-0.24
7320.521	-0.48	-0.29	-0.02	-0.29	-0.15
4856.495	-0.47	0	0	0.01	-0.01
4297.71	-0.57	0	0	0	-0.01
4220.677	Mult Open	Mult Open	Mult Open	Mult Open	Mult Open
4128.926	0	-0.01	0	0.01	-0.01
2920.284	-0.01	0	0	0.01	-0.01
2050.631	-0.01	0	0	0.01	-0.01
1257.684	0	0	0	0.01	0
541.9682	0	0	0	0	0
500	0	0	0	0.01	0
400	0	0	0	0.01	0
300	0	0	0	0	-0.01
200	0	0	0	0	0
100	0	0	0	0	0
95	-0.01	0	0	0.01	-0.01
94	Lat Struct	Lat Struct	Lat Struct	Lat Struct	Lat Struct
90	0	0	0	0.01	0
87	Lat Struct	Lat Struct	Lat Struct	Lat Struct	Lat Struct
85	0	0	0	0.01	0
80	0	0	0	0	0
77	Lat Struct	Lat Struct	Lat Struct	Lat Struct	Lat Struct
75	0	0	0	0.01	-0.01
70	0	0	0	0	-0.01
65	-0.01	0	0	0	-0.01
60	0	0	0	0.01	-0.01

Table 10. Water surface impacts at cross sections resulting from OC2.

Cross Section ID	50 YR (ft)	100 YR (ft)	100 YR FIS (ft)	200 YR (ft)	500 YR (ft)
32383.12	-0.09	0.04	0	-0.02	-0.03
31880.55	-0.1	0.04	0	-0.02	-0.03
31222.87	-0.2	0.04	0	-0.02	-0.04
31138.23	Mult Open	Mult Open	Mult Open	Mult Open	Mult Open
31054.76	-0.16	0.05	0.01	-0.03	-0.04
30508.8	-0.21	0.06	0	-0.03	-0.06
29647.74	-0.33	0.09	0	-0.04	-0.09
29612.74	Bridge	Bridge	Bridge	Bridge	Bridge
29577.74	-0.7	0.11	-0.19	-0.15	-0.37
29539.77	-0.44	-0.15	-0.12	-0.14	-0.34
28260.15	-0.68	-0.43	-0.29	-0.26	-0.44
27853.36	-0.88	-0.66	-0.28	-0.32	-0.49
26593.22	-1.14	-0.89	-0.54	-0.39	-0.57
25626.92	-1.53	-1.55	-1.48	-0.92	-0.92
24492.31	-1.19	-1.2	-0.65	-0.77	-0.75
23404.49	-1.08	-1.09	-0.79	-0.6	-0.54
22318.78	-1.18	-1.18	-0.78	-0.57	-0.6
20421.23	-1.14	-1.11	-1.07	-0.73	-0.67
19066.92	-1.02	-0.92	-0.79	-0.87	-0.7
18440.28	-1.04	-0.91	-0.97	-0.88	-0.7
16944.4	-1.18	-0.97	-1.05	-0.95	-0.72
14693.51	-1.3	-1.06	-1.12	-1.01	-0.73
13282.79	-1.32	-1.1	-1.21	-1.09	-0.72
11325.5	-1.04	-1.01	-1.38	-1.27	-0.74
9883.518	-1	-0.93	-1.34	-1.21	-0.53
8150.489	-0.62	-0.4	-0.48	-0.35	-0.26
7320.521	-0.5	-0.31	-0.35	-0.3	-0.17
4856.495	-0.47	0	0	0.01	-0.01
4297.71	-0.57	-0.01	0	0	-0.01
4220.677	Mult Open	Mult Open	Mult Open	Mult Open	Mult Open
4128.926	-0.01	-0.01	0	0.01	-0.01
2920.284	-0.01	0	0	0	-0.01
2050.631	-0.01	-0.01	0	0	-0.01
1257.684	-0.01	0	0	0.01	0
541.9682	-0.01	0	0	0	0
500	-0.01	-0.01	0	0	0
400	-0.01	0	0	0	-0.01
300	0	0	0	0	-0.01
200	-0.01	0	0	0	-0.01
100	-0.01	0	0	0	0
95	-0.01	0	0	0	-0.01
94	Lat Struct	Lat Struct	Lat Struct	Lat Struct	Lat Struct
90	0	0	0	0	0
87	Lat Struct	Lat Struct	Lat Struct	Lat Struct	Lat Struct
85	0	0	0	0	0
80	0	0	0	-0.01	-0.01
77	Lat Struct	Lat Struct	Lat Struct	Lat Struct	Lat Struct
75	-0.01	0	0	0	-0.01
70	-0.01	0	0	-0.01	-0.01
65	-0.01	-0.01	0	-0.01	-0.01
60	-0.01	0	0	0	-0.01

5. Summary

Alternatives for protecting the City of Beulah from the impacts of Knife River flooding were evaluated as part of this study. Alternatives included a series of levee options, removal of restrictions to increase conveyance, and creation of overflow conveyance channels. Alternatives were evaluated using a series of synthetic flow events created as part of this study.

This report provides preliminary options for the community and District to consider to reduce or prevent flood damage within the City of Beulah. This interim report contains hydraulic information that will be used by the Omaha District to screen alternatives. A future report prepared by the Omaha District will detail the cost/benefit evaluation of alternatives to determine feasibility.

6. References

Korkowski. West Tributary, Preliminary Findings Report. North Dakota State Water Commission, 2017.