Fargo, ND | HEI No. 8150-0002
May 3, 2023

May 22, 2013 – Cart Creek at Crystal, ND Looking Southeast

NORTH BRANCH PARK RIVER WATERSHED PLAN: APPENDIX D-3

Cart Creek Site 1 Concept Design Report

NORTH BRANCH PARK RIVER WATERSHED PLAN

CART CREEK SITE 1 CONCEPT DESIGN REPORT

May 3, 2023

Park River Joint Water Resource District

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I hereby certify that this plan, specification, or report was prepared by me or under my direct supervision, and that I am a duly Licensed Engineer under the laws of the State of North Dakota.

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Date	Date

TABLE OF CONTENTS

TABLES

FIGURES

APPENDICES

1 DATA SUMMARY

Table 1: Cart Creek Site 1 Summary Table

General Data		
Purpose	Flood Control	
Hazard Classification	High Hazard	
Drainage Area	33.8 square miles	
Dam Height (Average)	9.7 feet	
Maximum Dam Height	17.3 feet	
Embankment Length	13,740 feet	
Embankment Top Width	10 feet	
Embankment Upstream Slope	4H:1V	
Embankment Downstream Slope	4H:1V	
Critical Elevations (NAVD88)		
Principal Spillway Low Flow Culvert Invert	966.0 feet	
Principal Spillway Riser Tower Crest	975.7 feet	
Auxiliary Spillway Crest	979.8 feet	
Top of Dam	983.2 feet	
Storage Capacities	**Volume**	**Surface Area**
Principal Spillway Riser Tower Crest	1,054 acre-feet	291 acres
Auxiliary Spillway Crest	2,593 acre-feet	466 acres
Top of Dam	4,412 acre-feet	599 acres
Other Features		
Principal Spillway Low Flow Culvert	36-inch RCP	
Principal Spillway Riser Tower Width	10 feet	
Principal Spillway Riser Tower Length	24 feet	
Principal Spillway Riser Tower Weir Crest Length	48 feet	
Principal Spillway Outlet Conduit	10 feet wide x 9 feet high RCBC	
Auxiliary Spillway Total Width (including bays)	870 feet	
Auxiliary Spillway Flow Width	800 feet	

Cart Creek Site 1 Elevation Summary	Elevation (feet) (NAVD88)	Storage Volume (acre-feet)	Surface Area (acres)
Principal Spillway Low Flow Culvert Invert	966.00	0	0
2-year	972.23	293	152
5-year	973.96	609	215
10-year	975.59	1,020	287
Principal Spillway Riser Tower Crest	975.70	1,054	291
25-year	977.24	1,543	349
50-year	978.31	1,942	399
100-year	979.30	2,359	444
Auxiliary Spillway Crest	979.80	2,593	466
500-year	980.72	3,032	504
Stability Design Hydrograph	980.91	3,137	514
Freeboard Hydrograph	983.12	4,364	596
Top of Dam	983.20	4,412	599

2 BACKGROUND

The Park River Joint Water Resource District (PRJWRD) is completing a Watershed Plan through the Regional Conservation Partnership Program (RCPP) for the North Branch of the Park River. Part of the watershed planning process includes developing existing conditions modeling, screening of potential alternatives, and a detailed concept design of the preferred alternative. The development of existing conditions models is described in the *North Branch Park River Watershed Plan – Existing Conditions Hydrology and Hydraulics Report* (Houston Engineering, Inc., 2020).

Various flood reduction strategies were evaluated for the North Branch of the Park River (North Branch) Watershed. The screening of strategies and alternatives is described in the *North Branch Park River Watershed Plan – Screening of Alternatives for Detailed Review* (Houston Engineering, Inc., 2020). Flood reduction strategies and alternatives were screened based on technical data, practicality to implement, and their ability to satisfy the Purpose of the Watershed Plan.

Based on the screening of alternatives and local stakeholder input, one alternative has been identified as a potential project. The project concept defined within this report is a modification to Cart Creek Impoundment Site 1 presented in the *Screening of Alternatives Report*. The project concept herein is referred to as Cart Creek Site 1.

Cart Creek Site 1 is an off-channel impoundment site designed to store floodwaters from the Cart Creek subwatershed of the North Branch of the Park River Watershed. The project location, characteristics, dam hazard classification, site design, performance, and estimated project cost are described in the following sections of this report.

2.1 VERTICAL DATUM

All elevations within this report are in reference to North American Vertical Datum of 1988 (NAVD88).

3 SITE LOCATION

The proposed Cart Creek Site 1 is an off-channel impoundment constructed of an earthen embankment located within Section 24 of Thingvalla Township, Pembina County, North Dakota. The impoundment site is approximately 2.5 miles east and 1 mile south of Mountain, ND, and approximately 8 miles northwest of Crystal, ND. The impoundment location is shown on **Figure C-18** in **Appendix C**.

The impoundment site is approximately 1 mile upstream of the confluence of Cart Creek and Pembina County Drain 28. The contributing drainage area to the site is 33.8 square miles and is shown on **Figure C-18**. The Cart Creek Site 1 drainage area is approximately 13% of the 257 square mile Cart Creek subwatershed. The western portion of the contributing area consists of mostly agricultural land above the beach ridge. As flows move easterly, they are collected in valleys and ravines along the steep slopes of the beach ridge. The beach ridge then transitions to the Lake Agassiz lake plain which is characterized by flat slopes and a predominant agricultural land use. Near the impoundment location, the majority of the upstream drainage area flows through either Cart Creek or Pembina County Drain 28. Inlet channels will be constructed to divert floodwaters into the site from these two watercourses.

The drainage area to the site is predominantly agricultural land with a small amount of forested land. The Cart Creek Site 1 flood pool contains acreage enrolled in the Farm Service Agency (FSA) Conservation Reserve Program (CRP) as well as the NRCS Wetland Reserve Program (WRP).

4 FIELD INVESTIGATION

4.1 FIELD SURVEY

Field survey data was collected by HEI in the spring of 2014 as part of a planning effort that was underway prior to the North Branch Watershed Plan. Topographic field survey data was collected to aid in the development of an existing conditions hydraulic model. Data that was collected consisted of river channel hydraulic structures, river channel cross sections near hydraulic structures, and various culverts and bridges in the floodplain that convey breakout waters during large events. Additional information on the field survey data can be found in the *Existing Conditions Hydrology and Hydraulics Report* (Houston Engineering, Inc., 2020).

LiDAR topographic data made available through the International Water Institute (IWI, 2008-2009) was used to supplement the field survey data. The LiDAR data was collected in 2008 and 2009.

4.2 GEOTECHNICAL EVALUATION

A preliminary geotechnical evaluation was completed by Braun Intertec Corporation for Cart Creek Site 1. The evaluation was completed to characterize subsurface conditions and to determine their impact on the design of the impoundment. The evaluation included four standard penetration test borings, laboratory testing on select soil samples, and an analysis on the stability and seepage characteristics of the embankment design. The geotechnical evaluation report is provided in **Appendix D-9**.

5 SITE CHARACTERISTICS

Cart Creek Site 1 is an off-channel impoundment with an earthen embankment. Floodwaters are diverted into the site via two ungated inlet structures. The outlet consists of a low flow pipe, principal spillway riser tower, and an earthen auxiliary spillway. A site map is available in **Figure B-1**. All constructed components have been located to avoid impacts to the adjacent WRP easement. Preliminary site plans are shown in **Attachment D-3-A**. The following sub-sections describe the individual project components, and reference sections of the preliminary plans provided in **Attachment D-3-A**.

5.1 INLET COMPONENTS

There are three locations where floodwaters enter the site; direct drainage to the site, the north inlet, and the south inlet. The site consists of an embankment on the north, east, and south sides. This allows the direct drainage area to the west to flow freely into the site.

The north inlet is located along the south bank of Cart Creek downstream of the crossing with 131st Avenue NE. A crossing with a 73” x 45” arch pipe (60” equivalent circular pipe) will be constructed on Cart Creek to meter the flows along Cart Creek and allow flows to be diverted into the site. The inlet consists of a low flow 73” x 45” arch pipe (60” equivalent circular pipe) and a 450-foot sheet pile weir. The weir will be constructed to an elevation that will divert flows above the 2-year event. During events less than the 2-year event, flows will be split between the Cart Creek channel crossing and the low flow inlet pipe. Once flows exceed the 2-

year event, floodwater will either enter the site via the inlet weir and inlet pipe or continue downstream through the Cart Creek channel crossing. An overflow spillway will be constructed along the south side of the Cart Creek channel crossing. The inlet overflow spillway will allow flows above the 100-year event to bypass the inlet and continue downstream along Cart Creek.

Floodwaters overtopping the inlet weir will be conveyed to the site through a constructed channel. The inlet channel consists of a 200-foot bottom width, 4:1 side slopes, and a -0.03% channel gradient sloping back towards Cart Creek. While the intention of the channel is to convey flows into Cart Creek Site 1, an adverse slope is necessary to mitigate sediment deposition within the channel which will reduce the need for frequent maintenance. The channel will be constructed to a depth so that the 100-year water surface elevation within the channel is approximately equal to or below the adjacent field elevation. A levee will be constructed on the east side of the inlet channel to the water surface elevation resulting from the stability design hydrograph. The channel will contain flows for all events through the stability design hydrograph event. The stability design hydrograph is discussed in Section 7.2.1. The north inlet channel will enter the site in the northwest corner of Section 24 where it crosses 87th Street NE through 6-lines of 12’ x 4’ reinforced concrete box culverts. The channel will continue south for approximately 900 feet where it will terminate. Over the final 600 feet of the channel, a spill-out opening will be excavated on the east side of the channel at an elevation of 981.0 feet to allow flood waters to flow freely over the landscape to the east and into the site. The spill-out section will have a flat slope and will remain 600 feet wide until it intersects the existing ground. Due to the topography generally sloping towards the east side of Section 24, the flows will ultimately end up at the principal spillway outlet discussed in Section 5.3.1. The north inlet plans are shown in the C-1000 series in **Attachment D-3-A**.

The south inlet is located along Pembina County Drain 28 upstream of the crossing with 131st Avenue NE. The existing structure at 131st Avenue NE will be replaced and reduced to two lines of 44” x 27” arch pipes (36” equivalent circular pipe). This will meter flows along the drain and allow flows to be diverted into the site. An inlet channel upstream of 131st Avenue NE will be constructed with a bottom width of 50 feet, 4:1 side slopes, and a -0.03% channel gradient sloping back towards Pembina County Drain 28. The channel will allow flows to travel north for approximately 400 feet where it turns east to enter the site in the southwest corner of Section 24. The channel then crosses 131st Avenue NE with 3-lines of 10’ x 4’ reinforced concrete box culverts. At the end of the channel there is a 200-foot spill-out opening similar to what is proposed for the north inlet channel. The 200-foot spill-out section will be constructed at an elevation of 982.0 feet and will allow flood waters to flow freely over the landscape to the east and into the site. The spill-out opening will have a flat slope and will remain 200 feet wide until it intersects the existing ground. The south inlet plans are shown in the C-2000 series in **Attachment D-3-A**.

5.2 EMBANKMENT

The embankment consists of a 10-foot top width at an elevation of 983.2 feet with 4:1 side slopes on both the wet and dry side of the embankment. The embankment has a maximum height of 17.3 feet and an average height of 9.7 feet. The NRCS document *Technical Release 210-60: Earth Dams and Reservoirs* (NRCS, 2019) specifies that the minimum top width shall be 10 feet for a maximum embankment height of 15-19.9 feet. Based on the geotechnical evaluation, a clay core with 1.5:1 slopes on both the wet and dry sides of the dam will be constructed in the center of the embankment and general fill will be placed between the core and the 4:1 side slopes. The embankment ties-in to natural ground on the west side of the project site.

Based on the geotechnical evaluation, an inspection trench would be excavated below the embankment and filled with impervious clay material similar to the embankment clay core. The inspection trench has a 5-foot bottom width, 1:1 side slopes, and a maximum depth of 6 feet. The embankment plans are shown in the C-3000 series in **Attachment D-3-A**.

5.3 SPILLWAYS

Flows exit Cart Creek Site 1 via the principal spillway or the auxiliary spillway. The spillways are discussed in detail in the follow sub-sections.

5.3.1 PRINCIPAL SPILLWAY

The principal spillway consists of a riser tower with a primary low flow inlet pipe, a secondary inlet weir, and an outlet conduit. The low flow inlet is a 36-inch reinforced concrete pipe set at the upstream channel elevation of 966.0 feet. This allows the site to be completely drawn down without the operation of a gate structure. The low flow inlet is sized to meet the drawdown requirements discussed in Section 7.1.3.

The secondary inlet is the weir crest of the riser tower. The riser tower is a 10' x 24' concrete riser. At the crest elevation, the riser is open on 2 sides allowing for 48 feet of weir flow length. The crest of the riser tower is at an elevation of 975.7 feet. The weir crest begins to operate between a 10-year and 25-year event. During the 10-year event, only the primary low flow pipe is operating.

The outlet conduit carries flows from the riser tower, through the embankment, and outlets back into Cart Creek. The outlet conduit is a 10' x 9' reinforced concrete box culvert. The conduit was sized to ensure the hydraulic control switches from the weir to the conduit before orifice flow can occur. With this design, orifice flow and cavitation in the riser tower should not occur. The principal spillway structure details are shown on sheet C-3101 in **Attachment D-3-A.**

5.3.2 AUXILIARY SPILLWAY

Guidance from *National Engineering Handbook, Part 628 Dams, Chapter 50 Earth Spillway Design* (NRCS, 2014) was used to design the auxiliary spillway. The auxiliary spillway is an earthen ramp spillway in the southwest corner of Section 24 with a crest elevation of 979.8 feet. The spillway will be constructed in natural ground and not on placed fill material. The spillway is a total of 870 feet long and is divided into 4 bays to prevent velocity variations within the spillway cross section. This results in a weir crest length of 800 feet. The spillway outlets into Pembina County Drain 28 along the south embankment of the site. Drain 28 will be improved to consist of a 50-foot bottom width, 4:1 side slopes, and a 0.1% channel gradient. During the passage of the freeboard hydrograph, described in Section 7.2.2, the water surface in the outlet channel will not encroach upon the toe of the embankment. The auxiliary spillway details are shown on sheets C-4101 and C-4102 in **Attachment D-3-A**.

5.4 STAGE-STORAGE-AREA-DISCHARGE RELATIONSHIP

A stage-storage-area relationship has been developed based on LiDAR elevation data. The stage-storage-area relationship for Cart Creek Site 1 is shown on **Figure D-3-5.4a**.

A stage-discharge relationship was developed for the principal and auxiliary spillways for Cart Creek Site 1. The relationship was verified with the hydraulic model. Both the principal spillway and auxiliary spillway stage-discharge relationships for Cart Creek Site 1 are shown on **Figure D-3-5.4b**.

6 HAZARD CLASSIFICATION

6.1 BREACH CRITERIA

Guidance for peak breach discharge criteria for hazard classification of a dam is provided in *Technical Release 210-60: Earth Dams and Reservoirs* (NRCS, 2019). Based on this guidance, the dam failure shall be evaluated with a water surface elevation at the dam crest or the peak reservoir stage resulting from the probable maximum flood. For Cart Creek Site 1, the dam failure was evaluated based on the top of dam elevation of 983.2 feet. This was selected because it represents the worst-case scenario of the two water surface elevations.

TR 210-60 also provides equations to calculate the minimum peak discharge of the breach hydrograph based on volume of storage and site characteristics. Equations are provided for both a low narrow dam and a low wide dam. For Cart Creek Site 1, the minimum peak discharge of the breach hydrograph was calculated to be 14,000 cfs. The calculations to determine this discharge are shown in **Figure D-3-6.1a**. These calculations were completed using an excel file developed by the NRCS National Water & Climate Center (NRCS WCC, 2013). *(The equations were calculated by hand to ensure accuracy in a third party excel file).* The breach hydrograph is calculated based on site characteristics and is not the result of a hydrologic event.

The 1-dimension unsteady hydraulic model was used to perform the breach analysis. *TR 210-60* provides equations to calculate a theoretical breach width based on the depth of water at the time of the breach, and the peak breach discharge. For Cart Creek Site 1, the theoretical breach width was 431 feet. The "Breach Formation Time" variable within the HEC-RAS modeling software was adjusted until the peak outflow from the dam was within 5% of the calculated peak breach discharge. The Cart Creek Site 1 simulated breach outflow hydrograph is shown in **Figure D-3-6.1b**.

6.2 BREACH RESULTS

Once the breach hydrograph was developed based on NRCS guidance, the hydrograph was routed through the hydraulic model to evaluate the downstream impacts resulting in a dam breach. The floodplain resulting from the dam breach is shown on **Figure C-17**. The impacts and inundation shown on **Figure C-17** are solely related to the impoundment site breach hydrograph.

Downstream impacts from the dam breach include inundation of rural farmsteads; inundation of rural structures; overtopping of township roads and county roads; inundation of homes in the city of Crystal, ND; and inundation of industrial and commercial buildings including a school in the city of Crystal, ND.

6.3 HAZARD CLASSIFICATION

Title 210, National Engineering Manual, Part 520 Subpart C "Dams" (NRCS, 2017) describes the hazard potential resulting from failure of dams. According to this guidance, a High Hazard Potential is "Dams where failure may cause loss of life or serious damage to homes, industrial or commercial buildings, important public utilities, main highways, or railroad."

Additional guidance for determining the likelihood of loss of human life and/or determining if significant damage to infrastructure will occur downstream of the breached structure can be found in *ACER Technical*

Memorandum No. 11 – Downstream Hazard Classification Guidelines (U.S. Bureau of Reclamation, 1988). Figures 2 through 6 found in *ACER Technical Memorandum No. 11* provide depth-velocity relationships that can be used to determine if there is a high risk for loss of life. Though depth-velocity combinations of homes and industrial buildings downstream of Cart Creek Site 1 do not enter the high danger zone during a breach, inundation depths in excess of 1.5 feet and velocities greater than 2 feet per second do occur at various building sites of importance. Additionally, the inundation mapping shows flood depths greater than 6 inches at the elementary school in the City of Crystal, ND. Therefore, for the purposes of this report, a conservative assumption was made that Cart Creek Site 1 will be classified as a high hazard potential dam.

Based on the dam breach results presented in Section 6.2, Cart Creek Site 1 is a classified as a High Hazard Dam.

7 DAM SAFETY REQUIREMENTS

Technical Release 210-60: Earth Dams and Reservoirs (NRCS, 2019), provides guidance on the minimum spillway precipitation criteria for the three dam hazard classifications. **Table 2** presents the minimum precipitation data and precipitation depth for the design of principal and auxiliary spillways for a high hazard dam. The design hydrographs are described in detail in the following sub-sections. The flood pools for the principal spillway riser tower elevation, auxiliary spillway crest elevation, and top of dam elevation are shown on **Figure D-3-7**.

Table 2: Technical Release 210-60 Minimum Precipitation Data for High Hazard Dams

Design Event Hydrograph	Precipitation Data[1]	Depth (inches)
Principal Spillway Hydrograph	P_{100}	4.75 [2] 7.56 [3]
Auxiliary Spillway Hydrograph	$P_{100} + 0.26 * (PMP - P_{100})$	8.6 [4]
Freeboard Hydrograph	PMP	26.4

[1] P_{100} = Precipitation for the 100-year return period; PMP = Probable Maximum Precipitation
[2] Runoff depth based on *NEH Part 630 Chapter 21*. See Section 7.1.1
[3] Rainfall depth based on *NOAA Atlas 14*. See Section 7.1.2
[4] Rainfall depth based on a 6-hour duration event. See Section 7.2.1

7.1 PRINCIPAL SPILLWAY DESIGN

Based on *TR 210-60*, the principal spillway of a high hazard dam must pass, at a minimum, the 100-year return period storm without activating the auxiliary spillway. Guidance dictates this storm shall have a duration of not less than 10-days. Four methods to determine runoff volume for the design of the principal spillway are presented in *National Engineering Handbook, Part 630 Hydrology, Chapter 21 Design Hydrographs* (NRCS, 2019). For the design of Cart Creek Site 1, two methods were used to determine the critical event; runoff volume maps and runoff curve number procedure.

7.1.1 RUNOFF VOLUME MAPS

Runoff volume maps presented in *NEH Part 630 Chapter 21* were generated for areas where runoff from snowmelt can potentially produce greater runoff volumes than rainfall events. The 100-year 10-day runoff volume for Cart Creek Site 1 is 4.75 inches according to Figure D-3-21-2 of *NEH Part 630 Chapter 21*. No areal reduction is applied to this runoff volume. Curve Numbers in the hydrologic model were modified to result in 4.75 inches of runoff.

The total runoff of 4.75 inches is the result of a 10-day runoff. Guidance from *NEH Part 630 Chapter 21* was used to develop the principal spillway mass curve, or runoff distribution curve, for the 10-day event. For Cart Creek Site 1, 1-hour time increments were used to develop the distribution. Using equation 21-2 from *NEH Part 630 Chapter 21*, the total runoff at any given time during the event can be calculated. These 1-hour values can then be arranged in either a decreasing order (Curve A), an increasing order (Curve B), or a critical stacking order (Curve C). The principal spillway mass curves are shown on **Figure D-3-7.1.1a**.

The runoff volume of 4.75 inches was simulated through the hydrologic and hydraulic models using the principal spillway mass curves A, B, and C. All three curves were simulated to ensure the auxiliary spillway was not activated during any event, and the results are shown on **Figure D-3-7.1.1b**. The auxiliary spillway for Cart Creek Site 1 would not be activated during the passage of these principal spillway design events.

Quick Return Flow (QRF) is the rate of discharge that persists beyond the flood period of the principal spillway hydrograph. Based on guidance from *NEH, Part 630, Chapter 21*, the QRF for Cart Creek Site 1 is approximately 3.4 cubic feet per second, per square mile. QRF is only considered for the north inlet channel because it has a low flow pipe where the south inlet channel only has an overflow weir. The drainage area to the north inlet is approximately 26.1 square miles, which results in a QRF of approximately 90 cubic feet per second (cfs). The 90 cfs was applied upstream of the inlet channel and resulted in a QRF of 68 cfs into the site. The critical principal spillway mass curve was determined to be Curve B. The calculated QRF was added to the trailing limb of the critical principal spillway discharge hydrograph and is shown on **Figure D-3-7.1.1c**. The QRF causes the stage in the site to rise to 972.5 feet, which corresponds to a storage of approximately 331 acre-feet.

7.1.2 RUNOFF CURVE NUMBER PROCEDURE

The runoff curve number method presented in *NEH, Part 630, Chapter 21* uses climatic data and watershed characteristics to convert rainfall data into runoff volumes. The 100-year, 10-day rainfall event was simulated using depths published in *NOAA Atlas 14* (NOAA, 2017). For Cart Creek Site 1 the 100-year, 10-day rainfall depth is 7.56 inches. The simulation used a nested distribution as described in the *Existing Conditions Hydrology and Hydraulics Report* (Houston Engineering, Inc., 2020). A 10-day Curve Number with an average moisture condition (AMC II) was used. The stage and discharge hydrograph from this event are shown on **Figure D-3-7.1.2**. The Figure also includes the critical event, mass Curve B, from the runoff volume maps procedure discussed in Section 7.1.1.

7.1.3 PRINCIPAL SPILLWAY ADEQUACY

Guidance from *NEH 210-60* states that the principal spillway capacity should empty at least 85 percent of the principal spillway hydrograph in 10 days or less. The 10-day drawdown begins when the peak water surface elevation is attained in the site during the passage of the principal spillway hydrograph. For Cart Creek Site 1, the critical principal spillway event resulted from the runoff volume maps mass Curve B described in Section 7.1.1. For this event, the principal spillway passes 88% of the volume 10 days after the peak water surface elevation occurs. The drawdown storage volume hydrograph is shown on **Figure D-3-7.1.3**. Additionally, the storage in the site caused by quick return flow is less than the required 10-day drawdown storage. Therefore, the principal spillway meets the minimum 10-day drawdown capacity.

The auxiliary spillway for Cart Creek Site 1 would not be activated during the passage of the principal spillway design events from both Section 7.1.1 and Section 7.1.2. The principal spillway meets the 10-day drawdown requirement.

7.2 AUXILIARY SPILLWAY DESIGN

There are two critical hydrologic events that must be analyzed for the auxiliary spillway based on guidance from *NEH 210-60*. These events are the auxiliary spillway stability design hydrograph (SDH) and the freeboard hydrograph (FBH). For a high hazard dam, both the SDH and the FBH utilize the probable maximum precipitation (PMP) rainfall depth to calculate a minimum design rainfall event.

For this analysis, PMP rainfall depths were determined based on *Hydrometeorological Report No. 51* (NOAA, 1978), also known as *HMR-51*. For this analysis, the PMP rainfall depth was reduced based on areal adjustment factors. The areal reduction factor was determined by interpolating a rainfall depth for a 33.8 square mile drainage area between the published values for a 10- and 200-square mile drainage area. This resulted in an approximate reduction factor of 0.97 for the 6-hour through 24-hour rainfall depths.

The analysis for the stability and integrity of the auxiliary spillway was conducted with the use of the SITES program (USDA, 2014). Input parameters were added to the SITES program including elevation-storage data, principal spillway information, watershed data, and auxiliary spillway information. Estimates for parameters describing topsoil and subsurface conditions at the auxiliary spillway were developed based on aerial imagery, and the standard penetration borings collected at the site and described in Section 4.2. While the test borings weren't in the exact location of the proposed auxiliary spillway, the borings closest to the spillway location were used to estimate subsurface parameters. Future analysis would include multiple soil borings at the location of the auxiliary spillway to refine estimated soil parameters and ensure the integrity and stability of the auxiliary spillway.

7.2.1 STABILITY DESIGN HYDROGRAPH

The minimum precipitation event for the stability design hydrograph (SDH) defined by *NEH 210-60* is shown in **Table 2**. Based on guidance from *NEH 210-60*, a short duration storm is to be used to check the stability of vegetated auxiliary spillways. For this analysis, a 6-hour storm was used for the SDH. The SDH event increases the 100-year, 6-hour rainfall depth by a portion of the PMP rainfall depth. This results in a rainfall depth of 8.60 inches for the SDH.

The rainfall distribution was developed based on Figure 21-9 in *NEH, Part 630, Chapter 21*. Figure 21-9 shows the dimensionless design storm distribution for the SDH storm event. This distribution was set to match the 6-hour storm duration. The rainfall hyetograph and distribution are shown on **Figure D-3-7.2.1a**. The SDH was hydraulically routed to the Cart Creek Site 1 with the use of HEC-RAS software.

The peak water surface elevation within Cart Creek Site 1 during the passage of the stability design hydrograph is 980.9 feet which inundates 514 acres. This results in a max depth of flow over the auxiliary spillway of 1.1 feet and a combined peak discharge of approximately 2,960 cfs. The peak discharge through the auxiliary spillway is approximately 1,640 cfs. The stage hydrograph for Cart Creek Site 1 is shown on **Figure D-3-7.2.1b**. The principal spillway, auxiliary spillway, combined inflow, and combined outflow hydrographs are shown on **Figure D-3-7.2.1c**.

HEC-RAS software was used to hydraulically route flows through the site during the SDH. The peak discharge through the auxiliary spillway was duplicated in the SITES model. The results from the SITES model indicate that the total stress and soil effective stress on the auxiliary spillway were 1.45 pounds per square foot (psf) and 0.104 psf, respectively. Data from the soil borings described in Section 4.2 was used to estimate allowable effective stress and allowable vegetal stress based on guidance in *Stability Design of Grass-Lined Open Channels* (Temple, 1987). The estimated allowable total or vegetal stress is 4.20 psf and the estimated allowable effective stress is 0.115 psf. Therefore, the criteria for the SDH is met for Cart Creek Site 1.

The estimated effective stress in the auxiliary spillway is less than the allowable effective stress, and the estimated total stress in the spillway is less than the allowable total stress. Therefore, the auxiliary spillway passes the Stability Design Hydrograph without stability being compromised.

7.2.2 FREEBOARD HYDROGRAPH

The minimum design event for the freeboard hydrograph (FBH) defined by *NEH 210-60* is the probable maximum precipitation or PMP. The duration of the FBH was developed based on guidance from *NEH 210-60*. That guidance states that both the 6- and 24-hour storm durations shall be analyzed, and *NEH, Part 630, Chapter 21* states that a storm duration equal to or greater than the time of concentration shall be analyzed. The time of concentration to Cart Creek Site 1 is approximately 20 hours. Both a 6-hour and 24-hour storm were analyzed, and the 24-hour storm was the critical event. The PMP precipitation depth for a 24-hour storm at Cart Creek Site 1 is 26.4 inches of rainfall. 24-hour Curve Numbers with an average antecedent moisture condition (AMC II) were used to simulate the event.

The rainfall distribution for the PMP was developed based on guidance from *NEH, Part 630, Chapter 21.* A 5-point rainfall distribution was developed based on the *HMR-51* rainfall depths. The procedure to develop the 5-point curve includes critically stacking incremental rainfall amounts of successive 6-, 12-, 18- and 24-hour durations. The 5-point rainfall hyetograph and distribution curve for the Cart Creek Site 1 freeboard hydrograph is shown on **Figure D-3-7.2.2a**.

The peak water surface elevation within Cart Creek Site 1 during the passage of the freeboard hydrograph is 983.12 feet which inundates 596 acres. This results in a max depth of flow over the auxiliary spillway of 3.32 feet and a combined peak discharge of approximately 10,350 cfs. The peak discharge through the auxiliary spillway is approximately 8,870 cfs. The stage hydrograph for Cart Creek Site 1 is shown on **Figure D-3-7.2.2b**. The principal spillway, auxiliary spillway, combined inflow, and combined outflow hydrographs are shown on **Figure D-3-7.2.2c**.

The peak water surface elevation of 983.12 feet is below the top of dam elevation of 983.2 feet; therefore, the auxiliary spillway passes the FBH without overtopping.

An integrity analysis of the auxiliary spillway was developed through similar procedures outlined in Section 7.2.1. HEC-RAS software was used to hydraulically route flows through the site during the FBH. The peak discharge through the auxiliary spillway was duplicated in the SITES model, and the results were analyzed. The resulting erosion during the passage of the FBH is shown in **Figure D-3-7.2.2d**.

The headcut reaches the crest of the emergency spillway but does not reach the upstream side of the crest. Therefore, the structure passes the Freeboard Hydrograph without breaching.

8 SYNTHETIC RAINFALL EVENTS AND SITE PERFORMANCE

To analyze the performance of Cart Creek Site 1, synthetic rainfall events were simulated and routed through the hydraulic model. Synthetic rainfall events for the North Branch Watershed Plan are defined in the *Existing Conditions Hydrology and Hydraulics Report*. The events include 2-year through 500-year return periods based on NOAA Atlas 14 rainfall depths with a 4-day duration. Runoff Curve Numbers were adjusted from a 24-hour Curve Number to a 4-day Curve Number based on guidance from *NEH, Part 630, Chapter 21* and were set to average antecedent moisture condition (AMC II). The rainfall distribution used for the synthetic events was developed using a "nesting" technique described in *NEH, Part 630, Chapter 4* (NRCS, 2015). *(Note: The existing conditions model was modified to incorporate the Cart Creek Site 1 project components. Inundated acreages were updated for this report and may not match the Existing Conditions Hydrology and Hydraulics Report and the Alternative Screening Report).*

Impoundment Site Performance

Floodwaters were diverted into the site for the 2-year through 500-year events. The average rainfall depth, peak pool elevation, storage volume at peak elevation, pool area at peak elevation, and peak discharge through the principal spillway for each event are shown in **Table 3**.

For 2-year through 10-year events, only the primary low flow culvert of the principal spillway riser would be activated. The principal spillway riser tower crest would be activated between the 10-year and 25-year events. The peak water surface elevation within the site for the 100-year event would be 979.30 feet, or 0.5 feet below the auxiliary spillway. Inundation within the site would range from 152 acres to 504 acres for the 2-year through 500-year events.

Table 3: Cart Creek Site 1 Synthetic Rainfall Event Results

Event	NOAA Atlas 14 4-Day Rainfall Depth[1] (inches)	Peak Flood Pool Elevation (feet)	Storage Volume[2] (ac-ft)	Pool Area[2] (acres)	Principal Spillway Discharge (cfs)
2-year	2.70	972.23	293	152	72
5-year	3.35	973.96	609	215	86
10-year	3.94	975.59	1,020	287	100
25-year	4.80	977.24	1,543	349	292
50-year	5.51	978.31	1,942	399	519
100-year	6.27	979.30	2,359	444	774
500-year	8.18	980.72	3,032	504	1,190

[1] Average rainfall depth adjusted for areal reduction based on watershed size of 257 square miles
[2] Values are in reference to the Peak Flood Pool Elevation

Changes to Peak Flows Downstream of the Impoundment Site

Multiple reporting locations were selected in the *Alternative Screening Report*. These locations were selected to evaluate modeling results throughout the watershed at geographically significant locations. These locations include North Dakota State Highways, township roads, cities, and at the outlet of the watershed. The reporting locations are shown in **Attachment D-3-B**, **Figure D-3-C.1**, and are further summarized below. Hydrographs for the 2-year through 500-year events at the reporting locations are shown in **Attachment D-3-B**, **Figures D-3-C.2** through **C.8**. The peak discharges for the analyzed events at the reporting locations are shown in **Table 4**.

- Cart Creek at 86th Street NE – Downstream of the confluence of Cart Creek and Pembina County Drain 28.
- Cart Creek at Pembina County Road 12 – Downstream of the confluence of Cart Creek and an unnamed tributary.
- Cart Creek at 138th Avenue NE near Crystal, ND – Downstream of a railroad crossing and at the downstream end of where the Cart Creek flows through the community of Crystal.
- Cart Creek at North Dakota Highway No. 18. – Downstream of Crystal, between Crystal and the confluence with the North Branch Park River.
- North Branch Park River at 77th Street NE – Downstream of the confluence of the North Branch Park River and Cart Creek.
- North Branch Park River Outlet (Channel Only) – This reporting location only accounts for the flow within the North Branch Park River channel near the confluence with the Middle Branch Park River. The reporting location is located at the Burlington Northern Santa Fe (BNSF) Railroad crossing.
- North Branch Park River Outlet (Including Breakouts) – This reporting location accounts for both the channel flows measured at the BNSF Railroad crossing and all breakout/overland flows near the outlet of the North Branch Park River. Flows measured at this reporting location span an approximate 9 mile long transect.

At the first stream crossing downstream of the Cart Creek Site 1, 86th Street NE, peak flow reductions range from 39% to 68% for the 2-year through 500-year events. The 10-year through 100-year events all have reductions of greater than 60%. Approximately 8 miles southeast of the site, at Crystal, ND, peak flow reductions range from 14% to 28% for the 2-year through 500-year events. At the outlet of the North Branch Watershed, peak flows in the channel are reduced between 0.2% and 1.9%. These results indicate that flows within the channel will be slightly reduced at the outlet of the watershed. There are significant overland, or breakout, flows at the outlet of the North Branch Watershed. At the North Branch outlet, including the breakout flows, peak flow reductions range from 2% to 10%.

Cart Creek Site 1 will reduce peak flows along Cart Creek from 86th Street NE, through the community of Crystal, ND, all the way to the outlet of the North Branch Watershed for the 2-year through the 500-year events. There will also be a reduction in breakout flows at the outlet of the North Branch Watershed.

Floodplain Inundation Statistics

The inundation for the 2-year through 500-year events is shown in **Appendix C-1**. Inundation for both existing conditions (red) and the proposed Cart Creek Site 1 condition (blue) are shown on the figures. The red represents lands that are no longer flooded with the project for that event. Blue represents lands that are flooded for both conditions. In addition to inundation extents, critical structures that are affected by the existing conditions inundation are shown on the inundation figures in **Appendix C-1.** The figures show the maximum inundation extent that occurs during the event; therefore the full benefit of the project is not apparent on the inundation figures. Flood damages, especially damages to agricultural lands, are caused both by the extent of the inundation and, almost equally as important, the duration of inundation. The total inundated acres and cropland inundated acres for the analyzed events based on duration are shown in **Table 5**. Cropland acres were estimated using the National Agricultural Statistics Service (NASS) data from 2017 (USDA, 2017).

Cart Creek Site 1 reduces the total inundated acres for the 2-year through the 500-year by 5% to 9%, and cropland inundated acres are reduced by 5% to 10%.

Typical crops within the North Branch Watershed include wheat, soybeans, corn, dry beans, potatoes, and sugar beets. Flood inundation durations greater than four days generally represents the maximum anticipated damages, or total loss, for the crop types in the study area. **Table 6** shows total inundated acres for durations less than 4-days. To provide benefit to agricultural lands, flood durations between 0 and 4 days should be reduced. Zero to 4 days represents the time between no inundation and total crop loss inundation.

During the existing conditions 10-year event, there are 5,821 cropland acres inundated for less than 4-days. With the impoundment site, the same event would inundate 5,052 cropland acres for less than 4-days. This results in a reduction of 769 acres or 13.2%. This is a reduction in inundation of 1.2 square miles. Cart Creek Site 1 reduces the cropland inundation for durations less than 4-days by 8% to 17% for the 2-year through 500-year events.

Table 4: Peak Flow Changes

Location	Event	Existing Conditions	Cart Creek Site 1	% Change
86th St NE - Cart Creek	2-year	493	301	-39.0%
	5-year	867	370	-57.3%
	10-year	1201	432	-64.0%
	25-year	1680	530	-68.4%
	50-year	2143	731	-65.9%
	100-year	2841	980	-65.5%
	500-year	5080	2337	-54.0%
County Road 12 - Cart Creek	2-year	964	801	-17.0%
	5-year	1683	1369	-18.6%
	10-year	2478	2007	-19.0%
	25-year	3816	3024	-20.8%
	50-year	4915	4053	-17.5%
	100-year	5982	5030	-15.9%
	500-year	11936	9208	-22.9%
Crystal, ND - Cart Creek	2-year	961	825	-14.1%
	5-year	1696	1379	-18.7%
	10-year	2469	1964	-20.4%
	25-year	3708	3030	-18.3%
	50-year	4471	3856	-13.7%
	100-year	6280	4507	-28.2%
	500-year	11335	9400	-17.1%
Highway 18 - Cart Creek	2-year	907	782	-13.8%
	5-year	1580	1293	-18.2%
	10-year	2373	1843	-22.3%
	25-year	3669	2904	-20.8%
	50-year	4402	3815	-13.3%
	100-year	4961	4473	-9.8%
	500-year	6395	5908	-7.6%
77th St NE - North Branch Downstream of Cart Creek	2-year	1405	1329	-5.4%
	5-year	2423	2253	-7.0%
	10-year	3380	3089	-8.6%
	25-year	4541	4315	-5.0%
	50-year	5203	5039	-3.2%
	100-year	5797	5710	-1.5%
	500-year	7870	7852	-0.2%
North Branch Outlet (Channel Only)	2-year	602	595	-1.2%
	5-year	741	731	-1.3%
	10-year	810	794	-1.9%
	25-year	892	875	-1.9%
	50-year	931	919	-1.3%
	100-year	967	962	-0.5%
	500-year	1060	1058	-0.2%
North Branch Outlet (Including Breakouts)	2-year	1162	1135	-2.3%
	5-year	1987	1899	-4.4%
	10-year	2835	2649	-6.6%
	25-year	4194	3753	-10.5%
	50-year	5108	4818	-5.7%
	100-year	6593	6110	-7.3%
	500-year	11464	11100	-3.2%

Table 5: Inundated Acreage

Scenario	Duration (hours)	2-year		5-year		10-year		25-year		50-year		100-year		500-year	
		Cropland	Total	Cropland	Total	Cropland	Total	Cropland	Total	Cropland	Total	Cropland	Total	Cropland	Total
Existing Conditions	0-24	1,081	1,614	1,614	2,208	2,204	2,790	3,208	3,834	3,785	4,441	4,265	5,076	5,180	5,939
	24-48	748	1,088	1,184	1,702	1,630	2,212	2,110	2,697	2,786	3,372	3,266	3,832	4,522	5,149
	48-72	521	741	878	1,258	1,140	1,616	1,438	1,963	1,862	2,411	2,415	2,946	2,864	3,427
	72-96	246	366	523	731	847	1,144	1,061	1,445	1,207	1,610	1,368	1,747	2,102	2,551
	96-120	155	227	346	471	461	625	884	1,127	877	1,196	1,045	1,391	1,667	2,060
	>120	1,154	1,835	1,375	2,101	1,688	2,483	2,273	3,186	3,026	4,054	3,546	4,668	4,968	6,342
	TOTAL	3,905	5,871	5,920	8,471	7,970	10,870	10,974	14,252	13,543	17,084	15,905	19,660	21,303	25,468
Cart Creek Site 1	0-24	935	1,330	1,388	1,829	1,881	2,343	2,340	2,814	3,107	3,606	3,519	4,134	4,441	5,033
	24-48	663	979	1,046	1,531	1,505	2,084	1,883	2,412	2,319	2,819	3,009	3,505	4,126	4,657
	48-72	458	655	752	1,085	938	1,360	1,351	1,854	1,607	2,131	2,125	2,639	2,837	3,371
	72-96	224	338	467	661	728	991	953	1,315	1,164	1,557	1,237	1,614	2,145	2,614
	96-120	140	199	296	401	413	554	751	972	822	1,134	998	1,349	1,583	1,978
	>120	1,293	2,092	1,608	2,481	1,841	2,751	2,595	3,655	3,159	4,326	3,642	4,912	5,188	6,721
	TOTAL	3,713	5,593	5,557	7,988	7,306	10,083	9,873	13,022	12,178	15,573	14,530	18,153	20,320	24,374
% Change	0-24	-13.5%	-17.6%	-14.0%	-17.2%	-14.7%	-16.0%	-27.1%	-26.6%	-17.9%	-18.8%	-17.5%	-18.6%	-15.4%	-16.5%
	24-48	-11.4%	-10.0%	-11.7%	-10.0%	-7.7%	-5.8%	-10.8%	-10.6%	-16.8%	-16.4%	-7.9%	-8.5%	-9.2%	-10.0%
	48-72	-12.1%	-11.6%	-14.4%	-13.8%	-17.7%	-15.8%	-6.1%	-5.6%	-13.7%	-11.6%	-12.0%	-10.4%	-0.9%	-1.6%
	72-96	-8.9%	-7.7%	-10.7%	-9.6%	-14.0%	-13.4%	-10.2%	-9.0%	-3.6%	-3.3%	-9.6%	-7.6%	2.0%	2.4%
	96-120	-9.7%	-12.3%	-14.5%	-14.9%	-10.4%	-11.4%	-15.0%	-13.8%	-6.3%	-5.2%	-4.5%	-3.0%	-5.2%	-4.1%
	>120	12.0%	14.0%	16.9%	18.1%	9.1%	10.8%	14.2%	14.7%	4.4%	6.7%	2.7%	5.2%	4.3%	5.8%
	TOTAL	-4.9%	-4.7%	-6.1%	-5.7%	-8.3%	-7.2%	-10.0%	-8.6%	-10.1%	-8.8%	-8.6%	-7.7%	-4.7%	-4.4%

Table 6: Inundated Acreage Less than 4-Days

Scenario	Duration	2-year		5-year		10-year		25-year		50-year		100-year		500-year	
		Cropland	Total	Cropland	Total	Cropland	Total	Cropland	Total	Cropland	Total	Cropland	Total	Cropland	Total
Existing Conditions	Less than 4-days *(0-96 Hours)*	2,596	3,809	4,199	5,899	5,821	7,762	7,817	9,939	9,640	11,834	11,314	13,601	14,668	17,066
Cart Creek Site 1		2,280	3,302	3,653	5,106	5,052	6,778	6,527	8,395	8,197	10,113	9,890	11,892	13,549	15,675
Difference		-316	-507	-546	-793	-769	-984	-1,290	-1,544	-1,443	-1,721	-1,424	-1,709	-1,119	-1,391
% Change		-12.2%	-13.3%	-13.0%	-13.4%	-13.2%	-12.7%	-16.5%	-15.5%	-15.0%	-14.5%	-12.6%	-12.6%	-7.6%	-8.2%

**Inundated acres based on the flood extents shown on Figures C.9 to C.15. Inundation is not clipped to the North Branch Watershed*

9 WATERSHED PROTECTION FEATURES

Cart Creek Site 1 will function as a “dry dam”, meaning during non-flood periods the impoundment area will be fully evacuated with no permanent pool. The impoundment area will be managed to provide nutrient and sediment load reductions to the downstream channel, and enhanced wildlife habitat. Phosphorus from the upstream watershed will be extracted by promoting biomass growth that will be periodically removed from the site. To promote biomass growth, a system of shallow retention cells will be constructed within the impoundment area. Refer to **Appendix D-7** for additional information on the function of the biomass retention cells.

The biomass retention cells consist of approximately 12,900 lineal feet of shallow embankment, generally varying from 0’ – 5’ in total height. The embankment consists of trapezoidal section a 10’ top width and 4:1 side slope. Runoff will be routed into the biomass retention cells from Cart Creek via the north inlet, Pembina County Drain 28 via south inlet, and local drainage via culverts through 131st Ave NE. The north inlet will feature a 1,400' non-perforated 24” diameter HDPE pipe located within the township road right-of-way of 131st Ave NE. The south inlet will feature an open channel to route flows into the biomass retention cells. For both the north and south inlets, flows will first be routed into the biomass retention cells before the larger impoundment area as described in Section 5.1 of this report. Two 36” CMP culverts through 131st Ave NE will allow for runoff from the local watershed to enter the biomass retention cells.

Water levels within the biomass retention cells will be maintained at an average 1’ – 2’ of depth. Outlet structures consisting of a CMP standpipe riser and outlet conduit will be provided to control water levels within each retention cell. The biomass retention cells will be periodically drained to allow for biomass harvest. Gated low flow drawdowns will also be incorporated into outlet structures to provide for controlled drawdown. Perforated pattern tile will also be included within each retention cell to assist with drawdown for biomass harvest operations. Each retention cell will have a separate pattern tile configuration, connected with non-perforated lines to one outlet and pump system. In total, the pattern tile will manage subsurface water from 133.6 acres. All perforated tile lines will be a minimum of 80’ away from the adjacent WRP easement to minimize any potential lateral effect. Refer to **Attachment D-3-A** for drawings showing the configuration of the biomass retention cells. Further information on the operation of the impoundment site to attain watershed protection benefits is discussed in **Appendix D-7**.

10 ESTIMATED PROJECT COST

The engineer's estimated project cost is shown in **Table** 7. Quantities were based on the preliminary design and unit prices were estimated based on previous projects completed in the region. Unit prices are estimated in 2020 dollars. All preliminary plans for Cart Creek Site 1 are shown in **Attachment D-3-A**. ***The total estimated project cost for Cart Creek Site 1 is $12,228,700.***

Table 7: Cart Creek Site 1 Engineer's Cost Estimate

No.	Item	Unit	Quantity	Unit Price[1]	Total Price
1	Mobilization	LS	1	$380,000.00	$380,000.00
2	Stripping and Topsoiling (PV)	CY	211,500	$2.50	$528,750.00
3	Cutoff Trench (PV)	CY	38,650	$4.00	$154,600.00
4	Core Fill (PV)	CY	181,900	$4.00	$727,600.00
5	Random Fill (PV)	CY	218,800	$2.00	$437,600.00
6	Biomass Berm Fill (PV)	CY	35,000	$4.00	$140,000.00
7	Common Excavation (PV)	CY	448,300	$2.50	$1,120,750.00
8	Sheet Piling	SF	9000	$40.00	$360,000.00
9	24" CMP	LF	130	$65.00	$8,450.00
10	36" CMP	LF	160	$100.00	$16,000.00
11	44"x27" RCPA	LF	68	$180.00	$12,240.00
12	73"x45" RCPA	LF	58	$400.00	$23,200.00
13	44"x27" RCPA End Section	EA	4	$1,700.00	$6,800.00
14	73"x45" RCPA End Section	EA	4	$4,700.00	$18,800.00
15	Single 10'Wx4'H RCBC	LF	114	$1,000.00	$114,000.00
16	Single 12'Wx4'H RCBC	LF	252	$1,200.00	$302,400.00
17	Single 10'Wx4'H RCBC End Section	EA	6	$9,000.00	$54,000.00
18	Single 12'Wx4'H RCBC End Section	EA	12	$10,000.00	$120,000.00
19	Drain Tile System - Pipe	AC	140	$1,600.00	$224,000.00
20	Plug In-Place Tile System	LS	1	$20,000.00	$20,000.00
21	Drain Tile Outlet Structure and Pump	EA	1	$30,000.00	$30,000.00
22	Automated Remote-Control Value and Control Structure	EA	2	$21,000.00	$42,000.00
23	Underground Electric Utility Installation	LS	1	$45,000.00	$45,000.00
24	Riser Structure with Trash Rack (3)	LS	1	$26,000.00	$26,000.00
25	Watershed Protection Incidentals	LS	1	$90,750.00	$90,750.00
26	Riprap	CY	5,170	$90.00	$465,300.00
27	Erosion Control	LS	1	$104,000.00	$104,000.00
28	Principal Spillway Outlet Structure	LS	1	$666,000.00	$666,000.00
29	Seeding and Mulching	AC	700	$800.00	$560,000.00
30	Haul Road Restoration	LS	1	$25,000.00	$25,000.00
				Construction Subtotal	$6,823,240.00
				Contingencies (20%)	$1,364,648.00
				Total Construction Cost	$8,189,000.00
	Flood Protection Right of Way	AC	150	$2,800.00	$420,000.00
	Watershed Protection Right of Way	AC	534	$2,800.00	$1,495,200.00
	Flowage Easement	AC	19	$500.00	$9,500.00
				Wetland Mitigation	$16,000.00
				Design Engineering	$1,083,000.00
				Construction Engineering	$747,000.00
				Legal Administration and Bonding	$269,000.00
				Non-Construction Cost	**$4,039,700.00**
				Total Estimated Project Cost	**$12,228,700.00**

[1] 2020 Dollars

11 SUMMARY

As part of the North Branch Watershed Plan, a Purpose and Need for the project has been identified. The purpose of the proposed action is to implement flood prevention and flood damage reduction measures to;

1. Reduce flood damages for up to a 10-year rainfall event on cropland.
2. Increase flood resiliency for public and private infrastructure.
3. Increase flood resiliency for the community of Crystal, ND during a 100-year flood event.
4. Maintain or reduce flood flows at the confluence of the North Branch Park River with the Park River mainstem.
5. Improve soil health or water quality throughout the watershed.

During the alternative screening process, indicators were developed to establish criteria used in determining if an alternative meets the purpose. The indicators are presented in detail in the *Alternative Screening Report* (Houston Engineering, Inc., 2020). The summarized indicators and the synthetic modeling results for Cart Creek Site 1 are shown in **Table 8**.

Table 8: Cart Creek Site 1 Purpose and Need Evaluation Summary

Purpose and Need Indicator	Cart Creek Site 1 Results
INDICATOR 1: Reduce the 10-year cropland inundation for durations less than four days by 5% in Cart Creek Subwatershed.	769 Acres 13.2% Reduction
INDICATOR 2(a): Reduce the 10-year event peak flow rate by 20% on the Cart Creek at Crystal, ND.	20.4% Reduction
INDICATOR 2(b): Reduce the 10-year event peak flow rate by 10% on the North Branch at the confluence of the Cart Creek.	8.6% Reduction
INDICATOR 3: Reduce the 100-year event peak flow rate by 30% on the Cart Creek at Crystal, ND.	28.2% Reduction
INDICATOR 4: No increase in peak flow rate at the outlet of the North Branch Watershed.	Reduction ranges from 0.5% to 1.9% for the channel only Reduction ranges from 2.3% to 10.5% including breakout flows

While two of the five indicators fail to meet the target reduction, it should not be seen as a failure for the project as a whole. The indicators were established as a way to quantitively measure an alternative against the purpose of the project. The percentages selected for the indicators were based on preliminary modeling and were simply targets for flood reduction. Therefore, two indicators failing to reach the target by 1.4% and 1.8% is acceptable.

When examining the results qualitatively against the project purpose, flood damages to cropland will be reduced for the 2-year through 500-year events by reducing the inundation to cropland for durations of less than 4-days. Flood resiliency to public and private infrastructure and to the community of Crystal, ND will be improved by reducing peak flows along Cart Creek from the project location to the outlet of the North

Branch Watershed. The peak flows are reduced at the outlet of the North Branch Watershed, which will provide benefit downstream of the watershed. With the reduced cropland flooding and reduced peak flows, soil health and water quality throughout the watershed will be improved.

In addition to flood reduction benefits resulting from the implementation of Cart Creek Site 1, benefits to wetland habitat will also occur within the flood pool. For more details on the benefits to wetland habitat within the proposed site, refer to the Watershed Plan and Environmental Assessment for the North Branch Park River Watershed.

This report summarizes the project location, characteristics, dam hazard classification, site design, performance, and estimated project cost of Cart Creek Site 1. **Appendix D-4** of the North Branch of the Park River Watershed Plan presents the Economics Evaluation for Cart Creek Site 1 prepared by Gannett Fleming, Inc.

12 REFERENCES

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FIGURES

Figure D-3-5.4a: Stage-Storage-Area Relationship

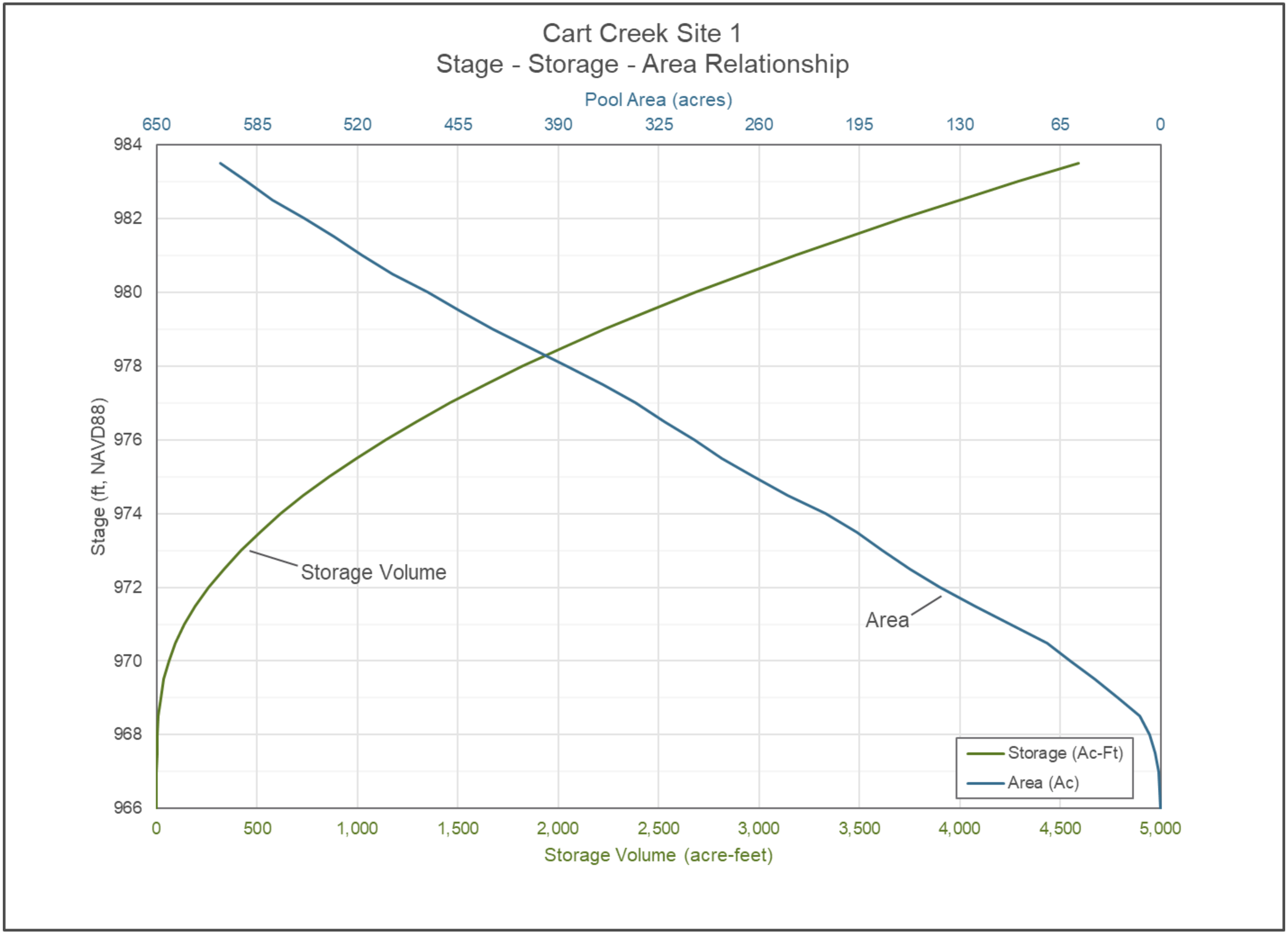


Figure D-3-5.4b: Stage-Discharge Relationship

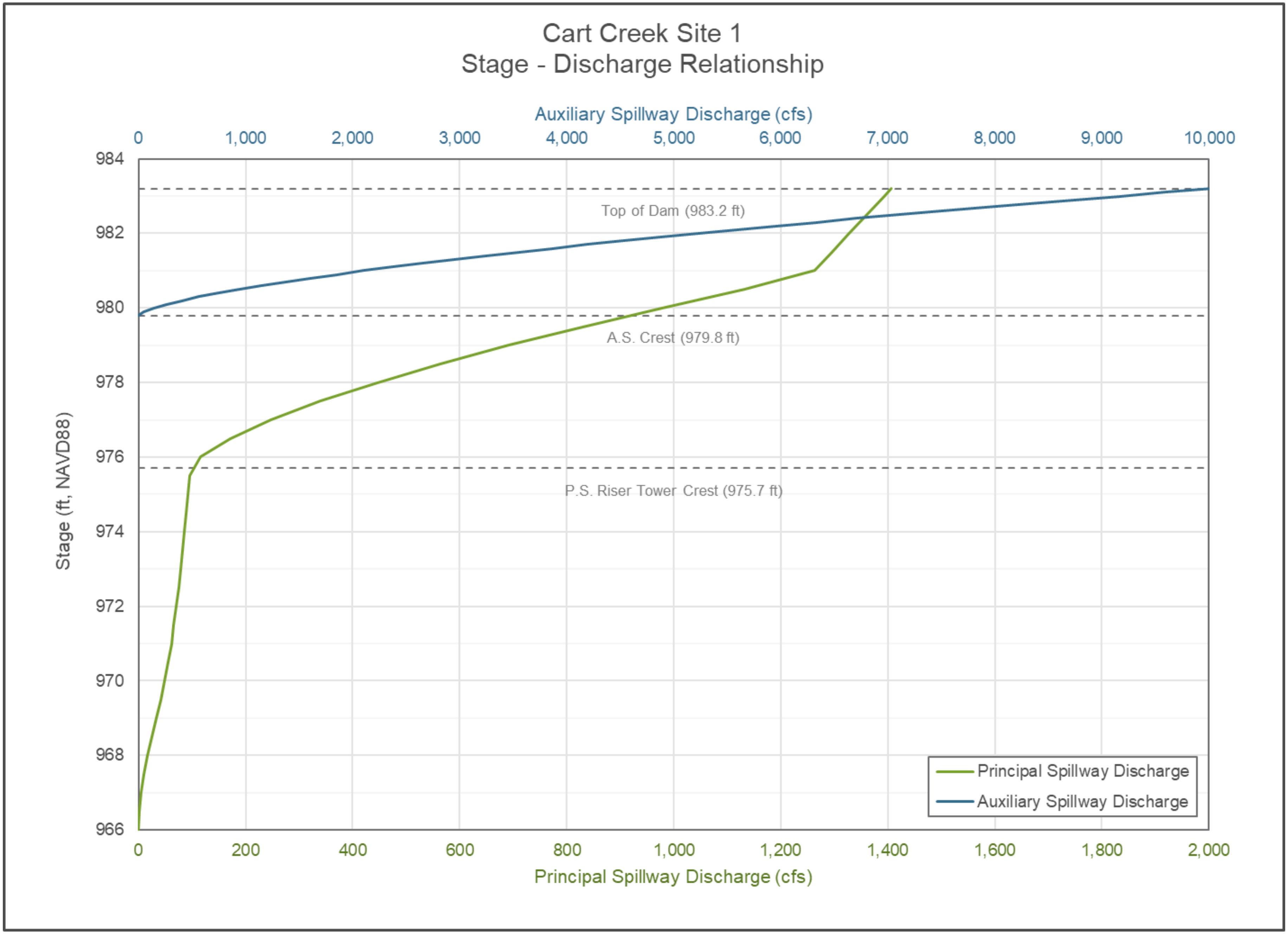


Figure D-3-6.1a: *TR 210-60 Dam Breach Calculations*

Watershed Name:	**NB Park River**			Date	**Sep 4, 2019**	
Site No.	**Cart Creek Site 1**			Prepared By:	**PDL**	
County, ST	Pembina County, ND					

Elevations						
Top of Dam	983.2	ft, NAVD88	Top Width		10 Ft	
Water Surface@Breach	983.2	ft, NAVD88	Upstream Slope Above Berm	4	:1	
Wave Berm	973.5	ft, NAVD88	Upstream Slope Below Berm	4	:1	
Average Valley Floor	965.0	ft, NAVD88	Downstream Slope Above Berm	3	:1	
Stability Berm	973.5	ft, NAVD88	Downstream Slope Below Berm	3	:1	
Length of Dam at Breach Elev	14,000	Ft	Wave Berm Width		0 Ft	L
Volume of Breach	4,195	Ac-ft	Stability Berm Width		0 Ft	

Breach Discharge Computations

Hw < 103 - Low Dam

Volume of Breach (Vs)	4,195	Ac-ft	
Height Of Breach (Hw)	18	Ft	Hw
Cross-Section Area at Breach (A)	1,341	Ft^2	
$T = 65(H^{0.35})/0.416$ - theoretical breach width	431	Ft	T

L > T - Wide Dam

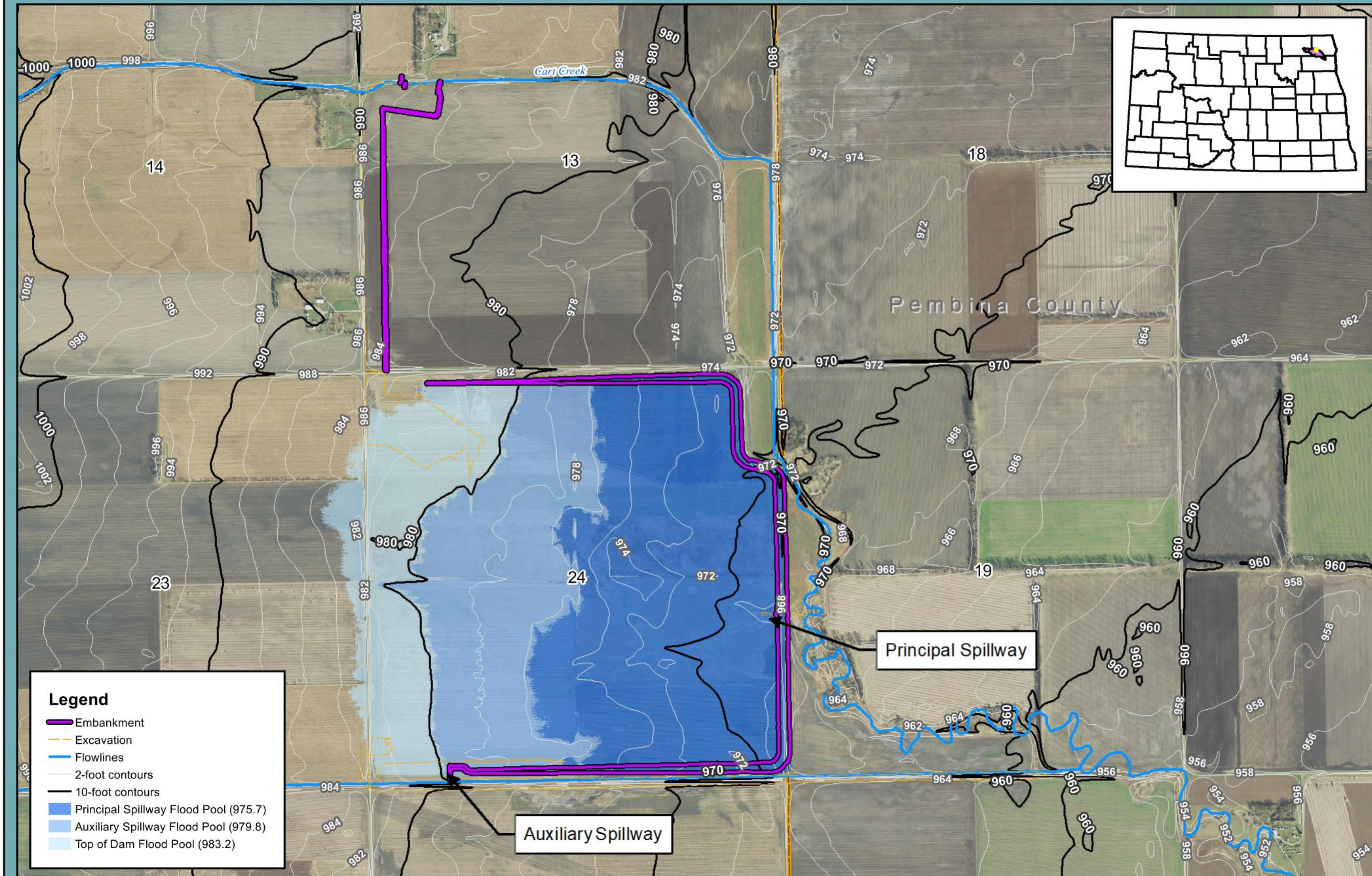
Q_{max} NOT GREATER THAN		Upper Bound Check			
$Q_{max} = 65(HW^{1.85})$	L>T Wide		13,933	cfs	UpBndWide
$Q_{max} = 0.416(L)(Hw^{1.5})$	L<T Narrow		452,198	cfs	UpBndNarrow

Br = (Vs * Hw)/A	Value	56.92		Br
$Q_{max} = 1,100\ (Br)^{1.35}$		257,632	cfs	

Q_{max} NOT LESS THAN	Lower Bound Check			
$Q_{max} = 3.2(Hw^{5/2})$		4,522	cfs	LowBnd

TR-60 Breach Q_{max} for Hazard Class: **14,000 cfs**

Figure D-3-6.1b: *Dam Breach Outflow Hydrograph*



F-D-3-7

Figure D-3-7: Cart Creek Site 1 Critical Flood Pools

North Branch Park River Watershed
Cart Creek Site 1 Concept Design Report
Park River Joint Water Resource District

N W E S

0 0.125 0.25 0.5 Miles

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Figure D-3-7.1.1a: Principal Spillway Mass Curves for Runoff Volume

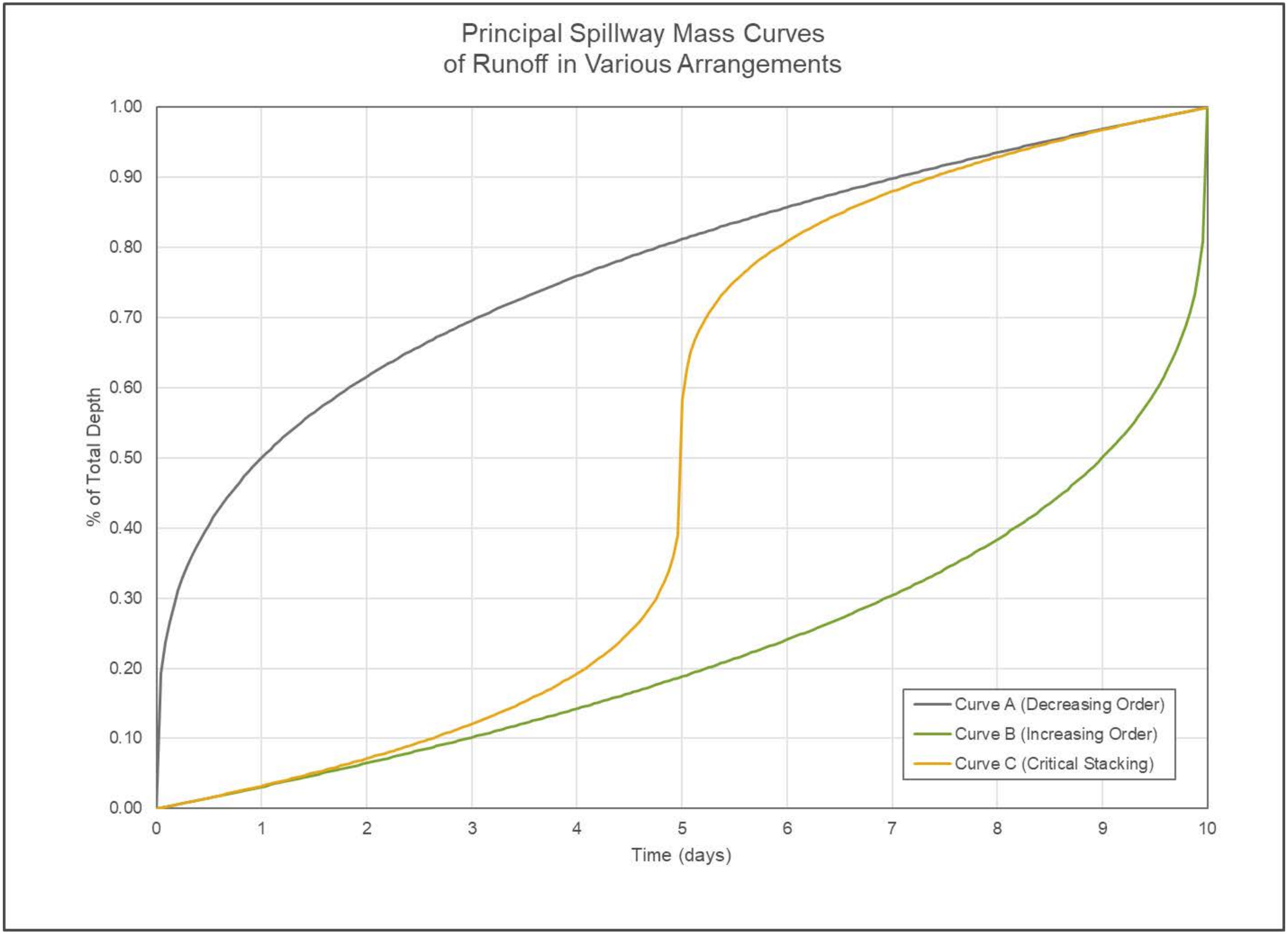


Figure D-3-7.1.1b: *Principal Spillway Runoff Volume Maps Hydrographs*

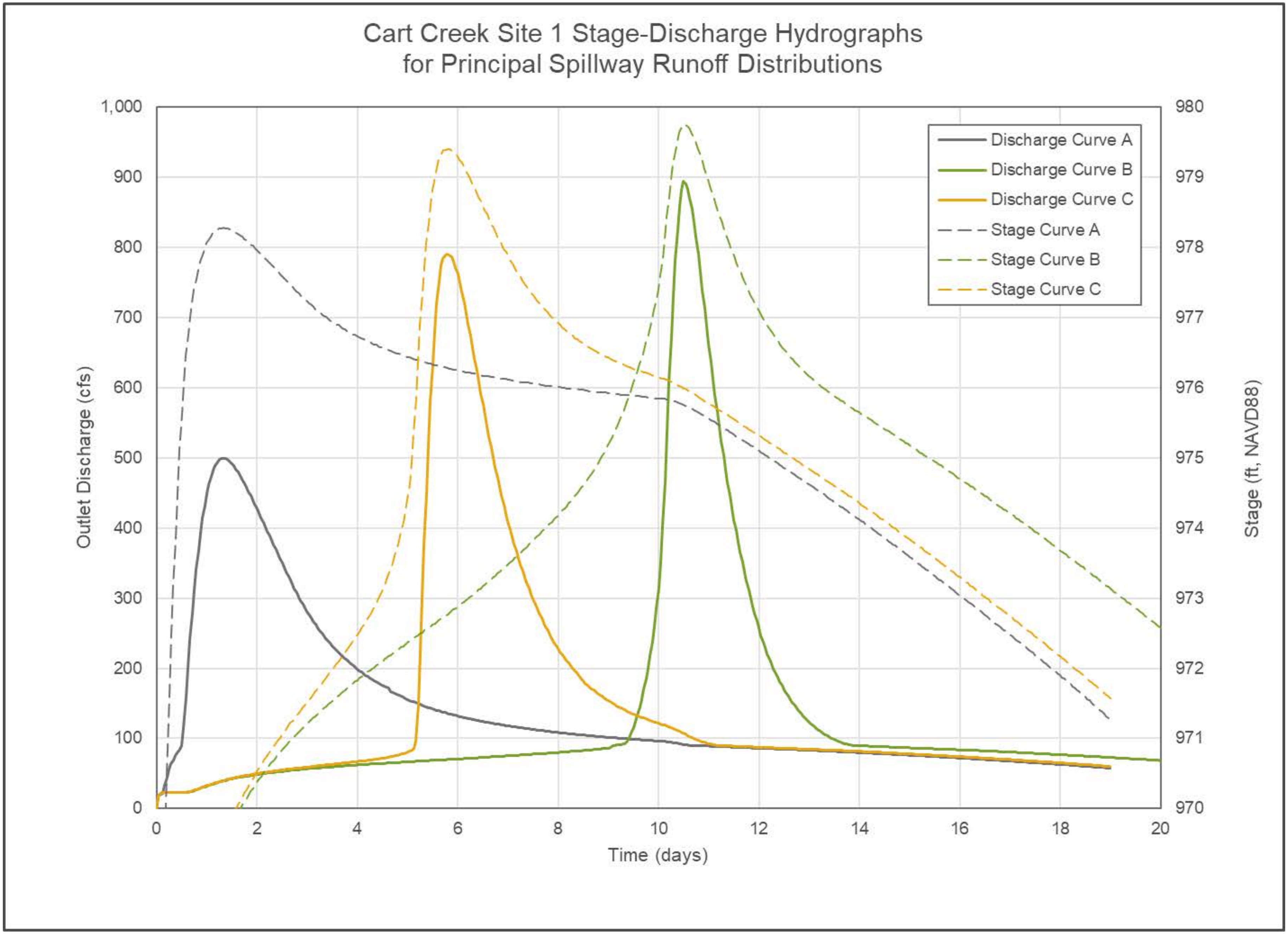


Figure D-3-7.1.1c: Principal Spillway Quick Return Flow (QRF)

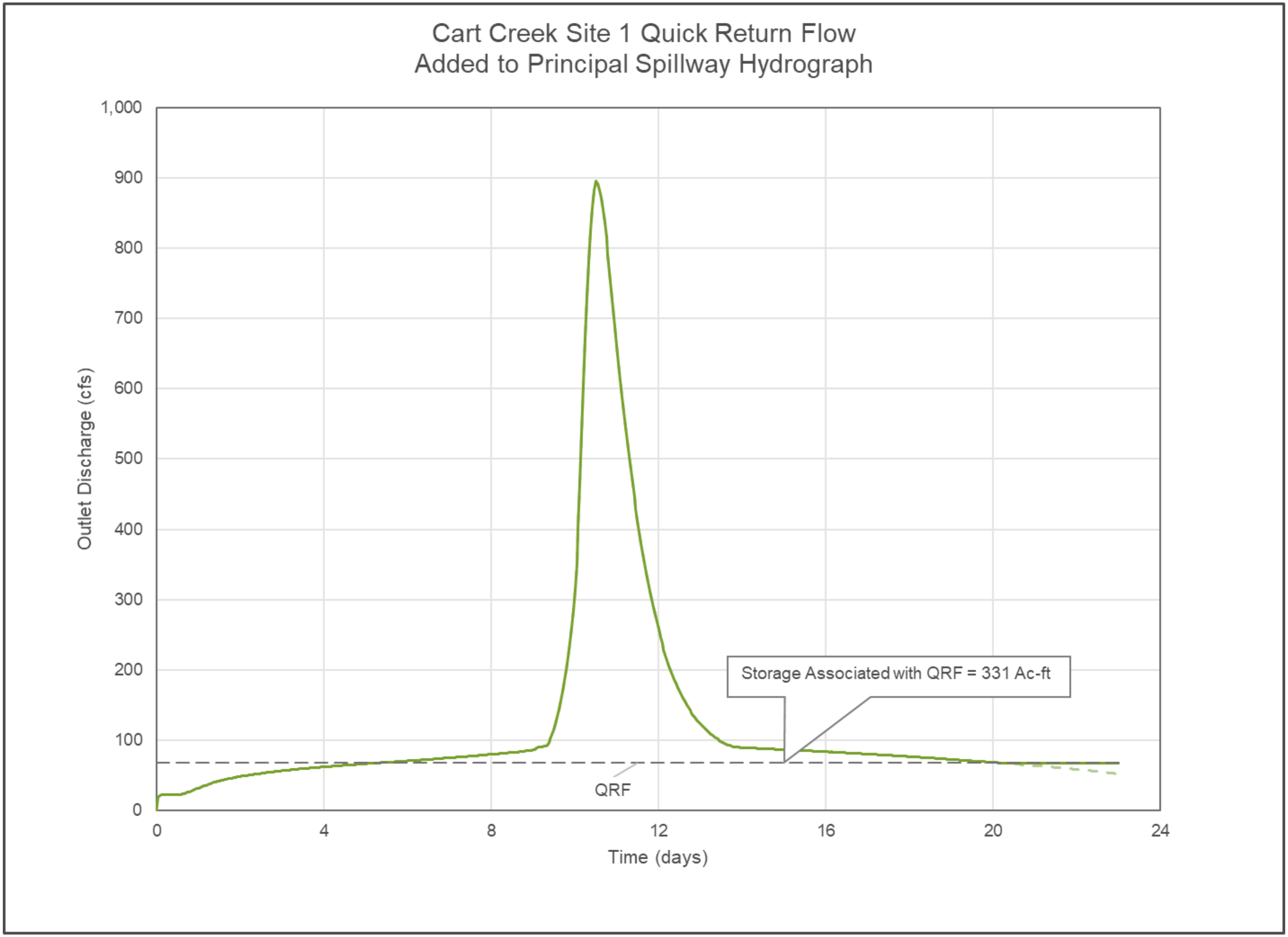


Figure D-3-7.1.2: *Principal Spillway Runoff Curve Number Procedure Hydrograph*

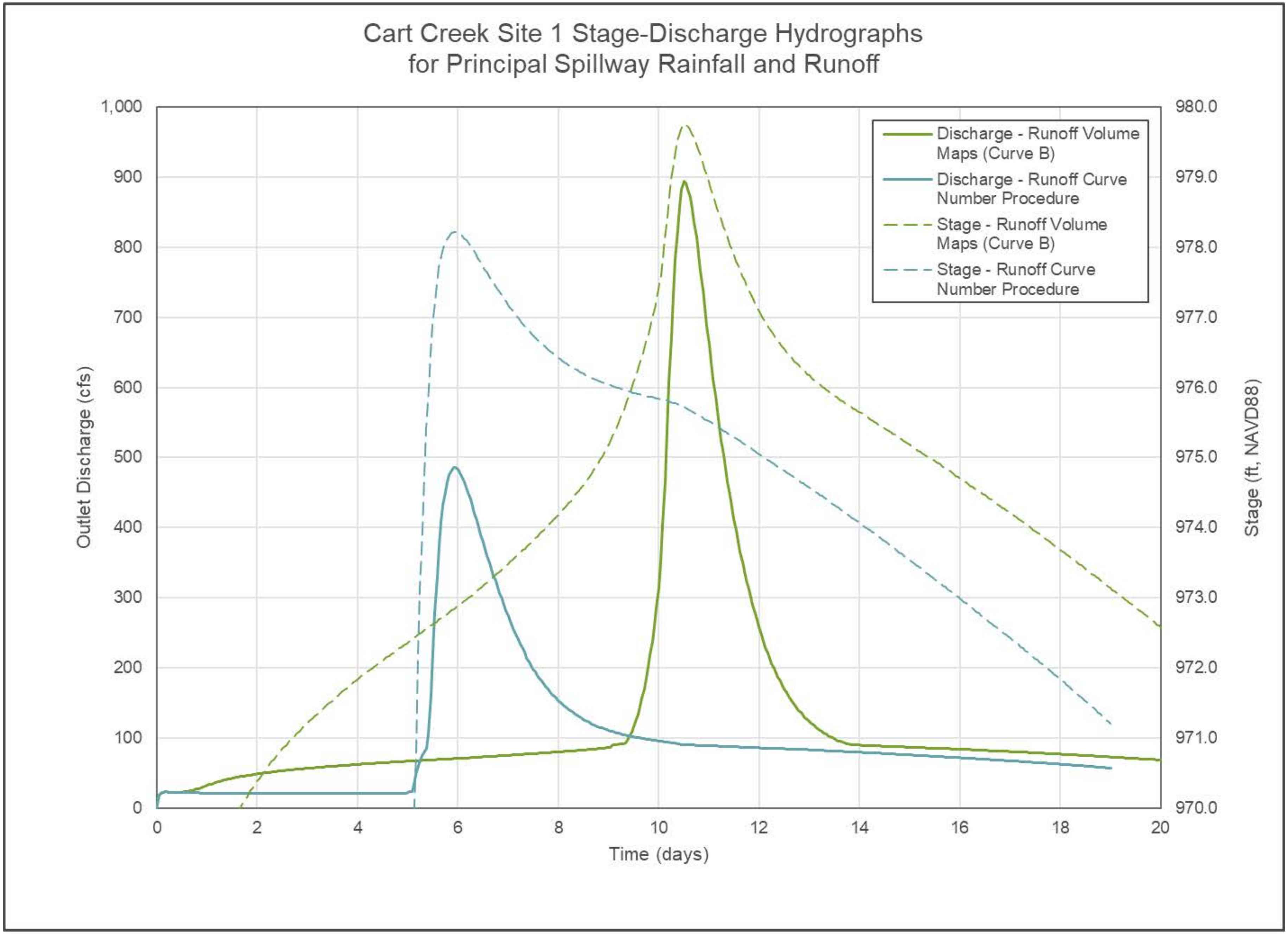


Figure D-3-7.1.3: *Principal Spillway 10-day Drawdown*

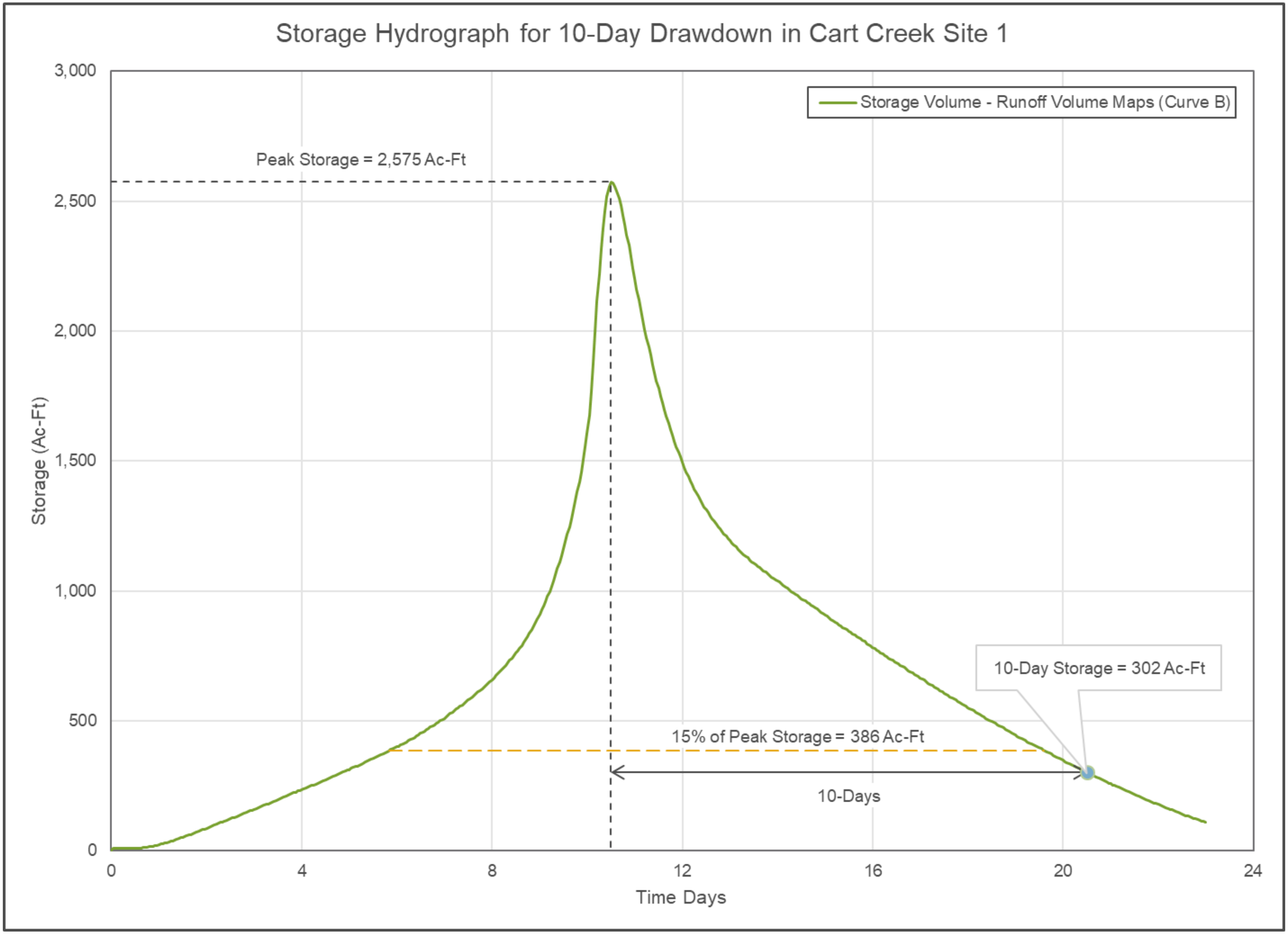


Figure D-3-7.2.1a: *Stability Design Hydrograph – Rainfall Hyetograph and Distribution*

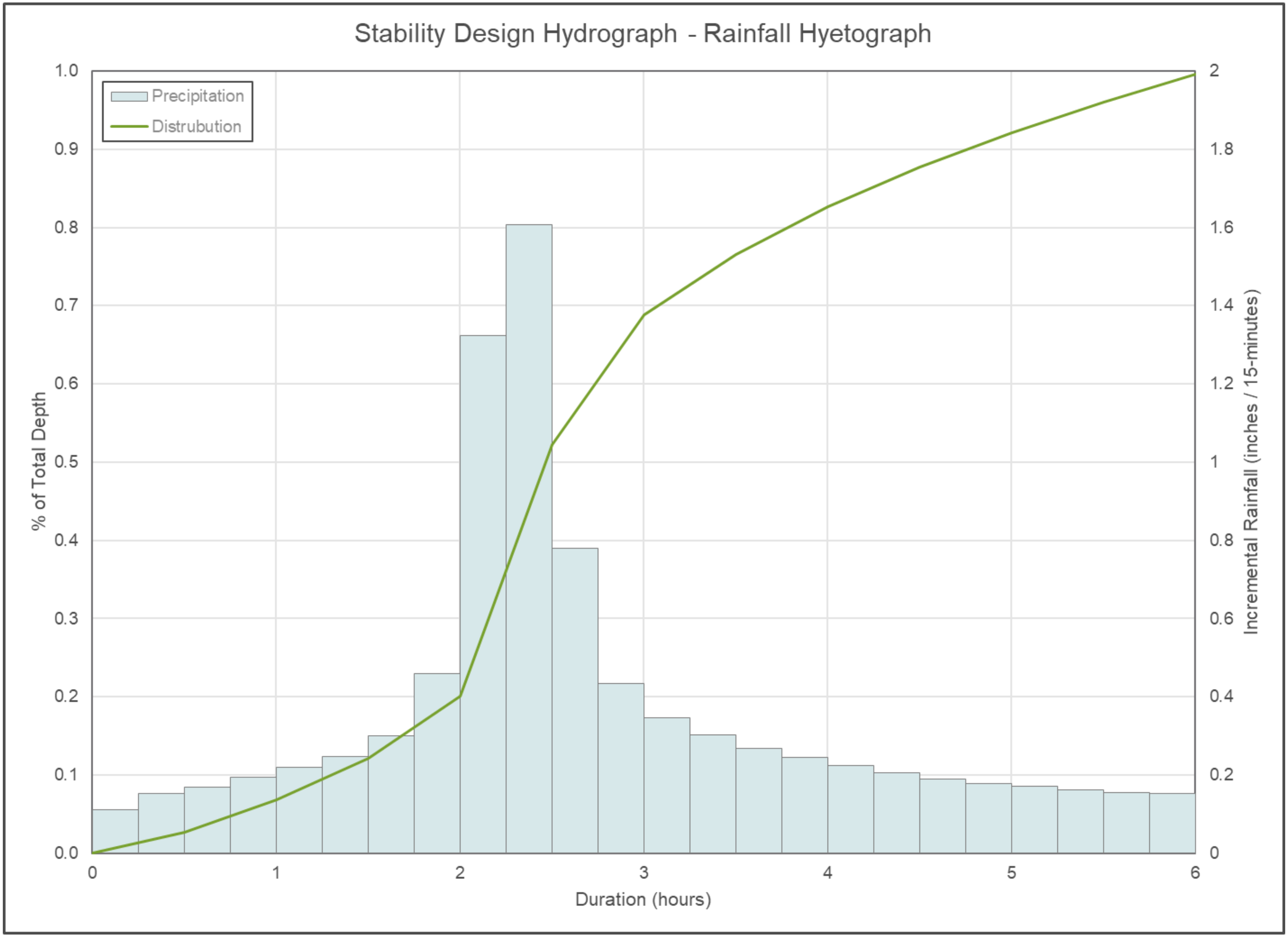


Figure D-3-7.2.1b: Stability Design Hydrograph – Cart Creek Site 1 Stage Hydrograph

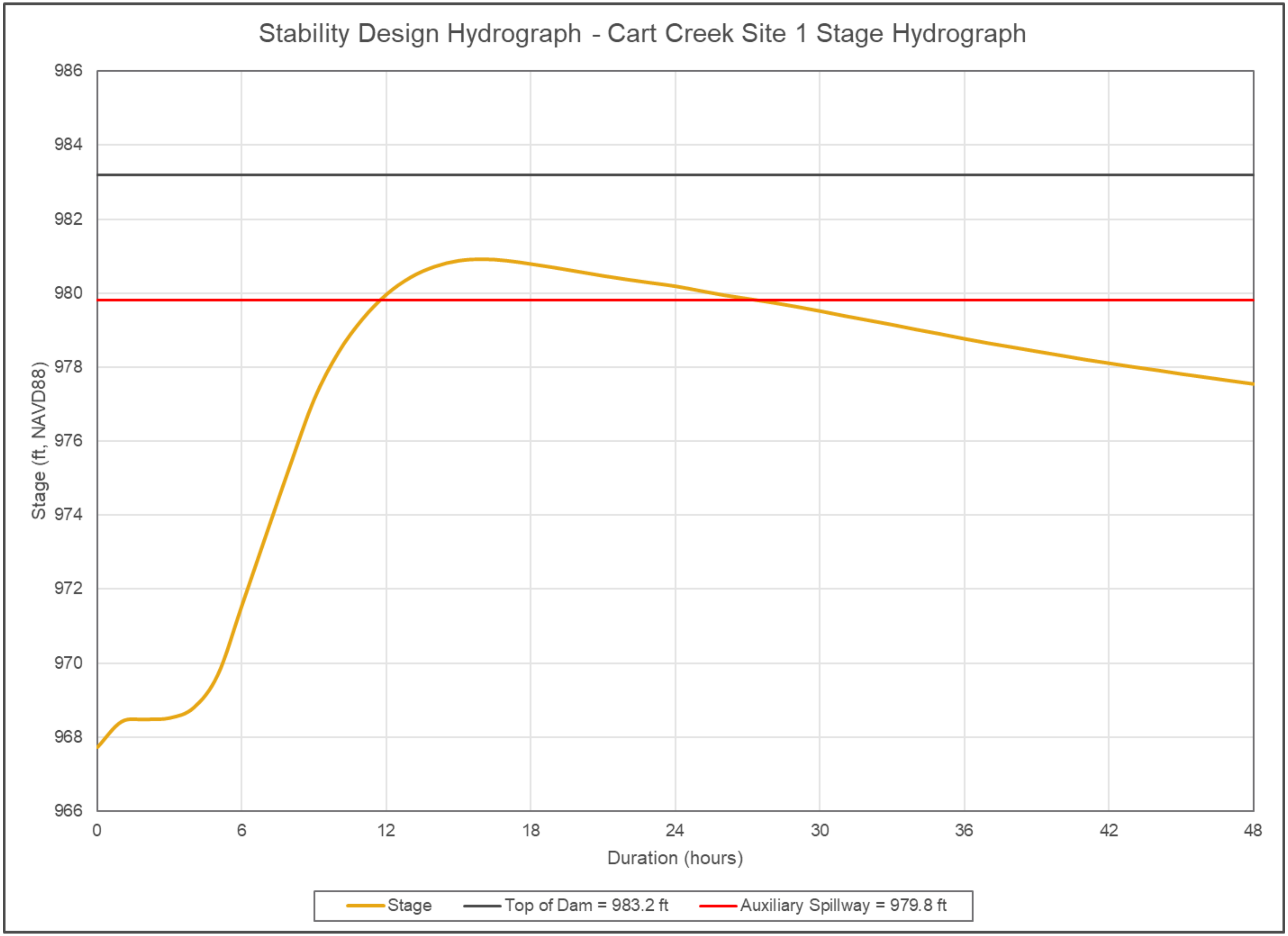


Figure D-3-7.2.1c: *Stability Design Hydrograph – Cart Creek Site 1 Inflow-Outflow Discharge Hydrograph*

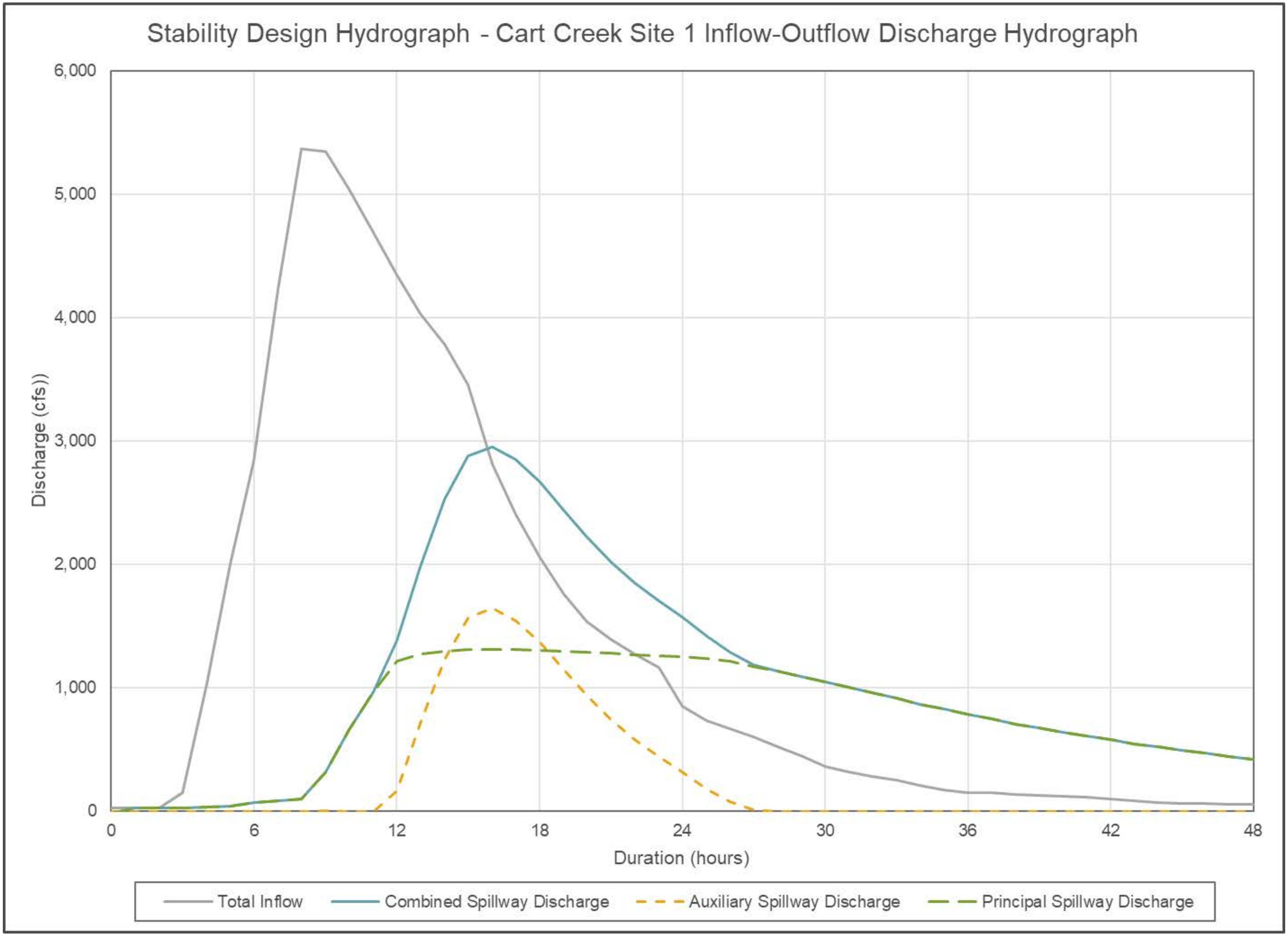


Figure D-3-7.2.2a: Freeboard Hydrograph – Rainfall Hyetograph and Distribution

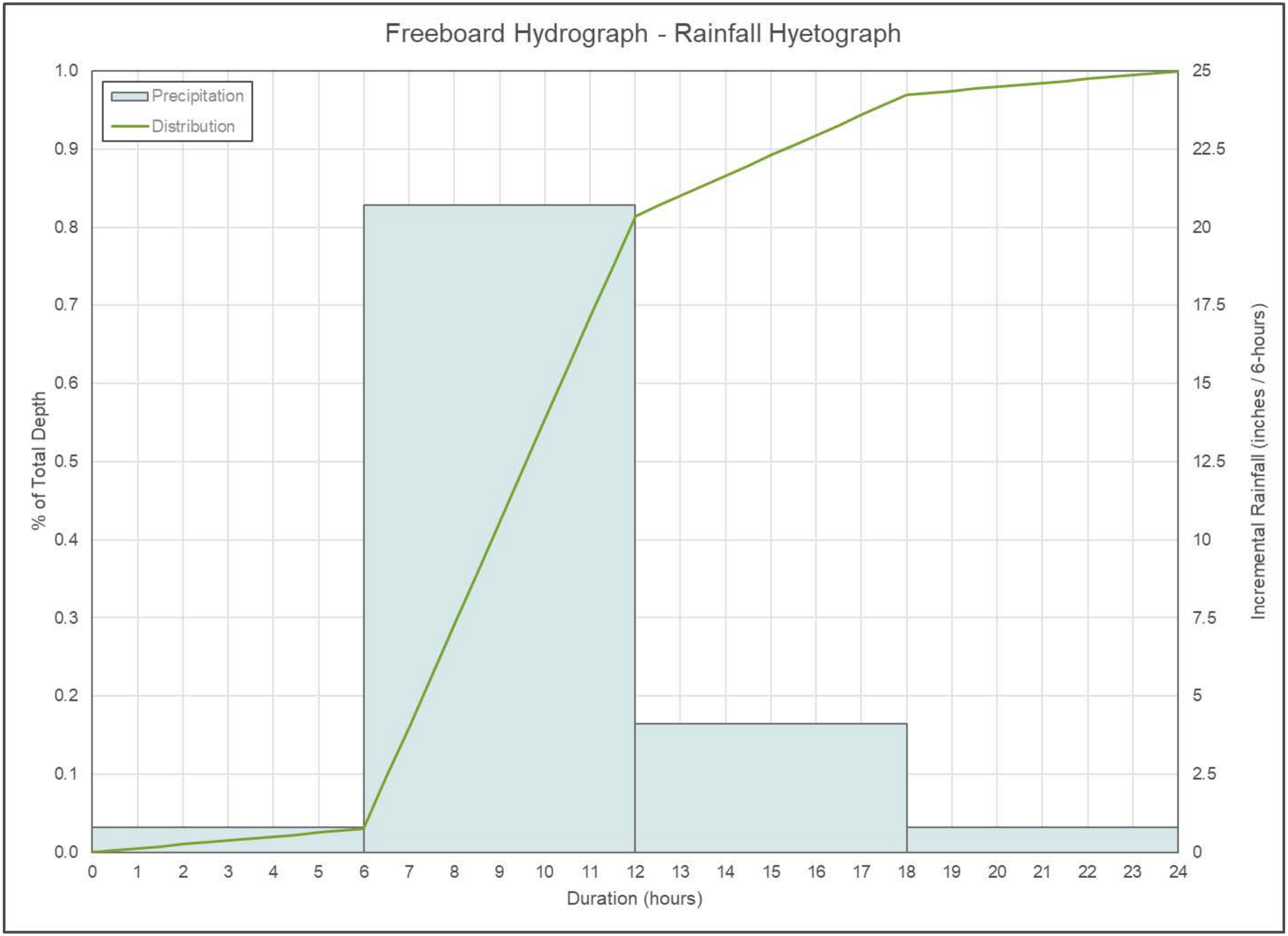


Figure D-3-7.2.2b: *Freeboard Hydrograph – Cart Creek Site 1 Stage Hydrograph*

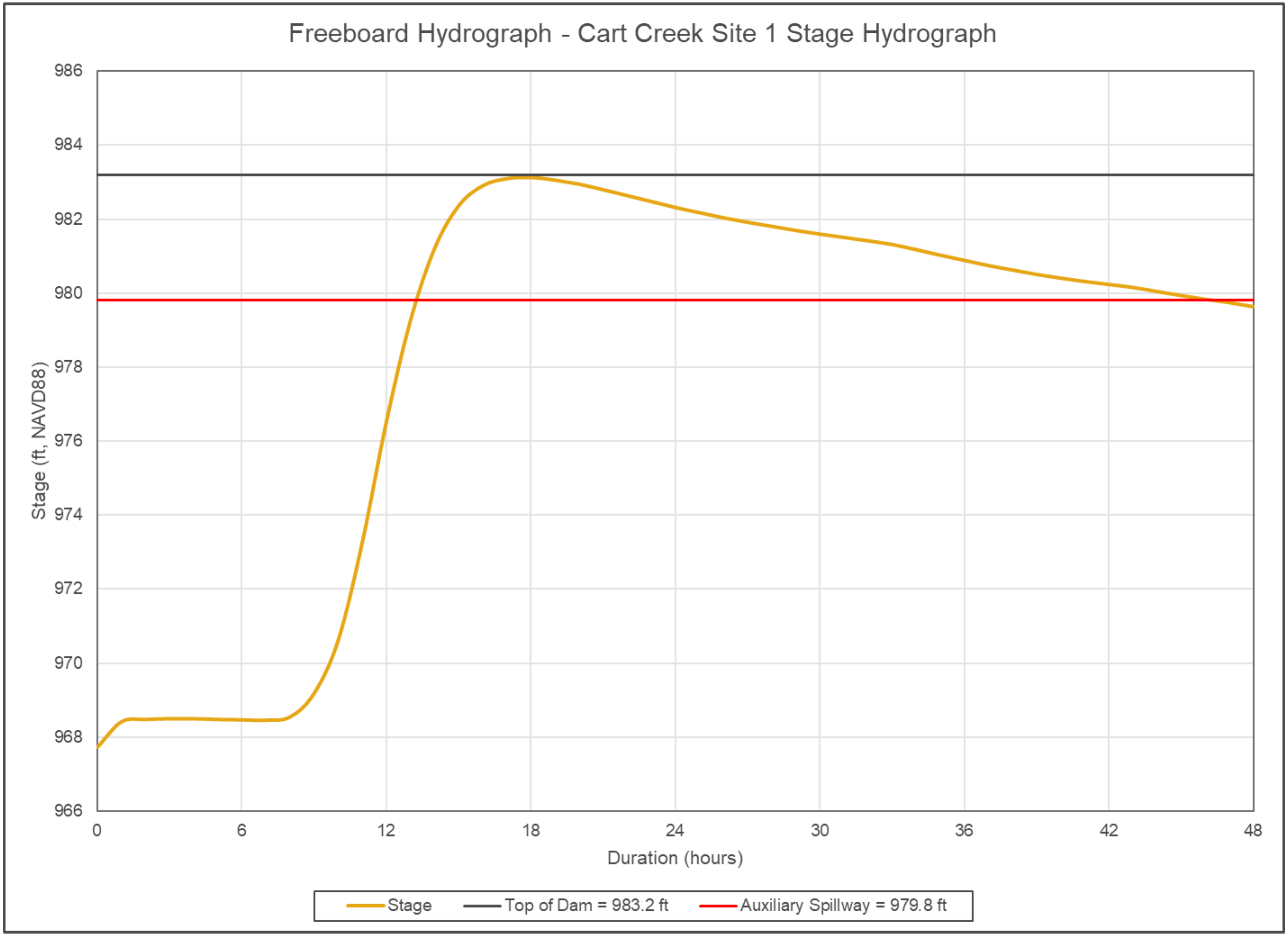


Figure D-3-7.2.2c: *Freeboard Hydrograph – Cart Creek Site 1 Inflow-Outflow Discharge Hydrograph*

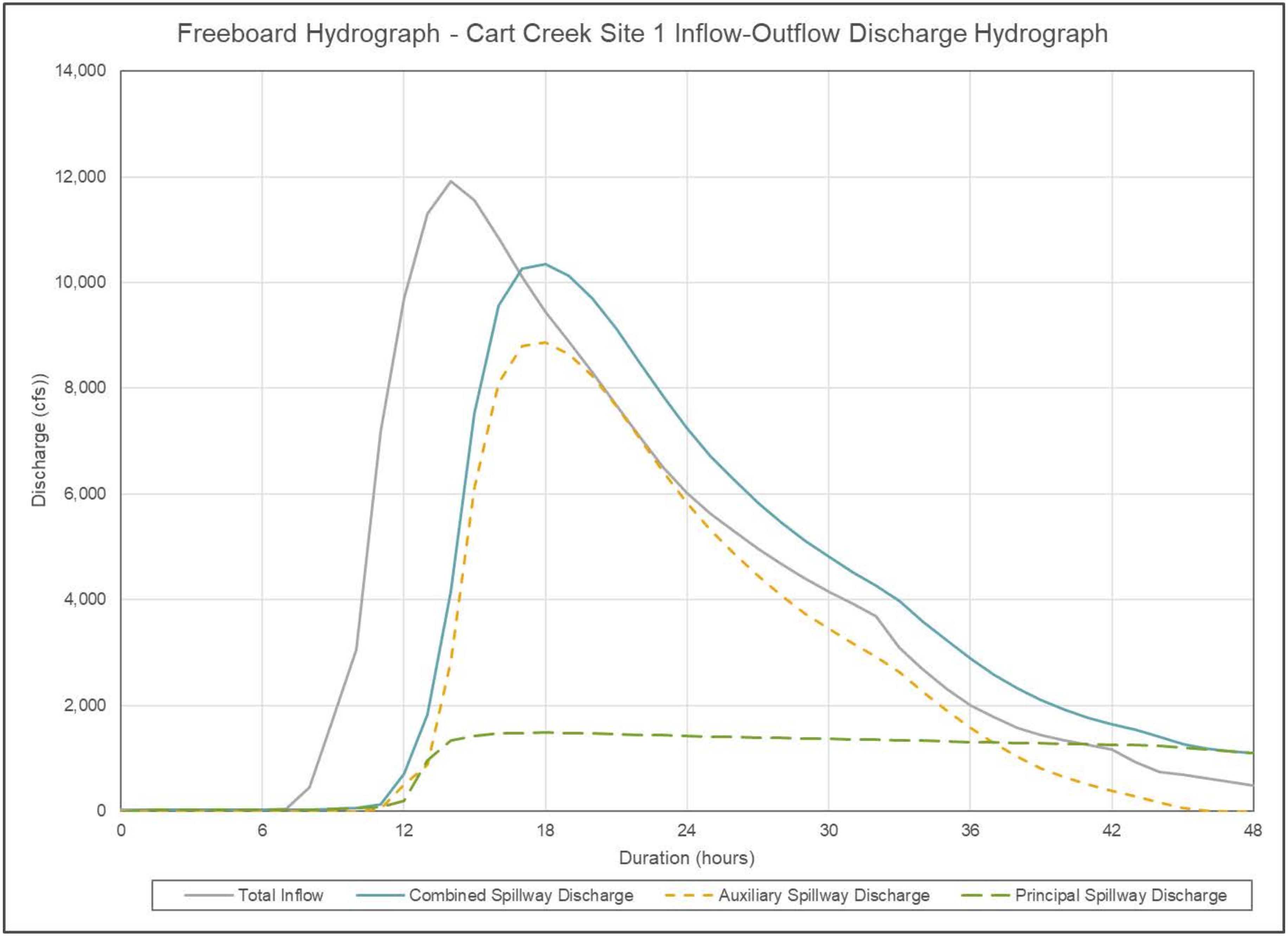
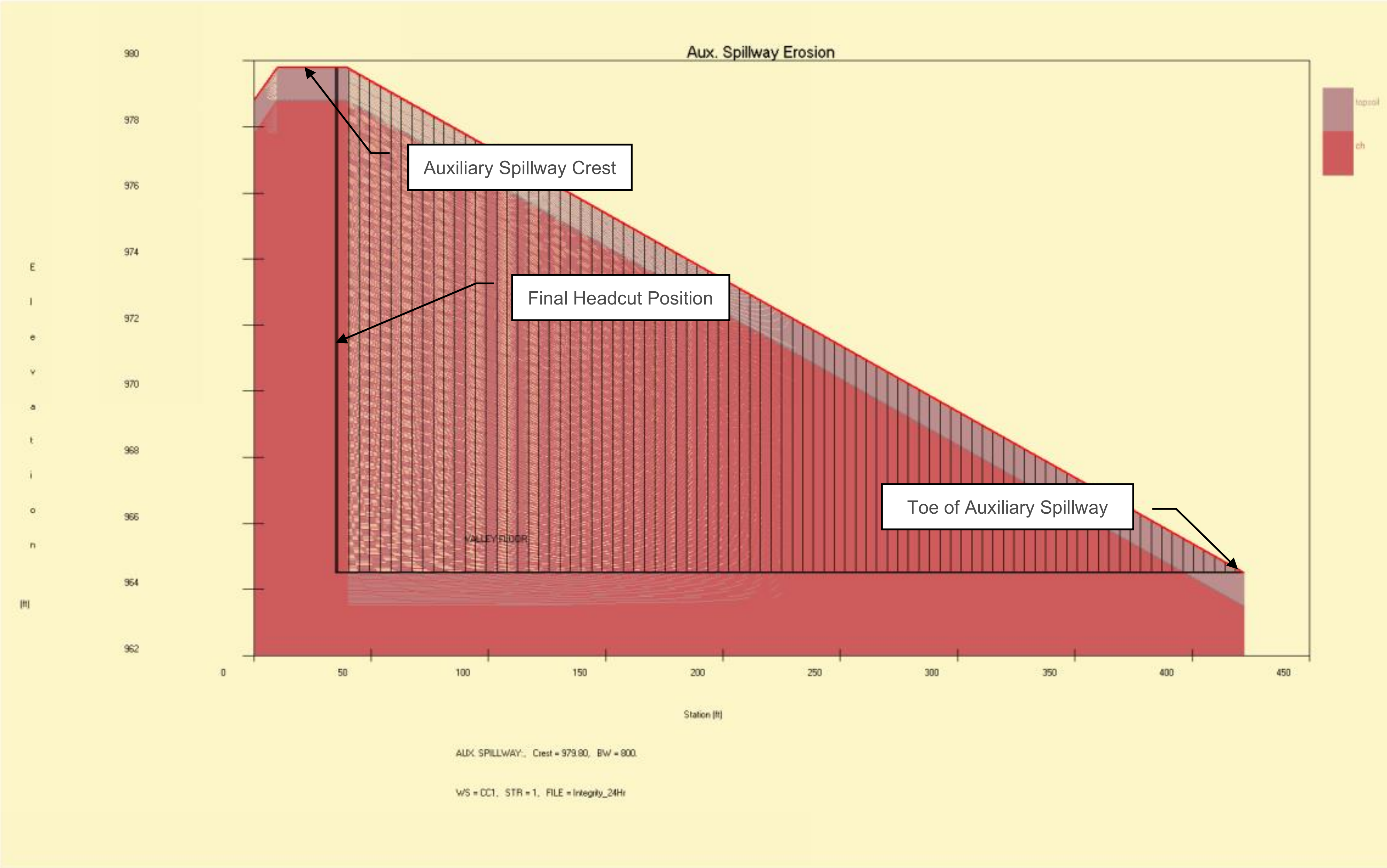


Figure D-3-7.2.2d: *SITES Integrity Analysis – Auxiliary Spillway Erosion*



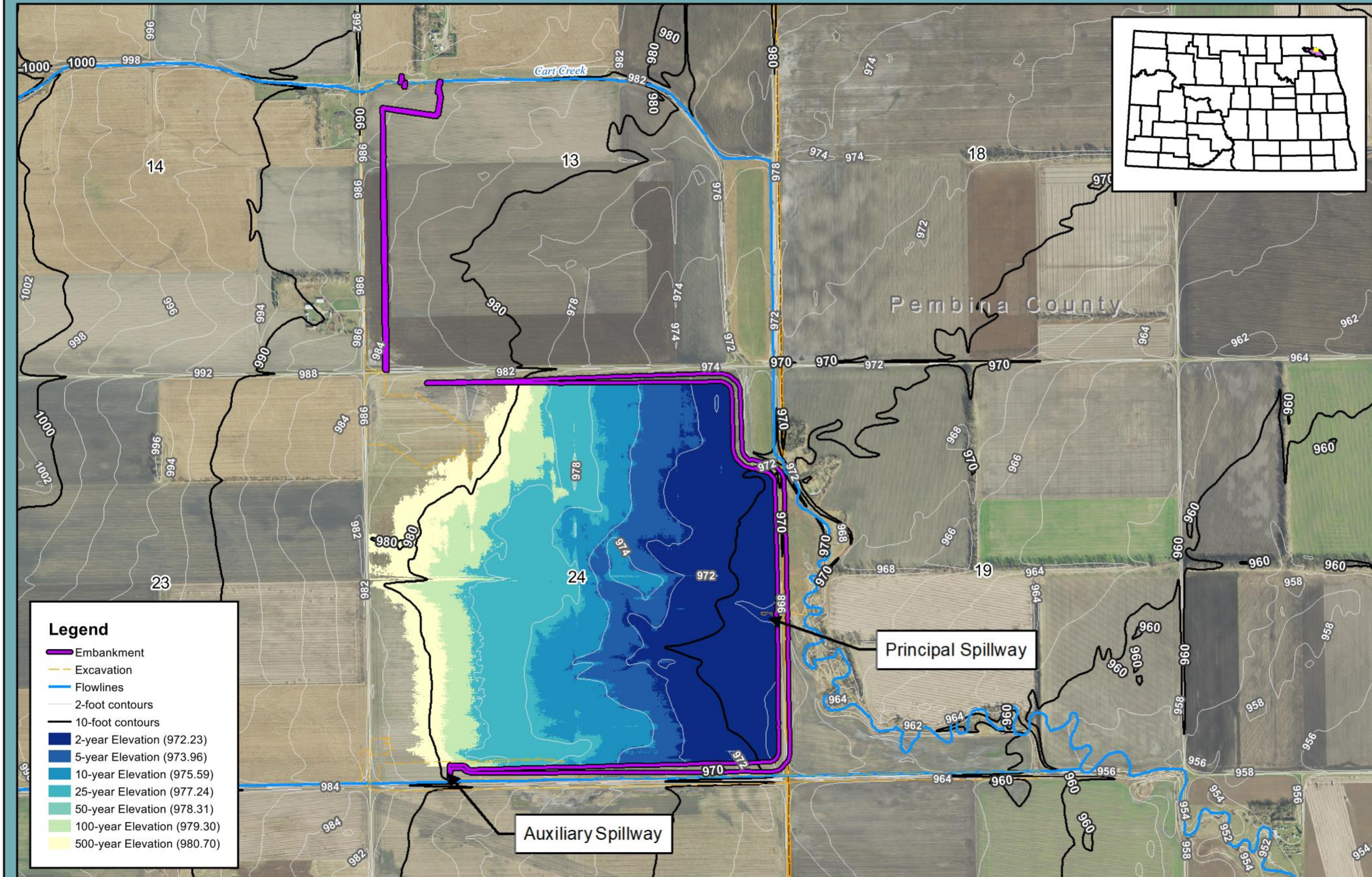


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Figure D-3-7: Cart Creek Site 1 Synthetic Event Flood Pools

North Branch Park River Watershed
Cart Creek Site 1 Concept Design Report
Park River Joint Water Resource District

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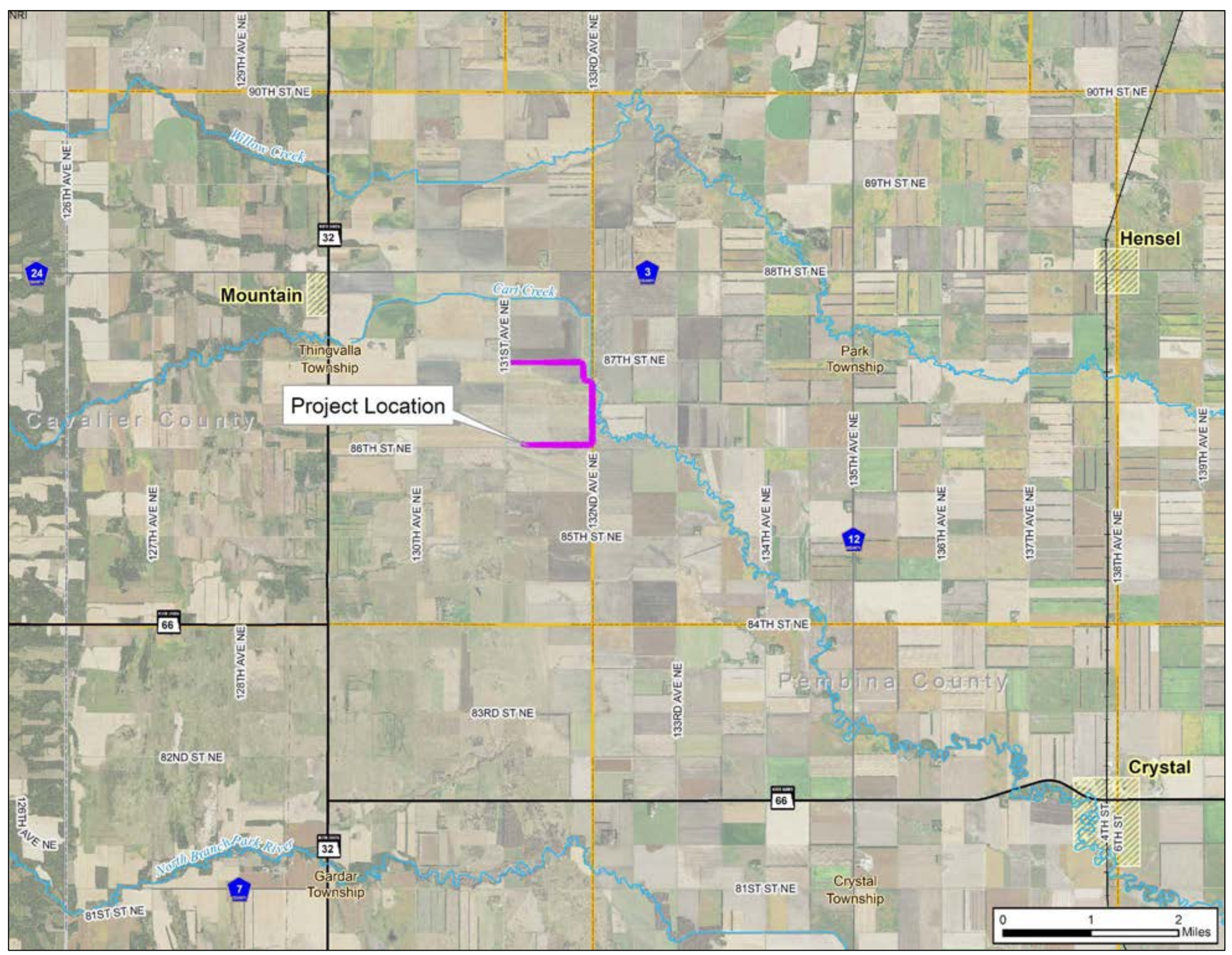
ATTACHMENT D-3-A

Preliminary Design Drawings

PRELIMINARY PLANS (NOT FOR CONSTRUCTION)
FOR
NORTH BRANCH PARK RIVER WATERSHED
CART CREEK SITE 1 DETAILED REVIEW
PARK RIVER JOINT WATER RESOURCE DISTRICT
GRAFTON, NORTH DAKOTA
APRIL, 2023



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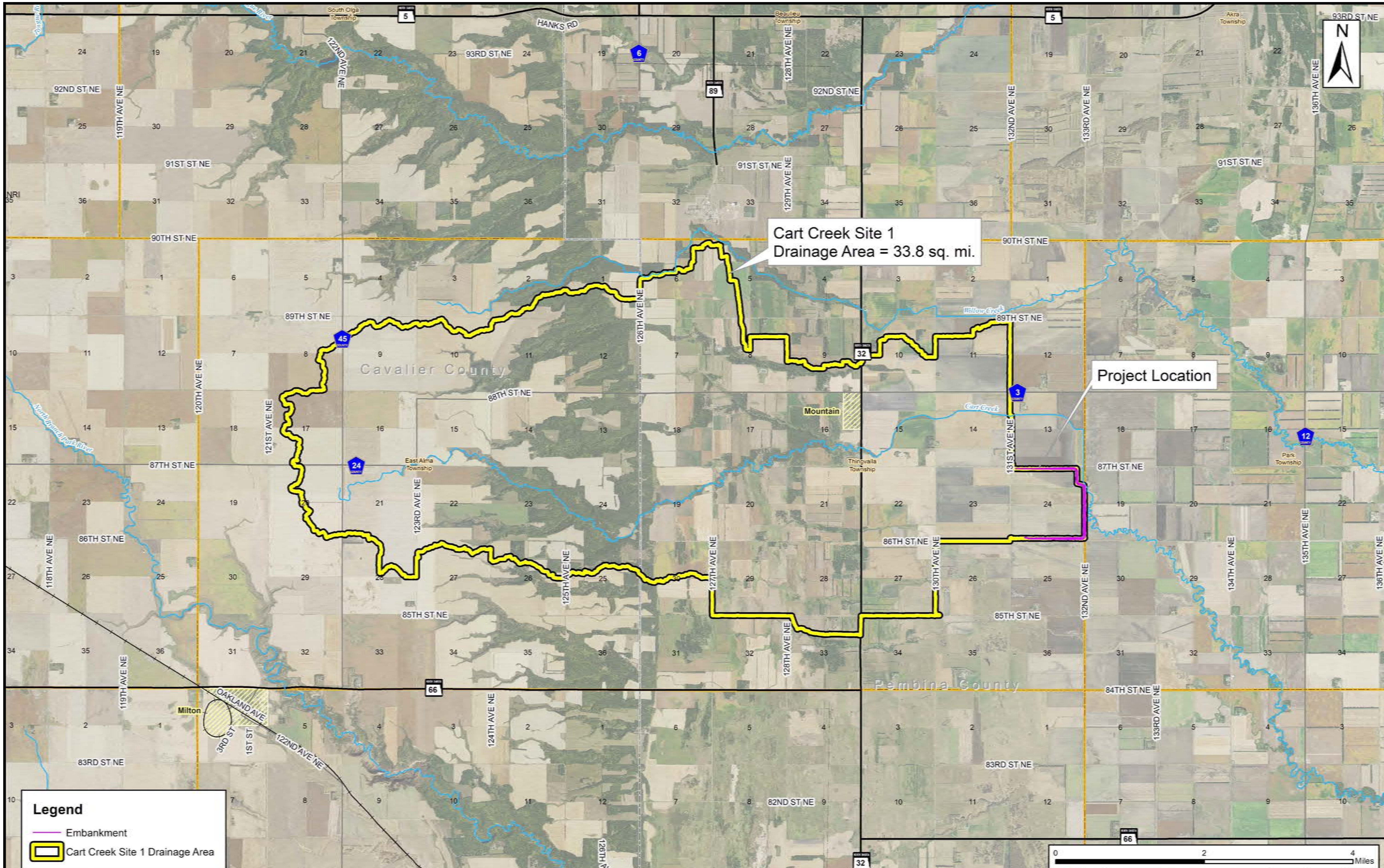

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GRAFTON, NORTH DAKOTA

DRAINAGE AREA MAP

PROJECT NO. 8150-0002

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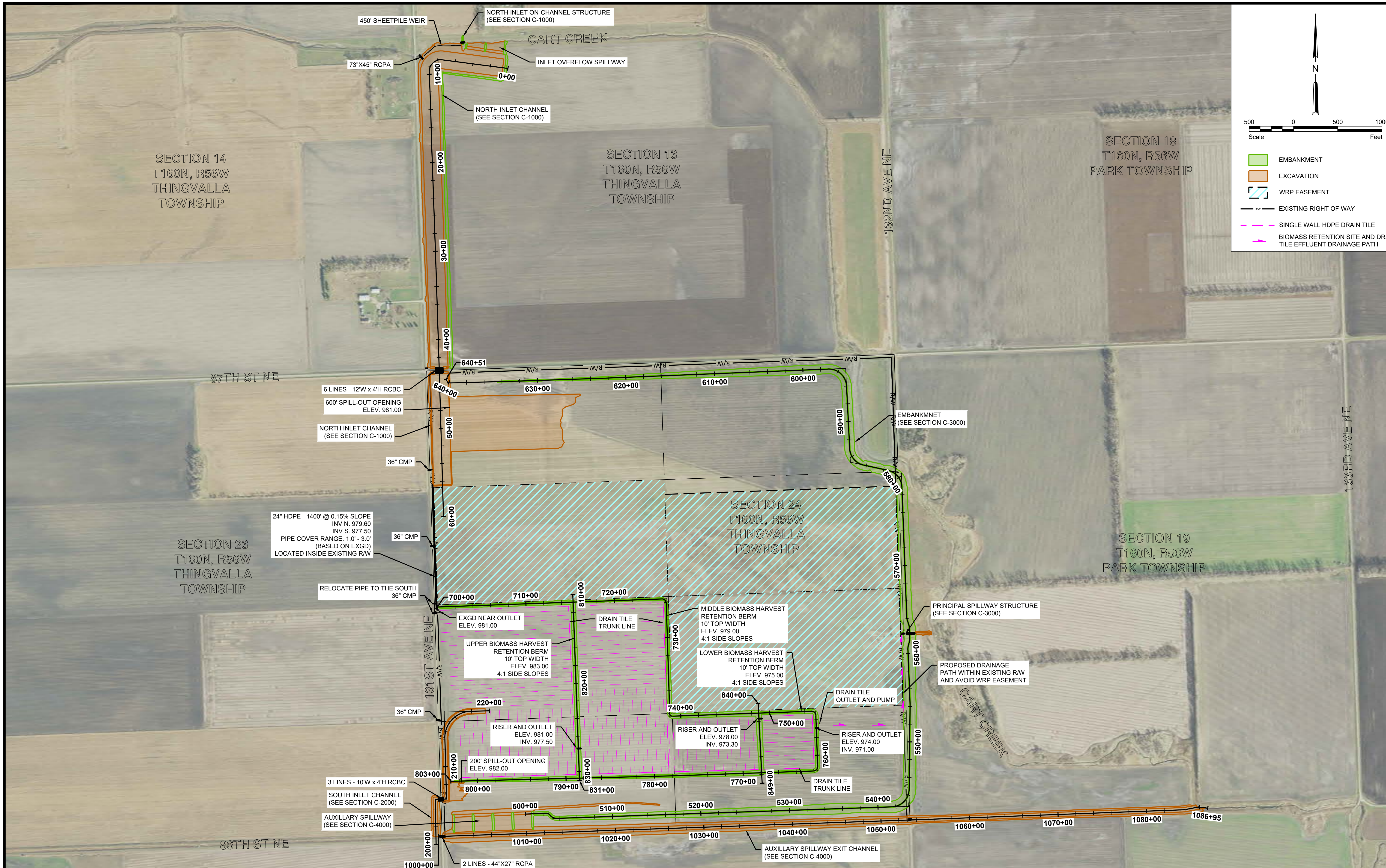

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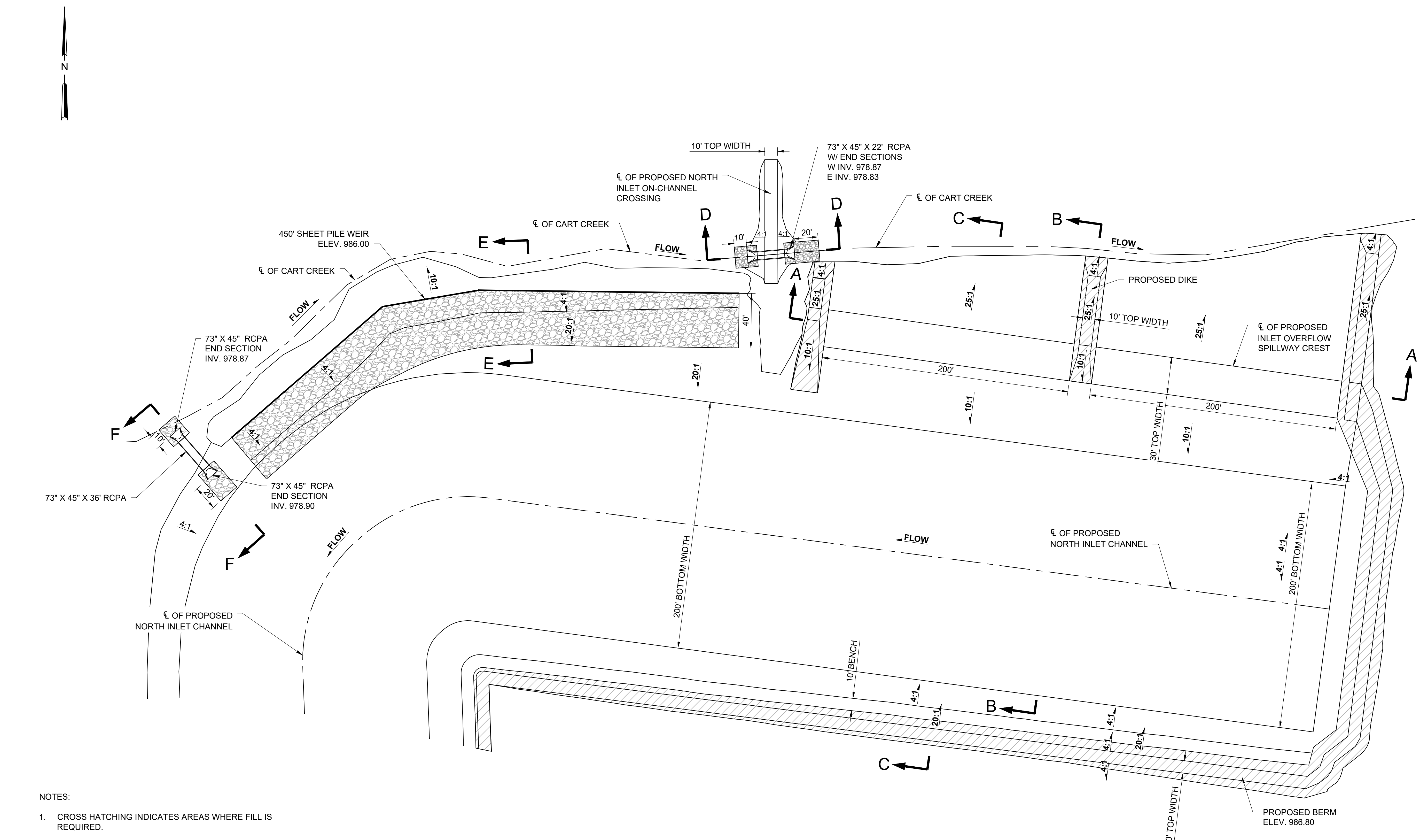

NOTES:

1. CROSS HATCHING INDICATES AREAS WHERE FILL IS REQUIRED.
2. EARTHEN SPILLWAYS ARE DIVIDED INTO BAYS OF 200 FOOT SECTIONS PER GUIDANCE FROM THE NATIONAL ENGINEERING HANDBOOK, PART 628, CHAPTER 50.

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PROJECT NO. 8150-0002

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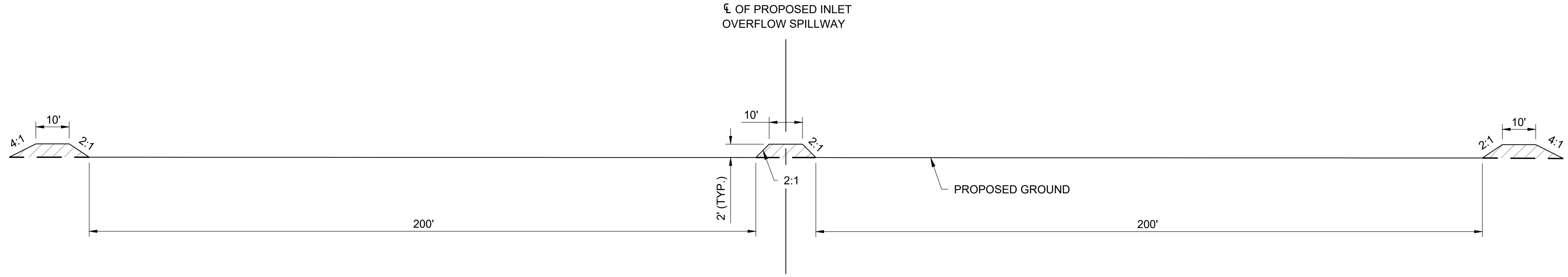

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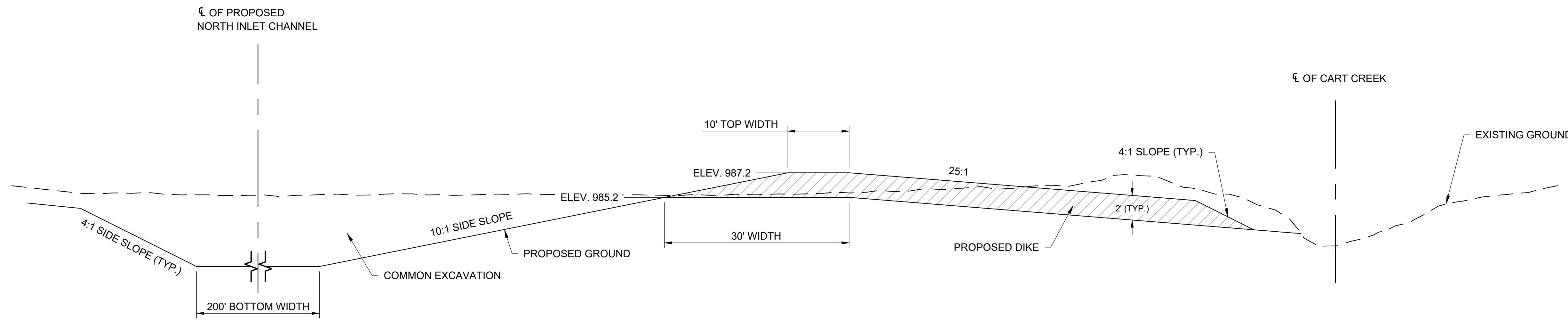

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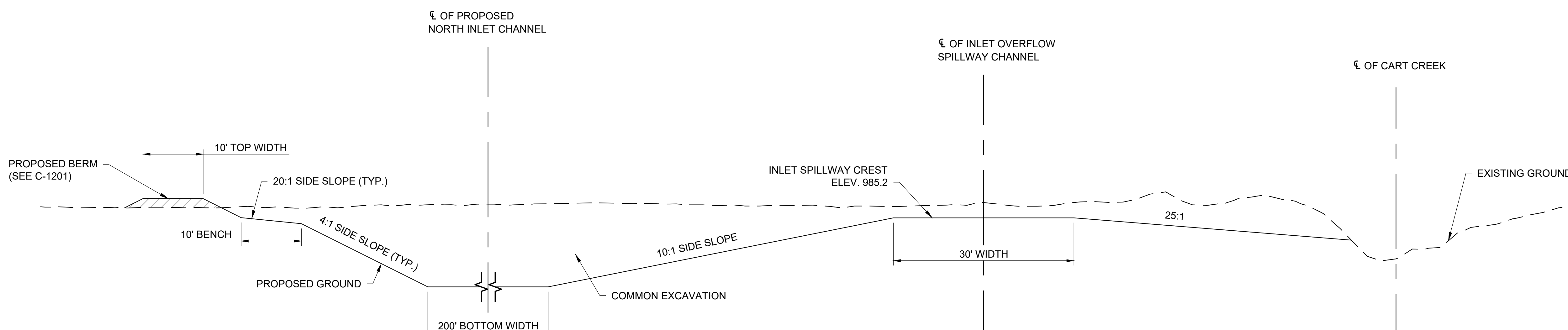

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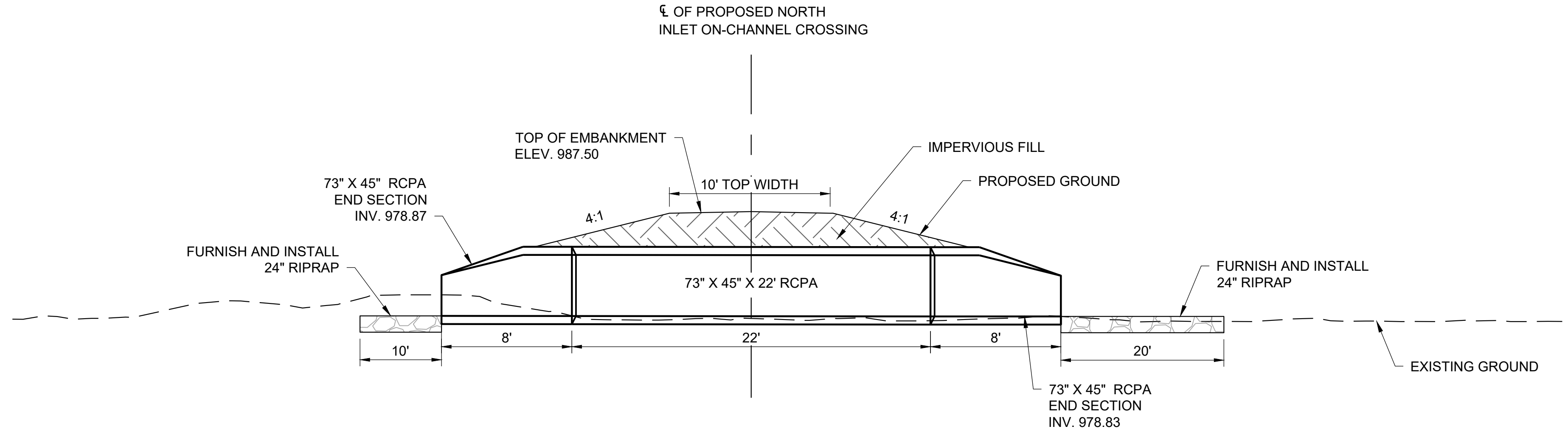

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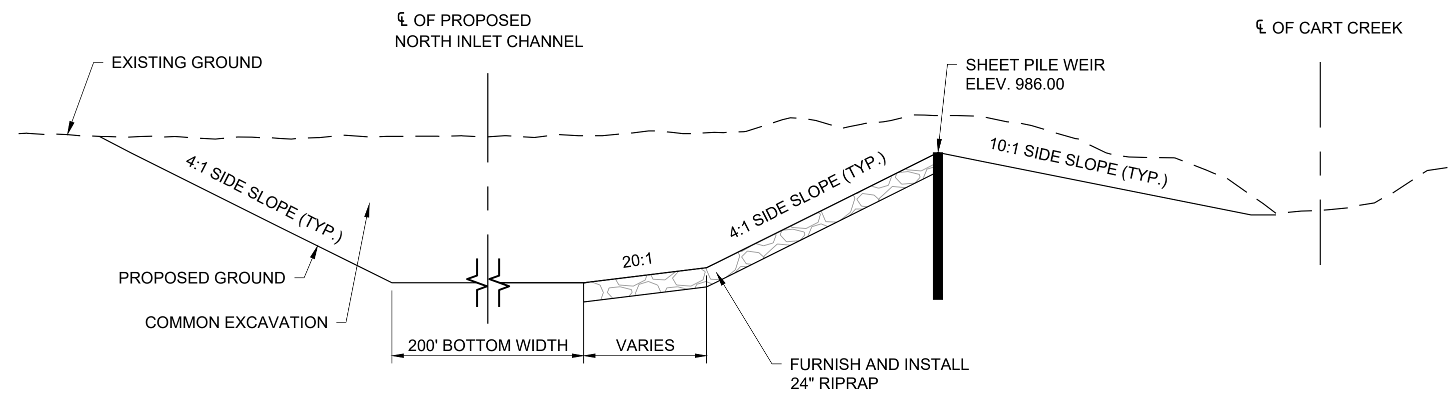

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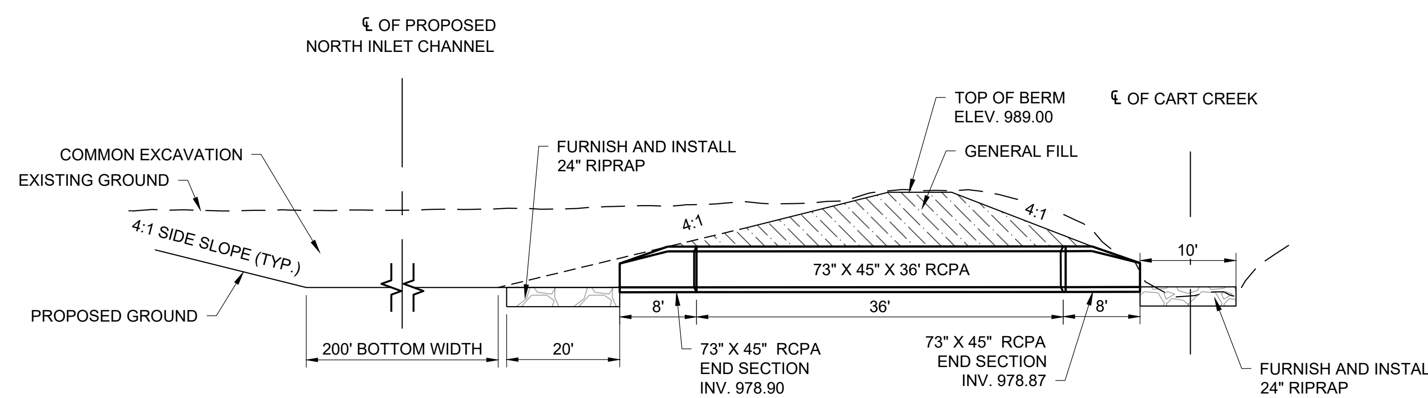

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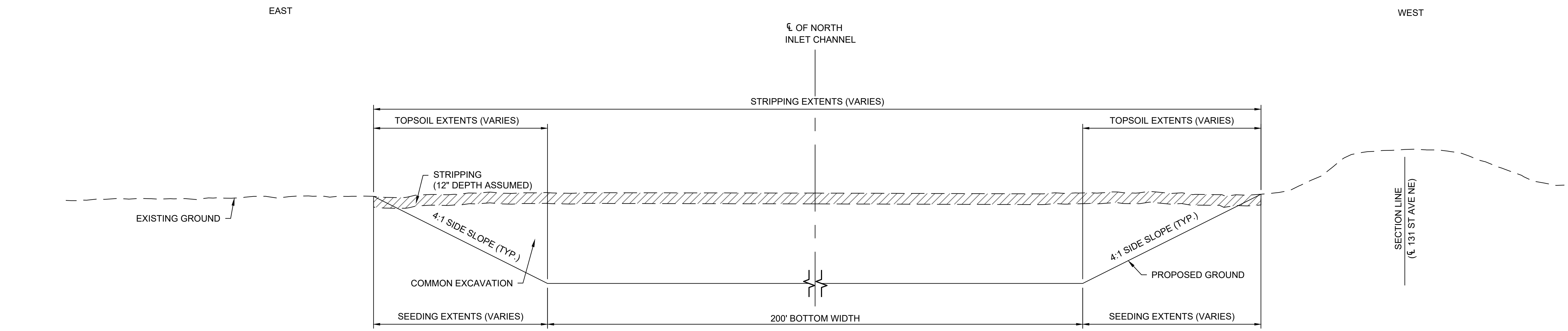

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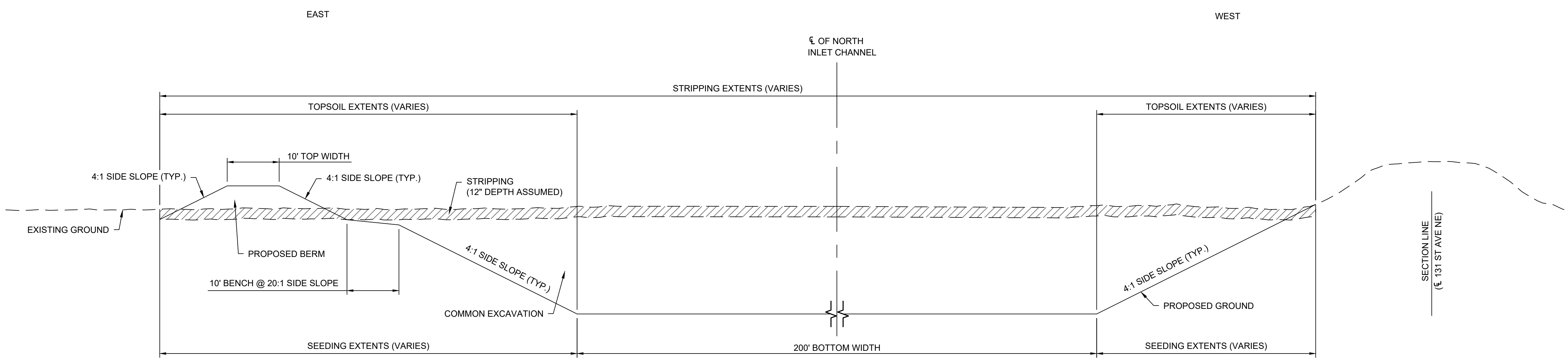

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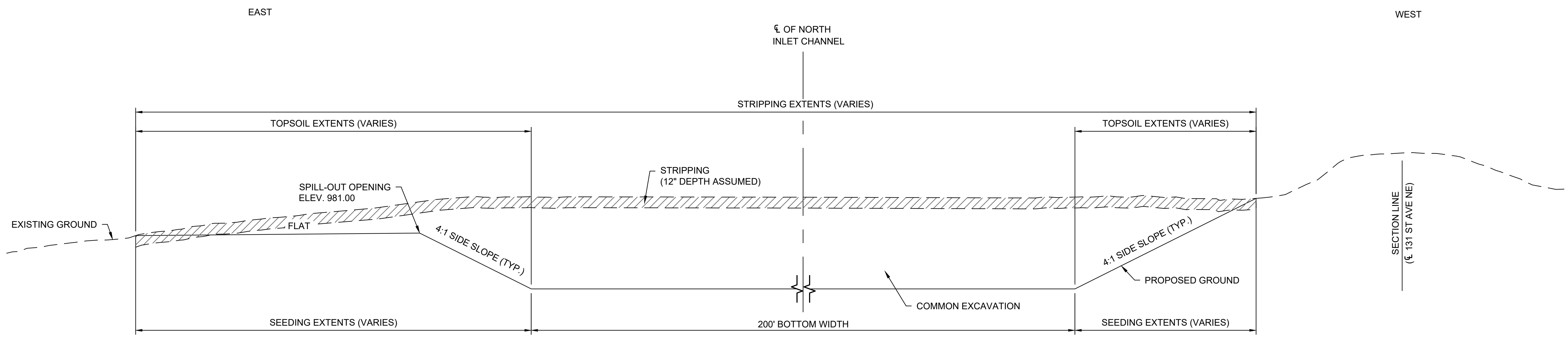

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PARK RIVER JOINT WATER RESOURCE DISTRICT
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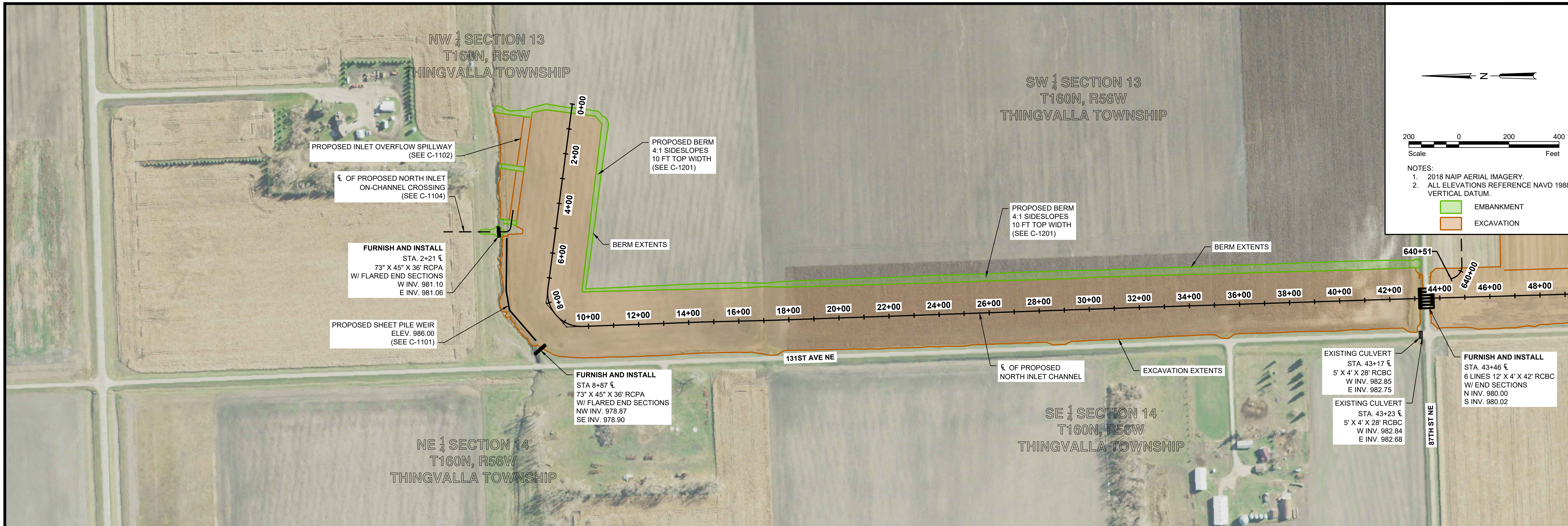

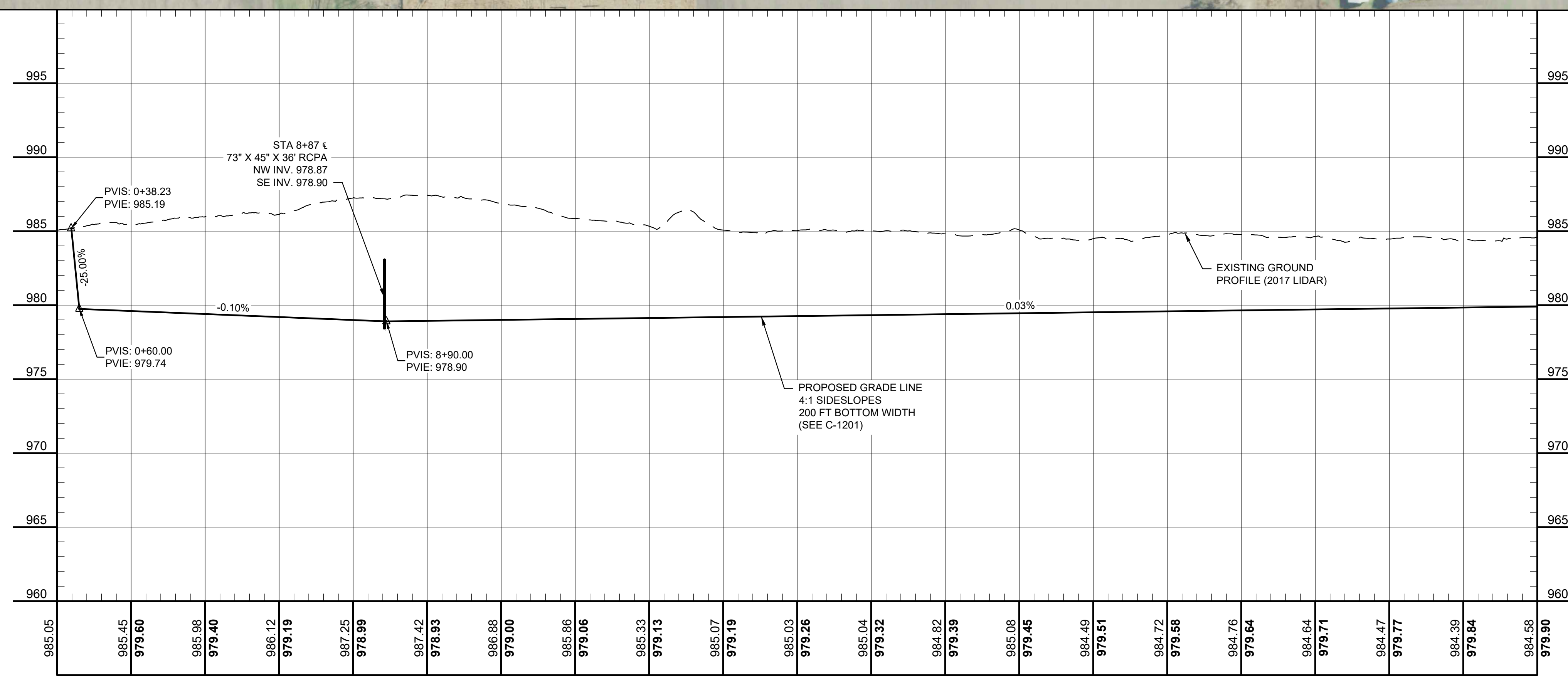

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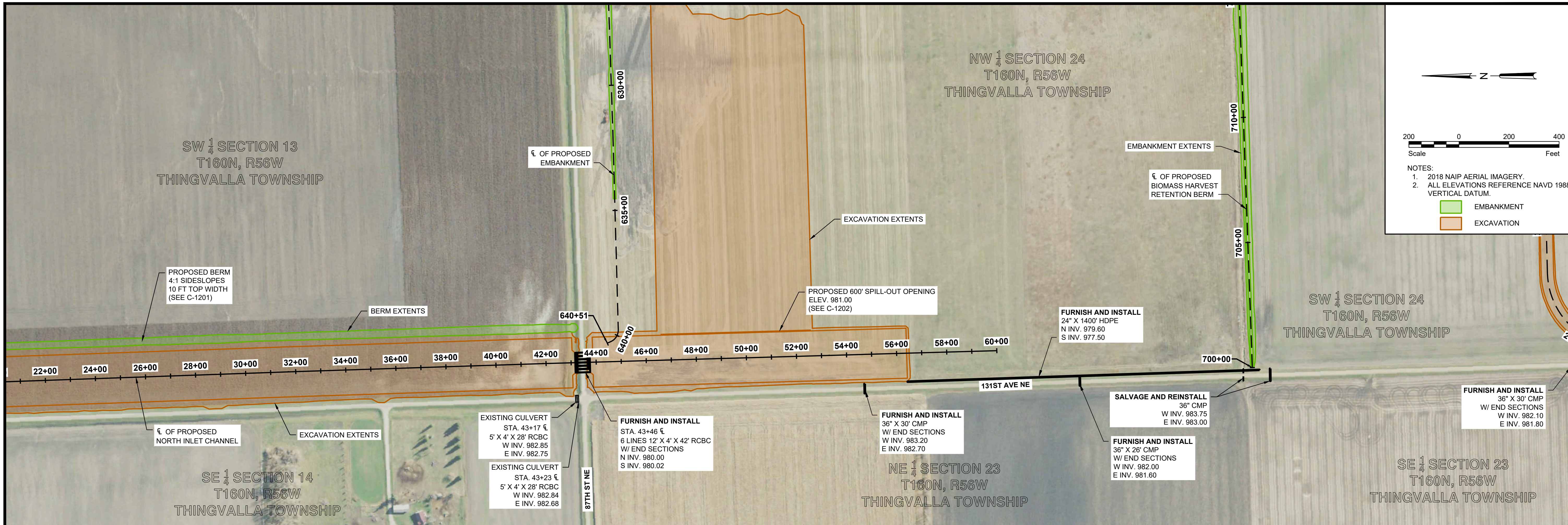

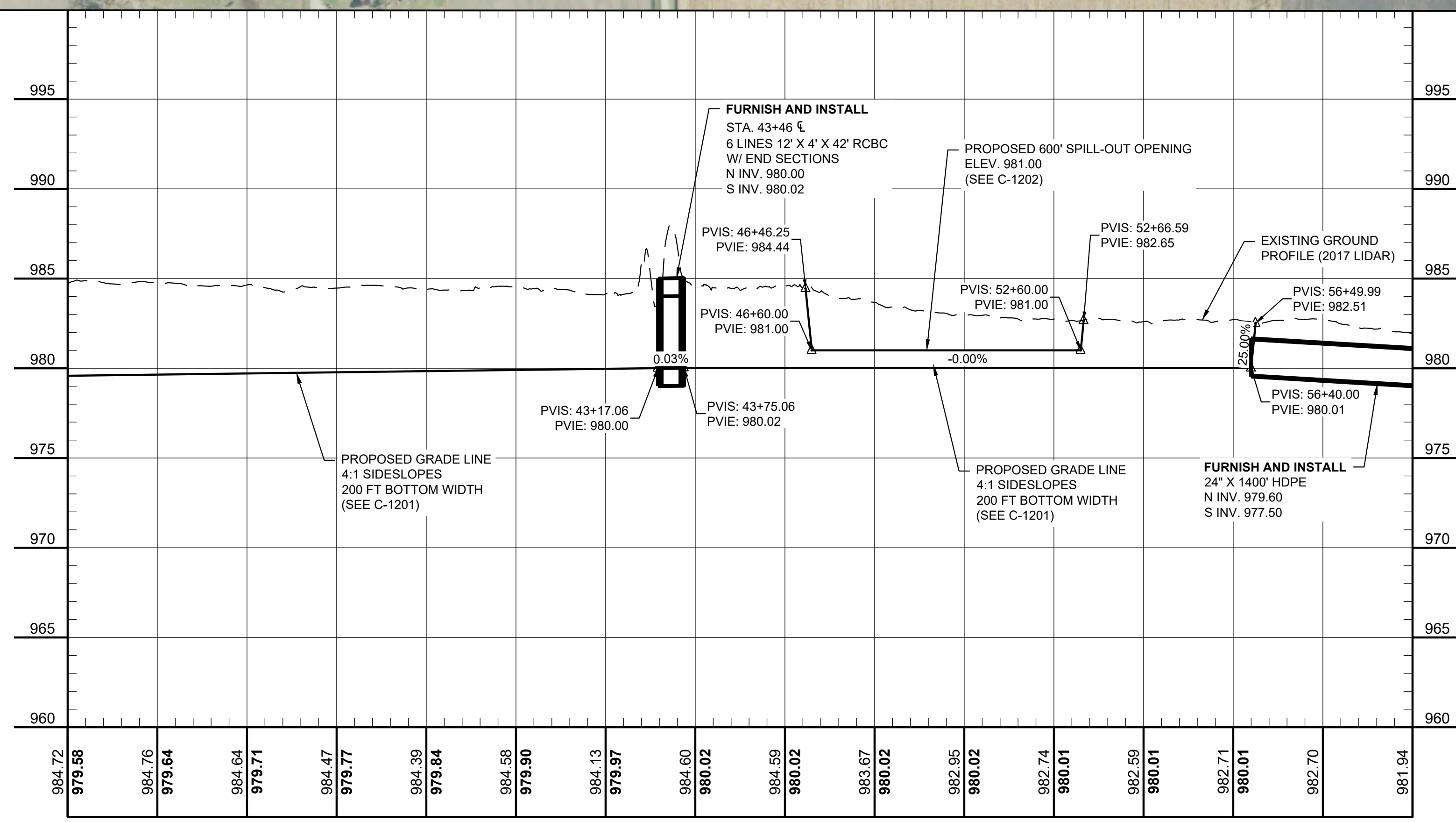

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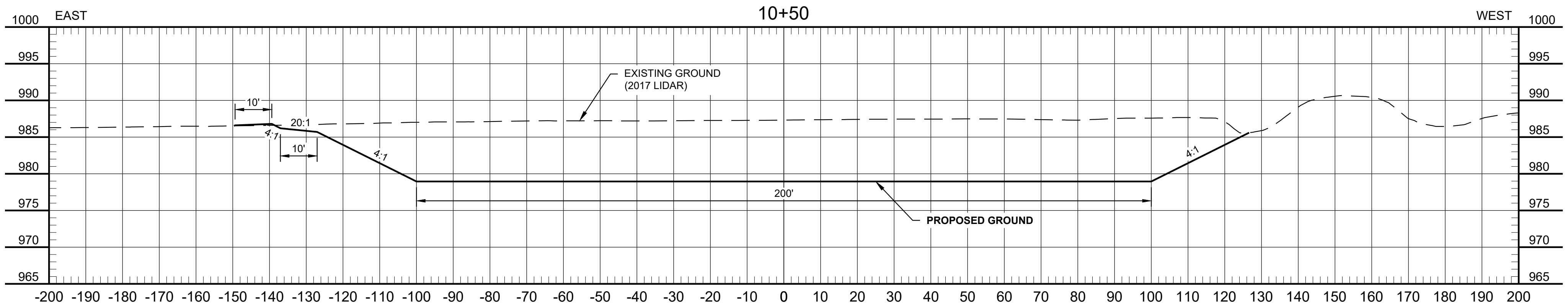

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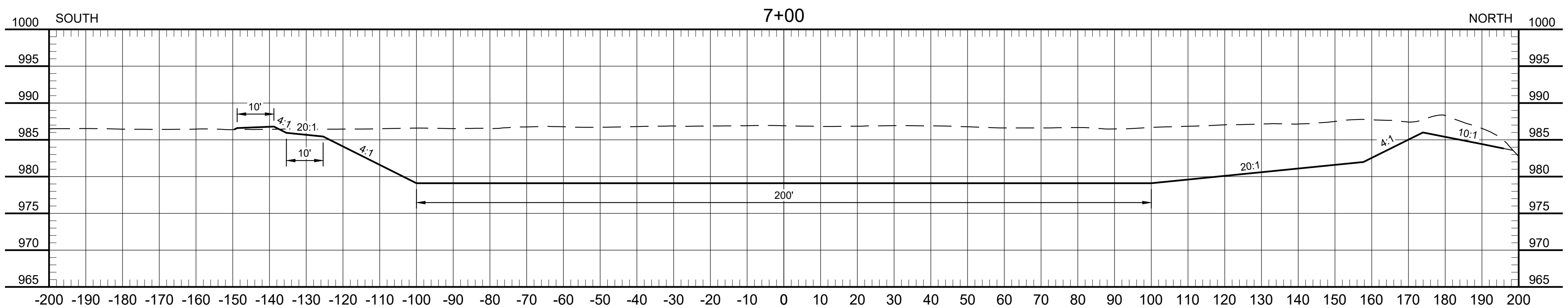

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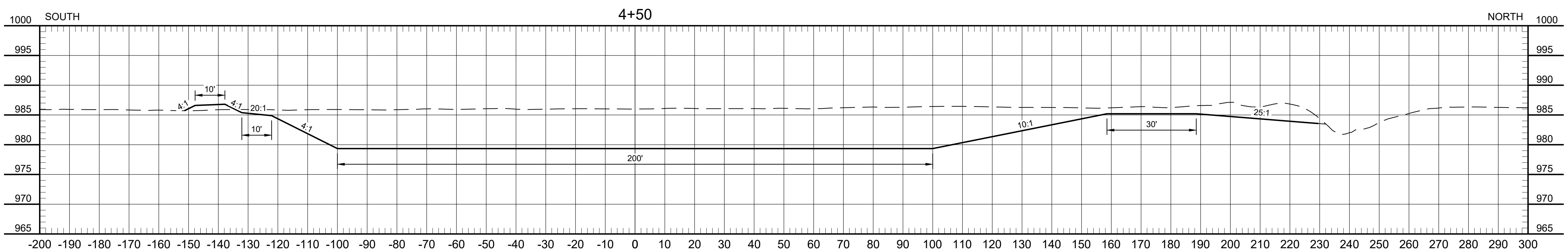

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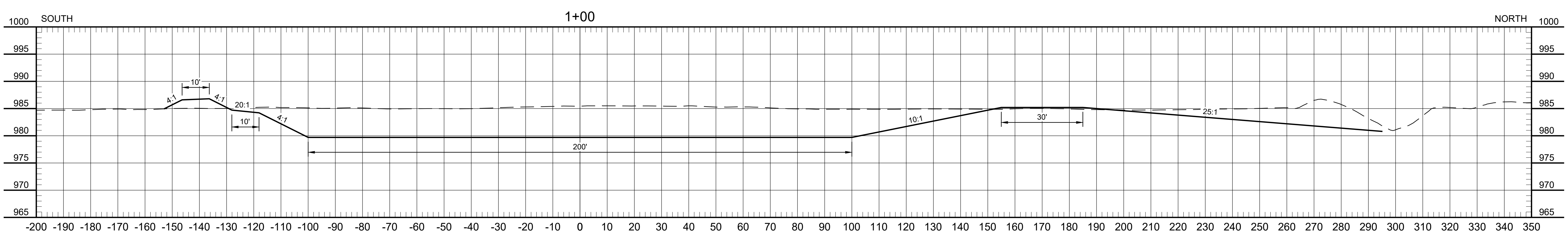

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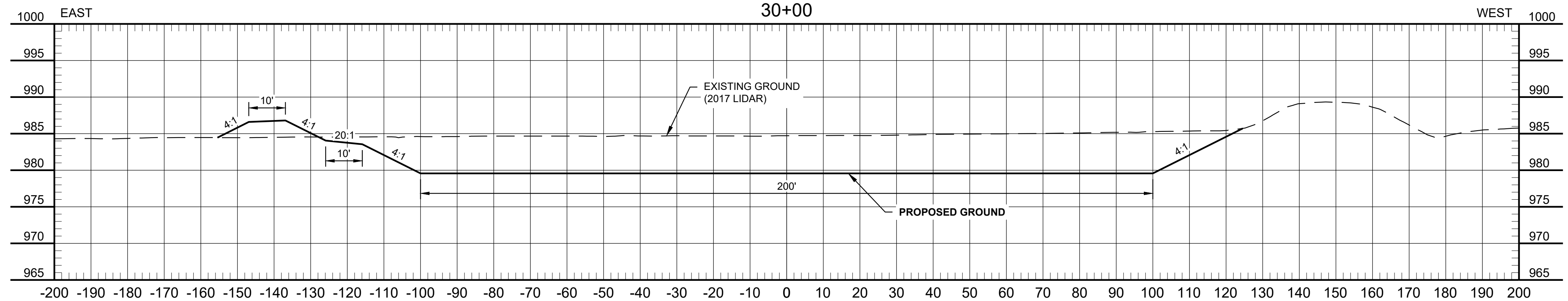

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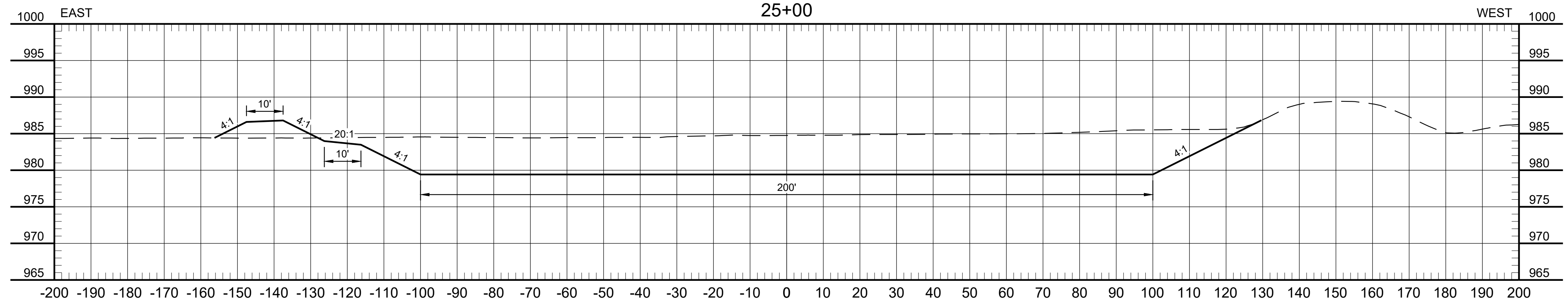

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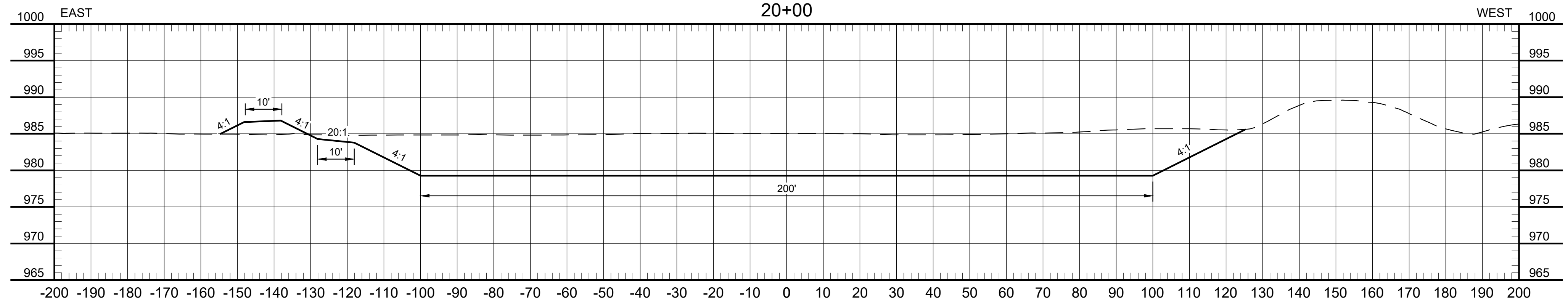

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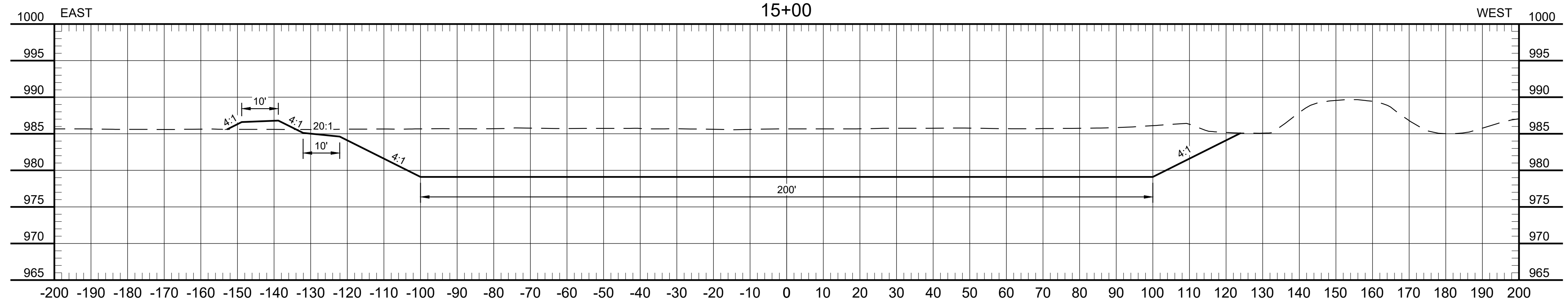

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PARK RIVER JOINT WATER RESOURCE DISTRICT
GRAFTON, NORTH DAKOTA

NORTH INLET CHANNEL SECTIONS

PROJECT NO. 8150-0002

SHEET C-1402

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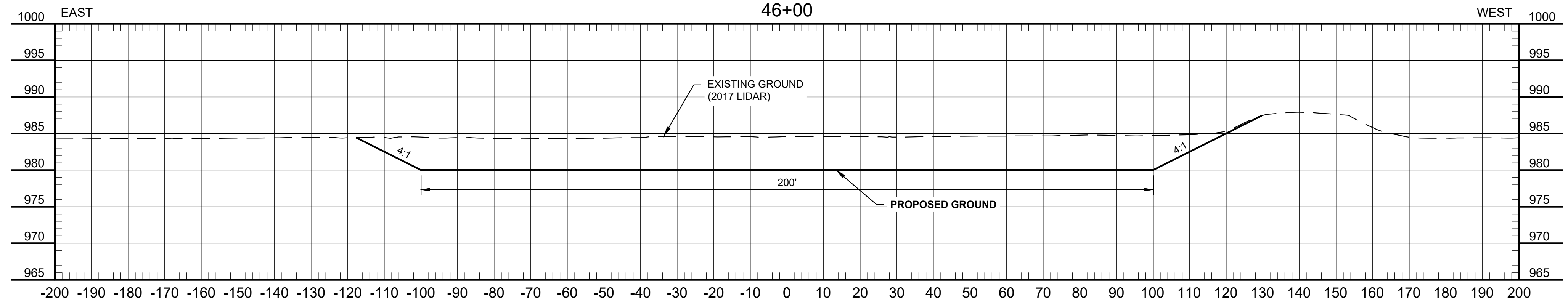

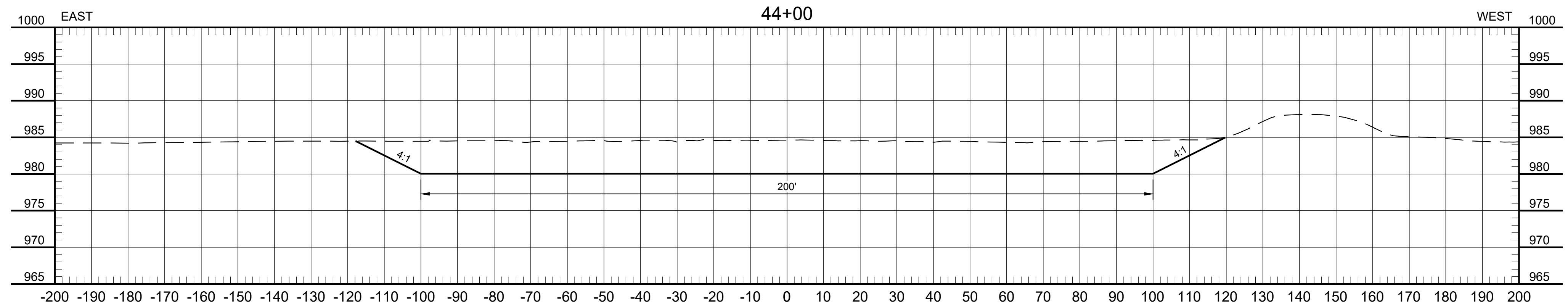

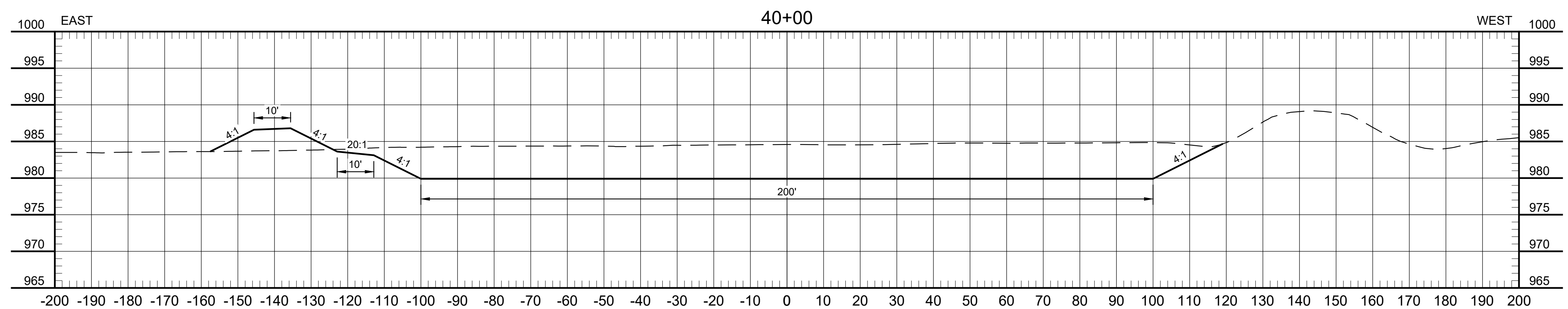

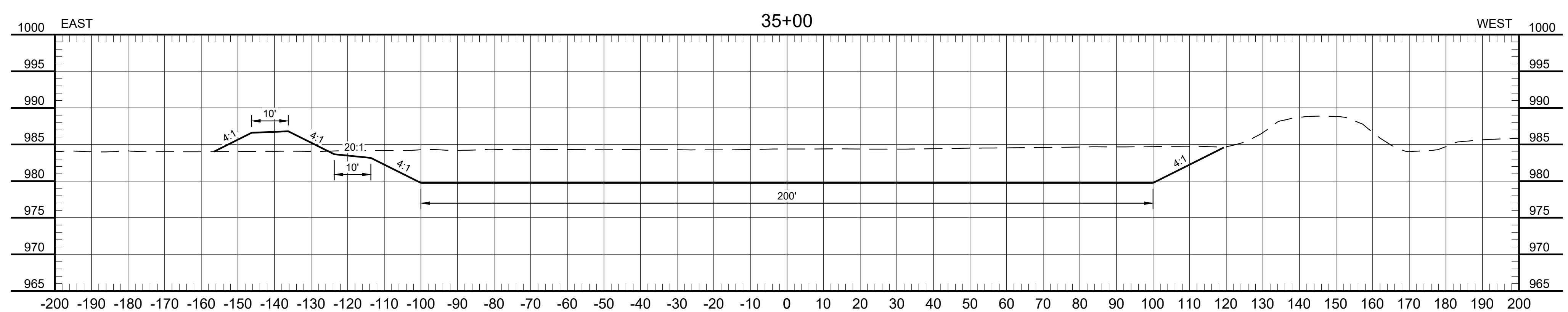

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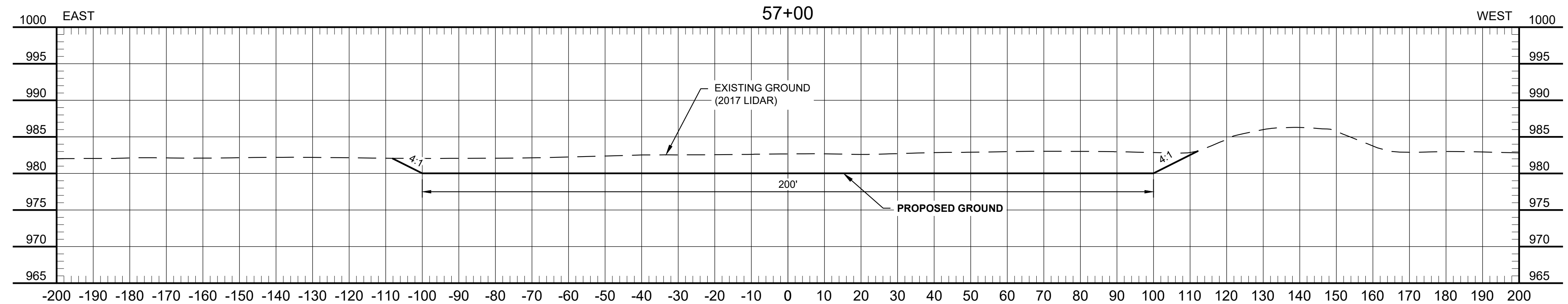
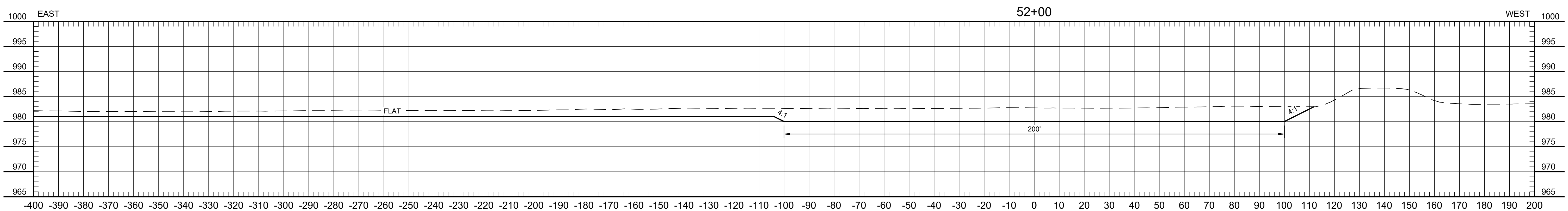
NORTH BRANCH PARK RIVER WATERSHED
CART CREEK SITE 1 DETAILED REVIEW
PARK RIVER JOINT WATER RESOURCE DISTRICT
GRAFTON, NORTH DAKOTA

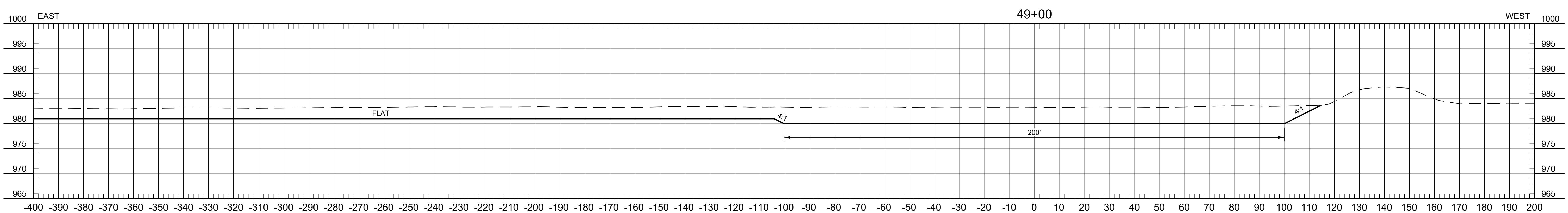
NORTH INLET CHANNEL SECTIONS

PROJECT NO. 8150-0002

SHEET
C-1403







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NORTH BRANCH PARK RIVER WATERSHED
CART CREEK SITE 1 DETAILED REVIEW
PARK RIVER JOINT WATER RESOURCE DISTRICT
GRAFTON, NORTH DAKOTA

NORTH INLET CHANNEL SECTIONS

PROJECT NO. 8150-0002

SHEET
C-1404

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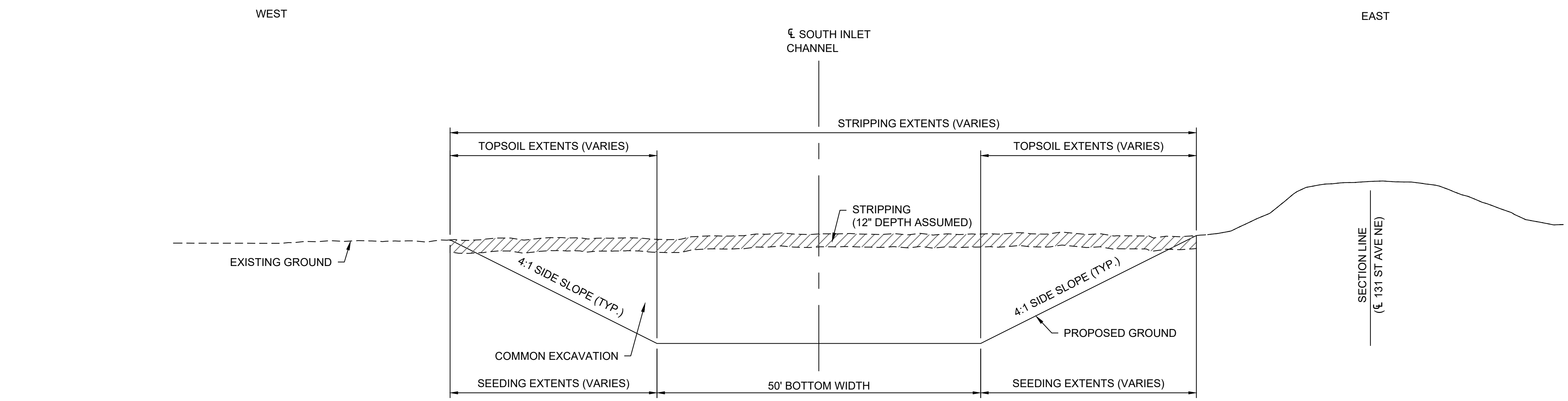
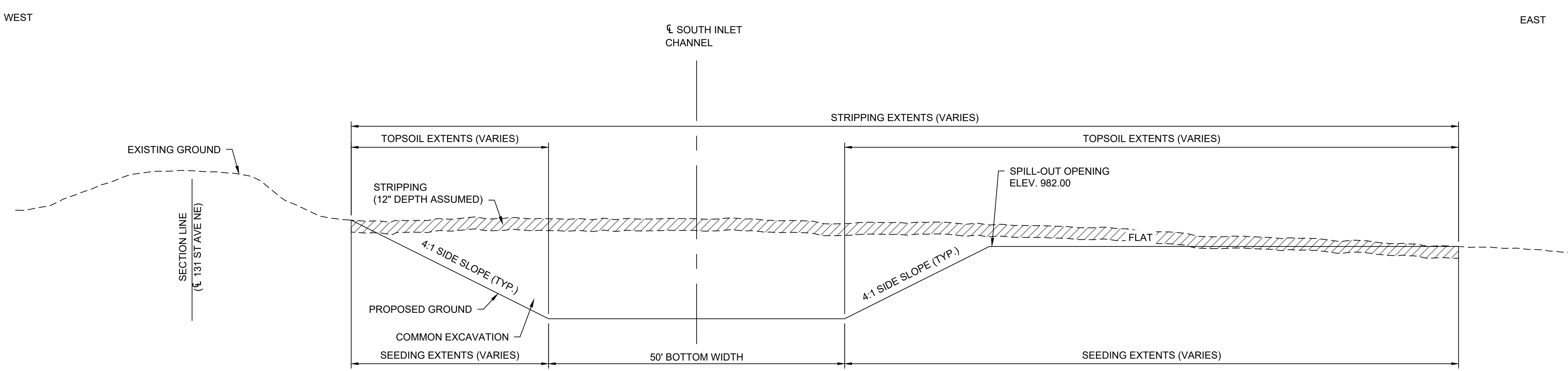


SOUTH INLET CHANNEL TYPICAL SECTION (STA. 200+90 TO STA. 206+16)

NOT TO SCALE



SOUTH INLET CHANNEL TYPICAL SECTION (STA. 206+16 TO STA. 208+16)

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SOUTH INLET CHANNEL
TYPICAL SECTIONS

PROJECT NO. 8150-0002

SHEET
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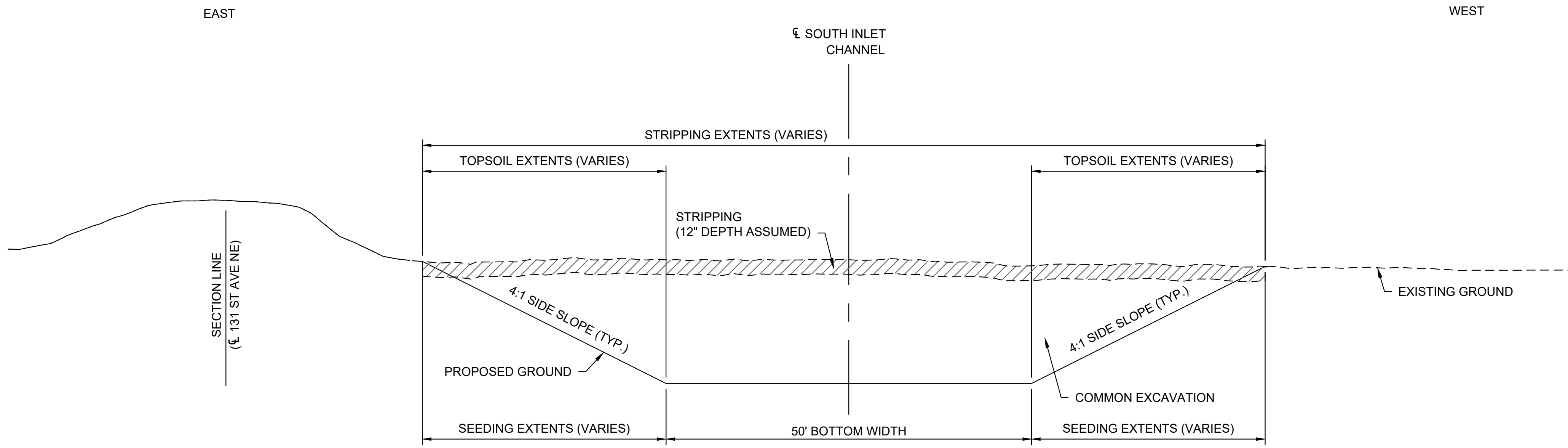

SOUTH INLET CHANNEL TYPICAL SECTION (STA. 208+16 TO STA. 219+53)

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NORTH BRANCH PARK RIVER WATERSHED
CART CREEK SITE 1 DETAILED REVIEW
PARK RIVER JOINT WATER RESOURCE DISTRICT
GRAFTON, NORTH DAKOTA

SOUTH INLET CHANNEL TYPICAL SECTIONS
PROJECT NO. 8150-0002

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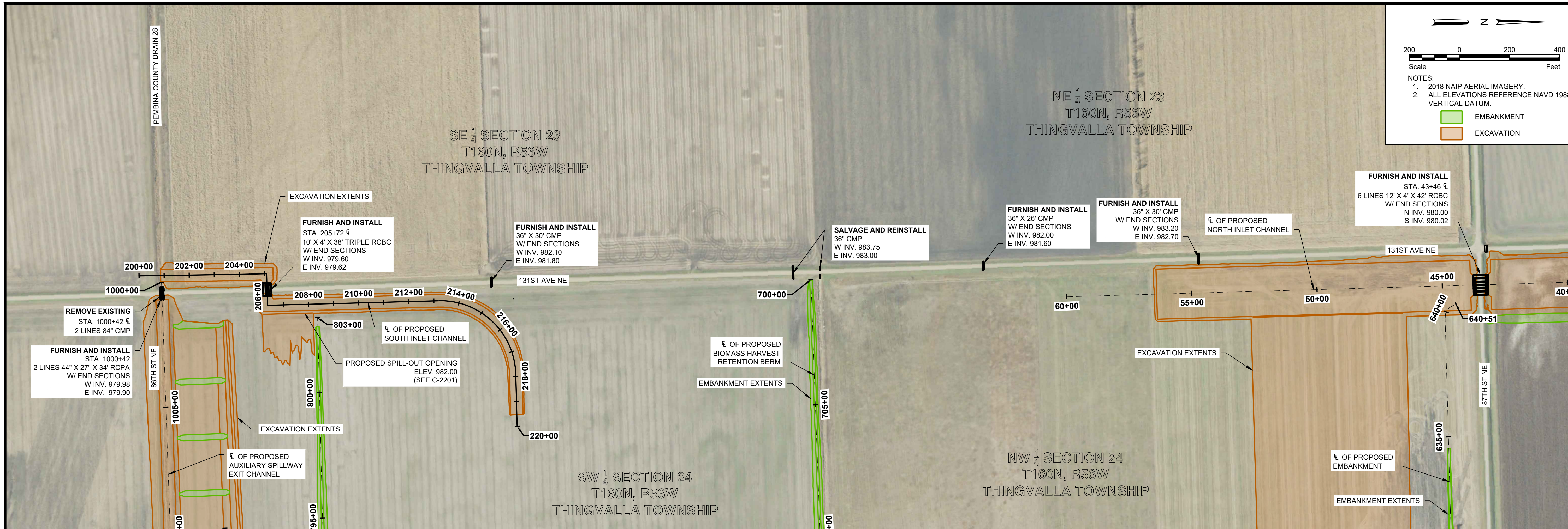

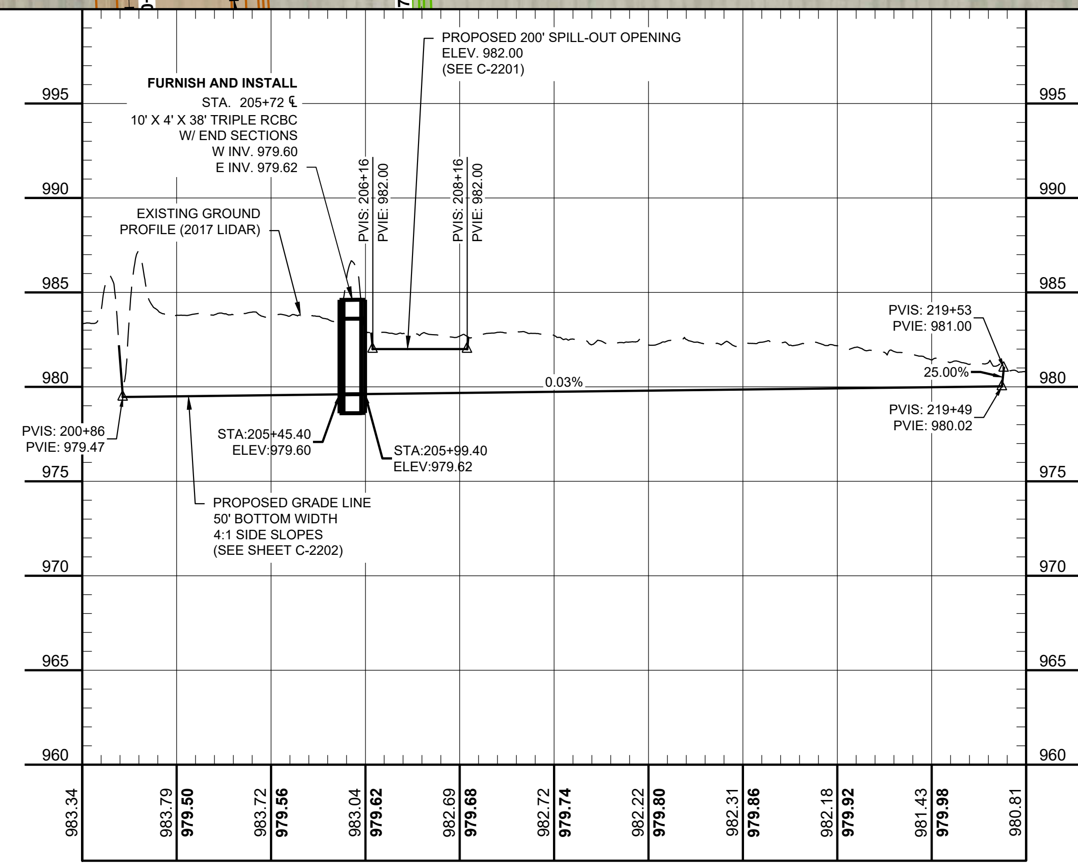

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NORTH BRANCH PARK RIVER WATERSHED
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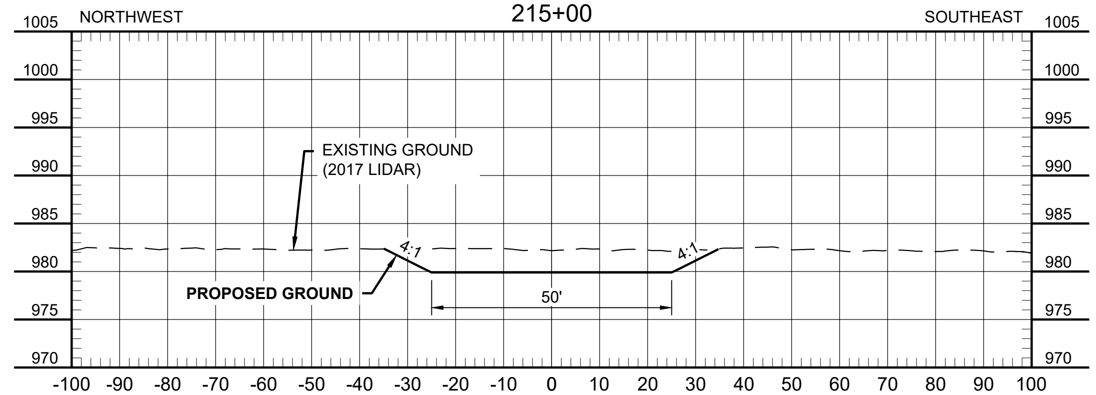
PARK RIVER JOINT WATER RESOURCE DISTRICT
GRAFTON, NORTH DAKOTA

SOUTH INLET CHANNEL PLAN AND PROFILE

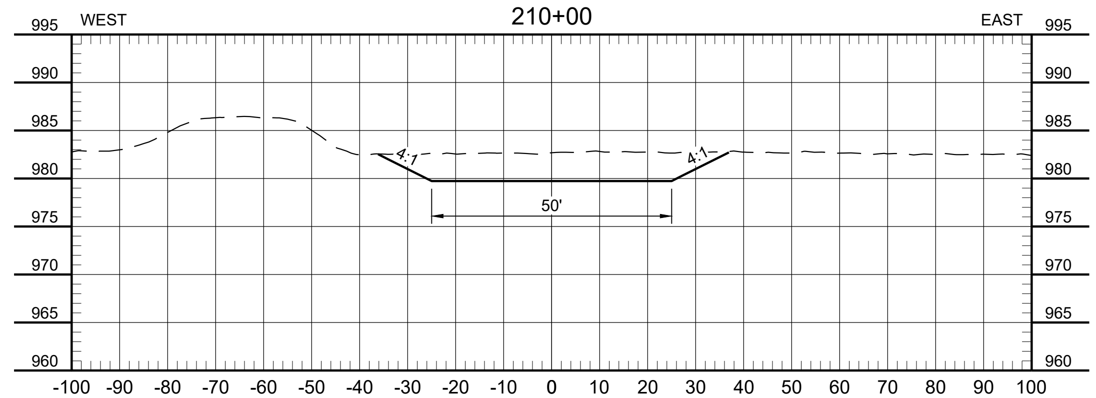
PROJECT NO. 8150-0002

SHEET C-2301

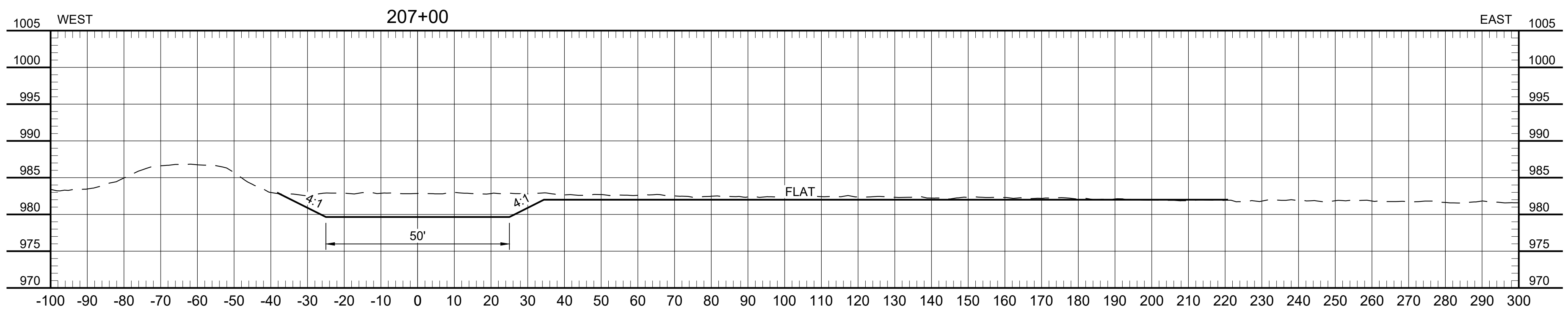
215+00



210+00



207+00



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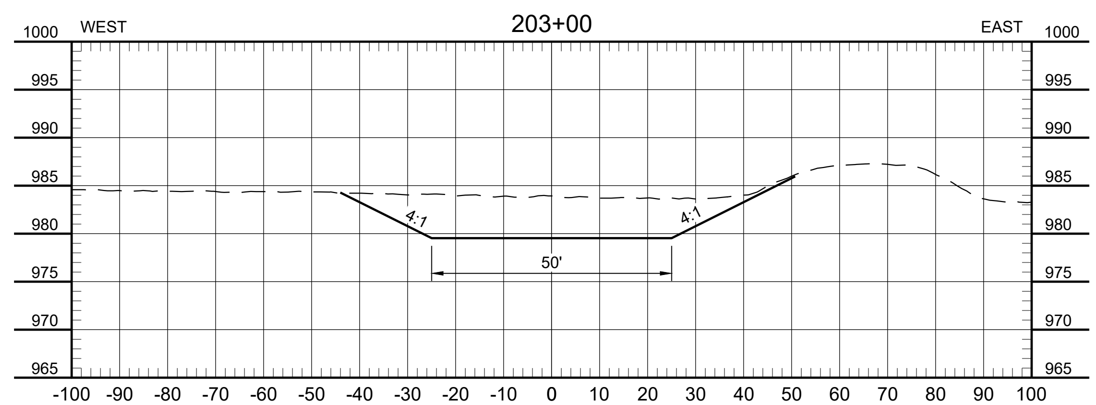

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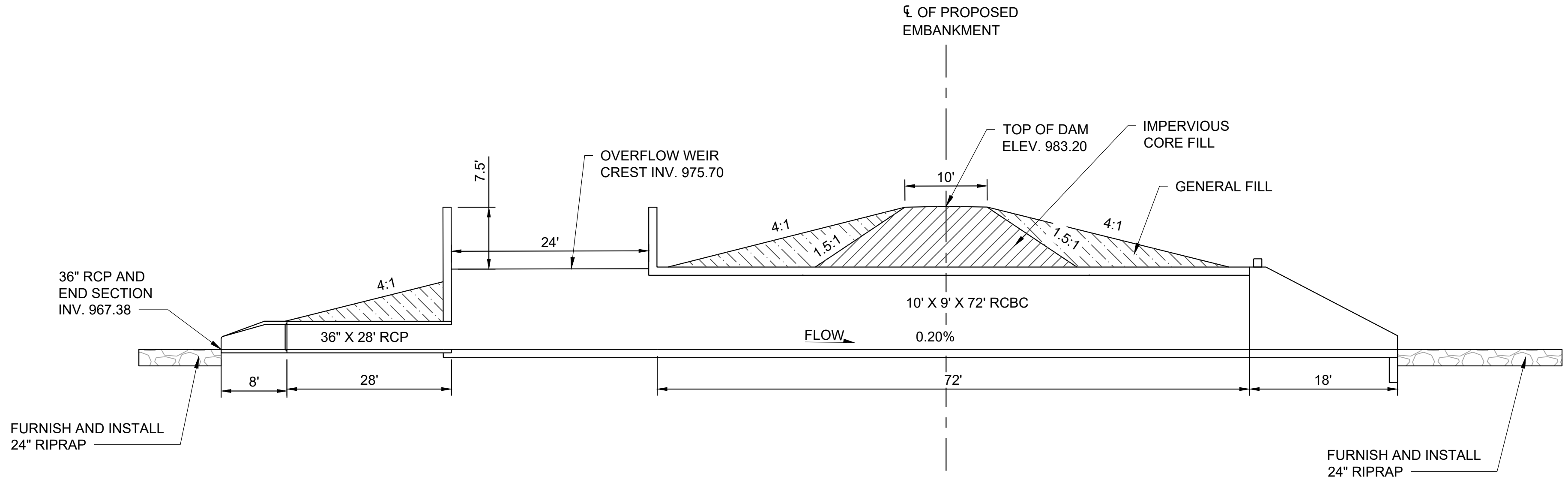
NORTH BRANCH PARK RIVER WATERSHED
CART CREEK SITE 1 DETAILED REVIEW
PARK RIVER JOINT WATER RESOURCE DISTRICT
GRAFTON, NORTH DAKOTA

SOUTH INLET CHANNEL SECTIONS

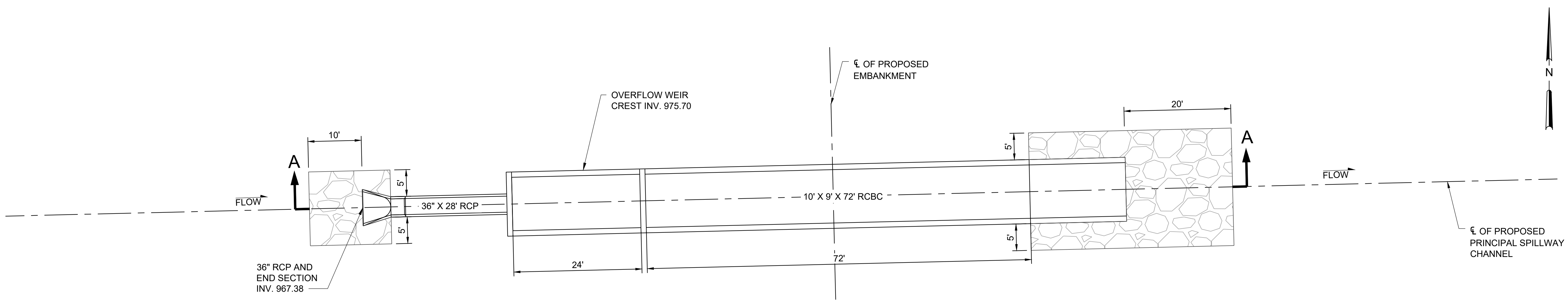
PROJECT NO. 8150-0002

SHEET
C-2401



SECTION A-A

NOT TO SCALE



PLAN VIEW

PROPOSED PRINCIPAL SPILLWAY STRUCTURE DETAILS (STA. 562+19)

NOT TO SCALE

NOTES:

1. TRASH RACK AND CATWALK PLATFORM SHALL BE INSTALLED WITH THE PRINCIPAL SPILLWAY STRUCTURE.
2. THE OUTLET CONDUIT FOR THE PRINCIPAL SPILLWAY STRUCTURE SHALL BE INSTALLED WITH A FILTER DIAPHRAGM BASED ON GUIDANCE FROM THE NATIONAL ENGINEERING HANDBOOK, PART 628, CHAPTER 45.

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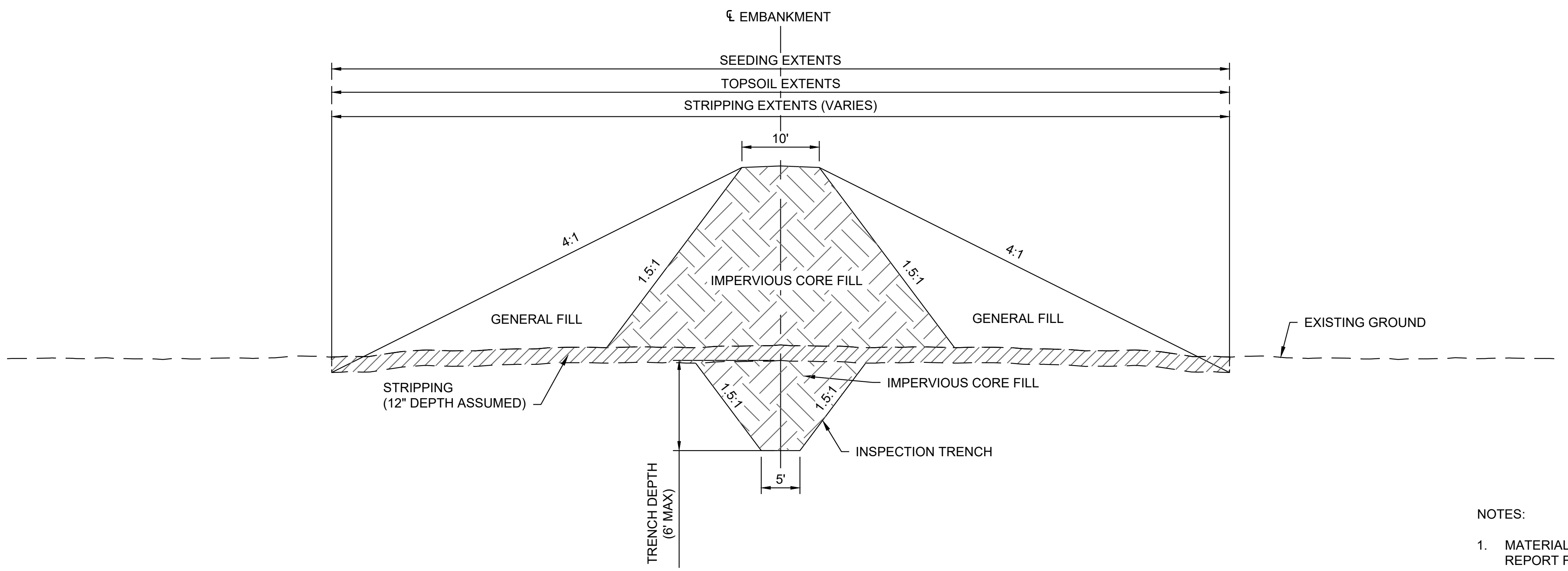
NORTH BRANCH PARK RIVER WATERSHED
CART CREEK SITE 1 DETAILED REVIEW
PARK RIVER JOINT WATER RESOURCE DISTRICT
GRAFTON, NORTH DAKOTA

PRINCIPAL SPILLWAY DETAILS
PROJECT NO. 8150-0002

SHEET
C-3101



EMBANKMENT TYPICAL SECTION (STA. 500+95 TO STA. 634+02)

NOT TO SCALE

NOTES:

1. MATERIAL SPECIFICATIONS SHALL BE BASED ON GUIDANCE FROM THE GEOTECHNICAL REPORT FOR CART CREEK SITE 1.

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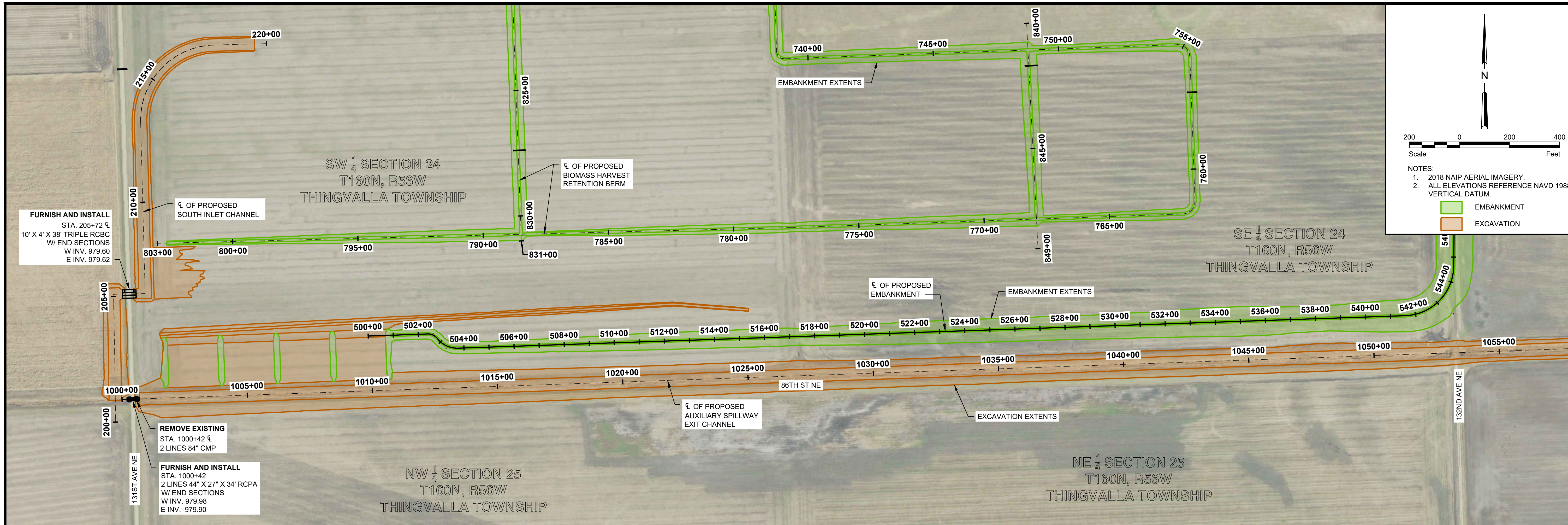
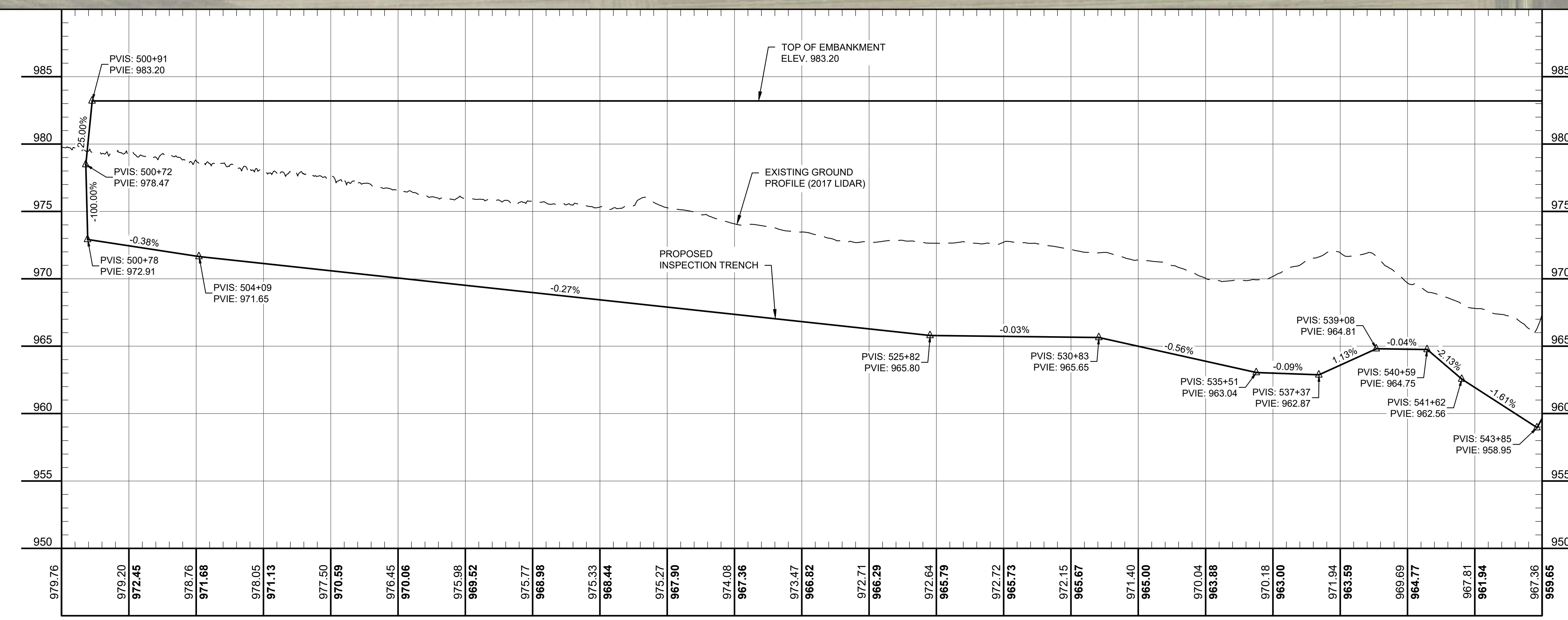
NORTH BRANCH PARK RIVER WATERSHED
CART CREEK SITE 1 DETAILED REVIEW
PARK RIVER JOINT WATER RESOURCE DISTRICT
GRAFTON, NORTH DAKOTA

EMBANKMENT
TYPICAL SECTIONS

PROJECT NO. 8150-0002

SHEET
C-3201





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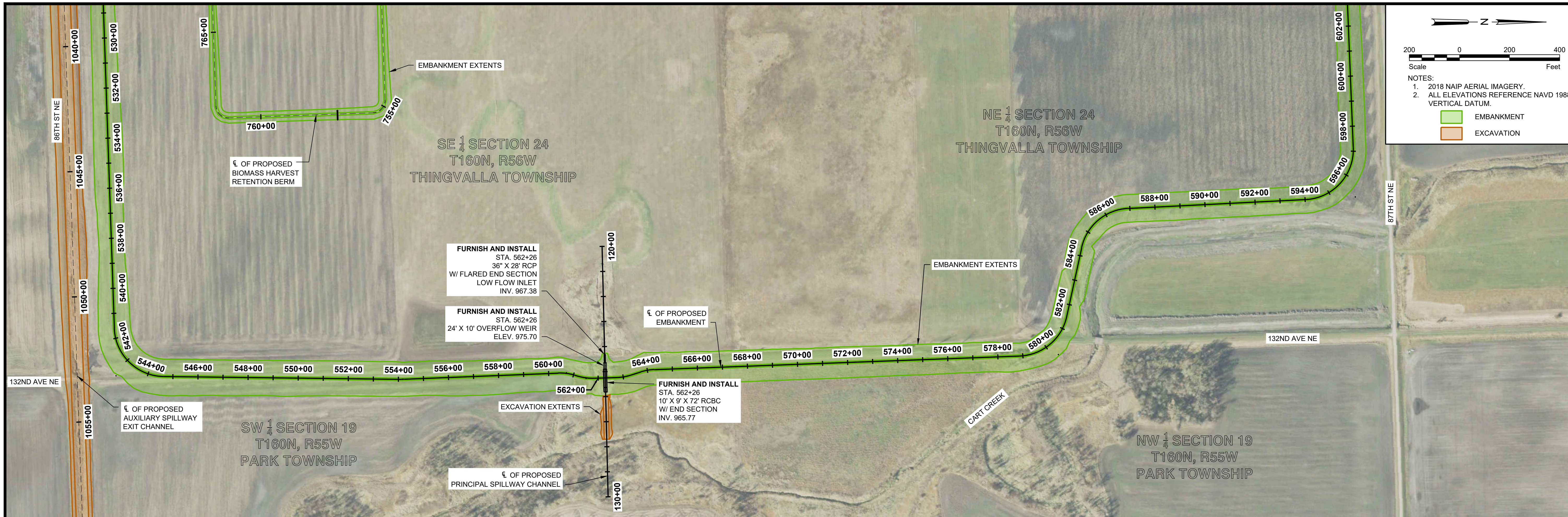
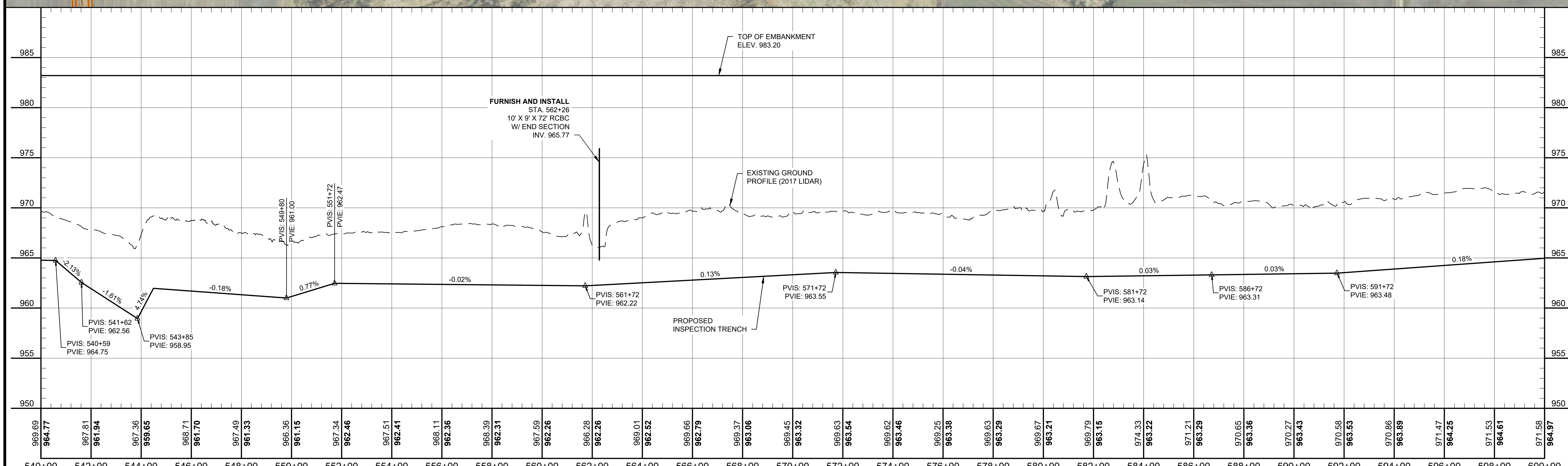
NORTH BRANCH PARK RIVER WATERSHED
CART CREEK SITE 1 DETAILED REVIEW
PARK RIVER JOINT WATER RESOURCE DISTRICT
GRAFTON, NORTH DAKOTA

EMBANKMENT
PLAN AND PROFILE

PROJECT NO. 8150-0002

SHEET
C-3301





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NORTH BRANCH PARK RIVER WATERSHED
CART CREEK SITE 1 DETAILED REVIEW
PARK RIVER JOINT WATER RESOURCE DISTRICT
GRAFTON, NORTH DAKOTA

EMBANKMENT
PLAN AND PROFILE

PROJECT NO. 8150-0002

SHEET
C-3302

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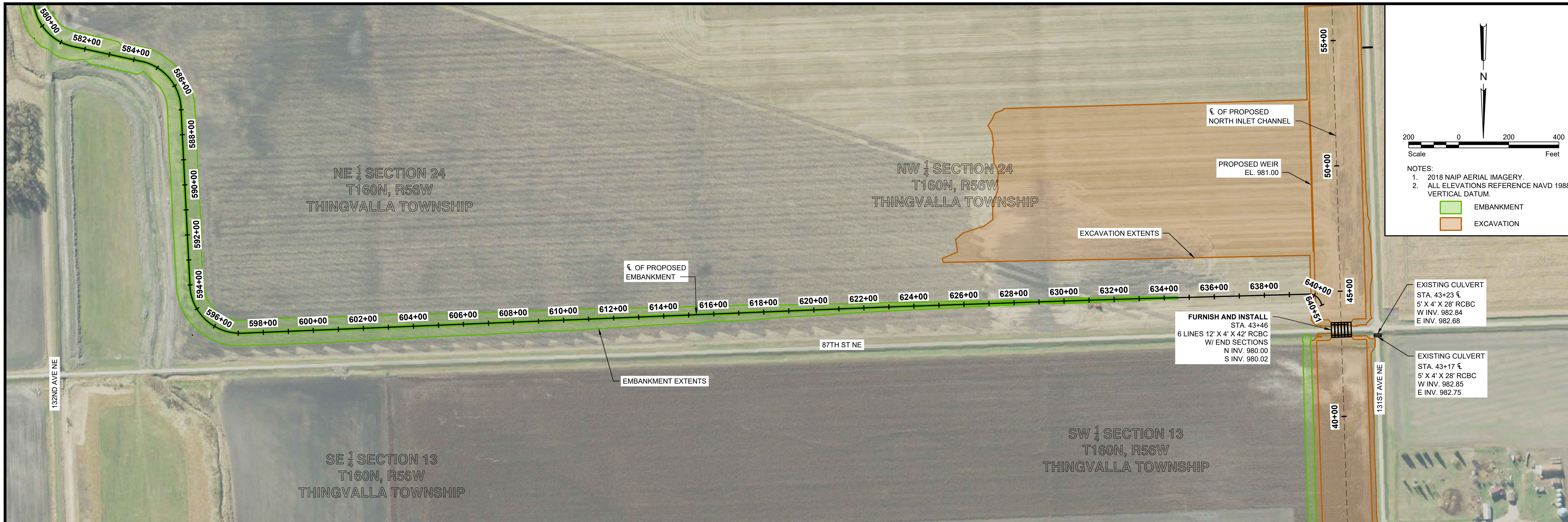

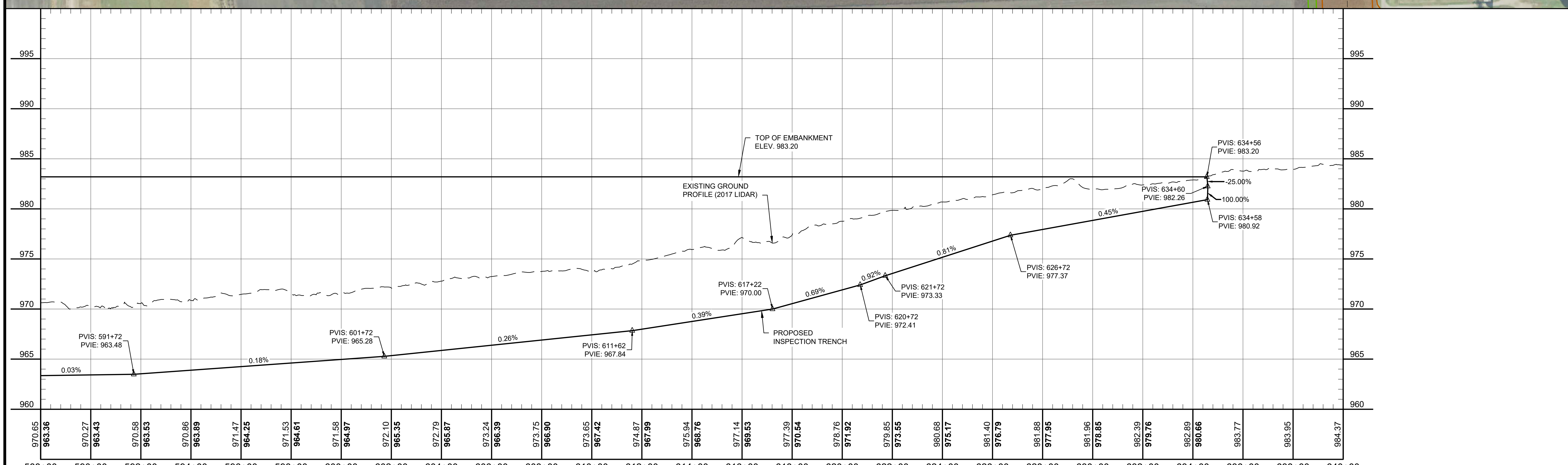

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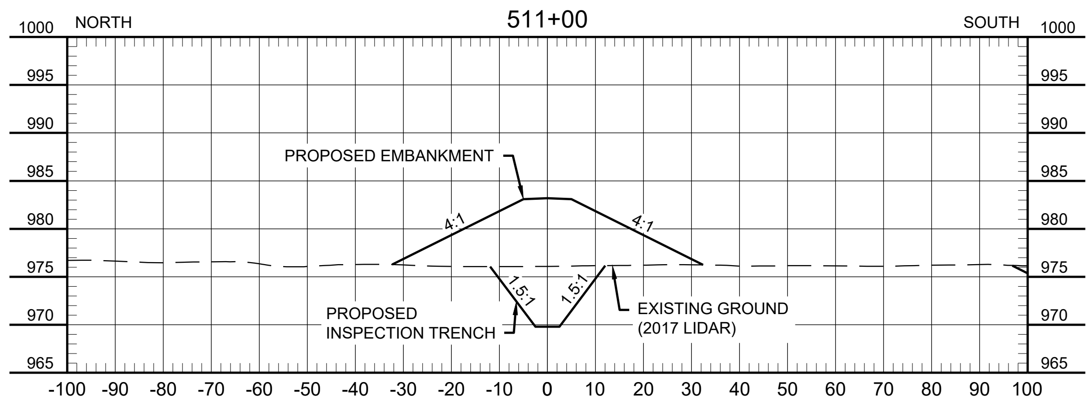
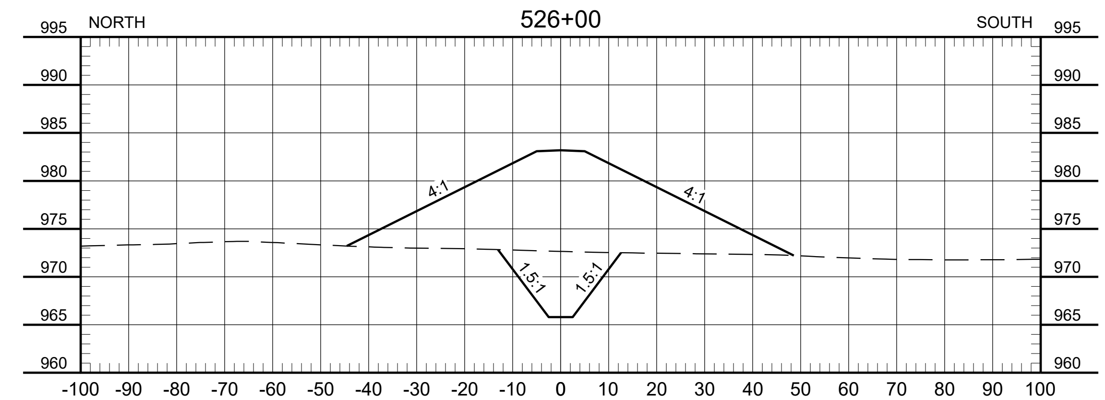
NORTH BRANCH PARK RIVER WATERSHED
CART CREEK SITE 1 DETAILED REVIEW
PARK RIVER JOINT WATER RESOURCE DISTRICT
GRAFTON, NORTH DAKOTA

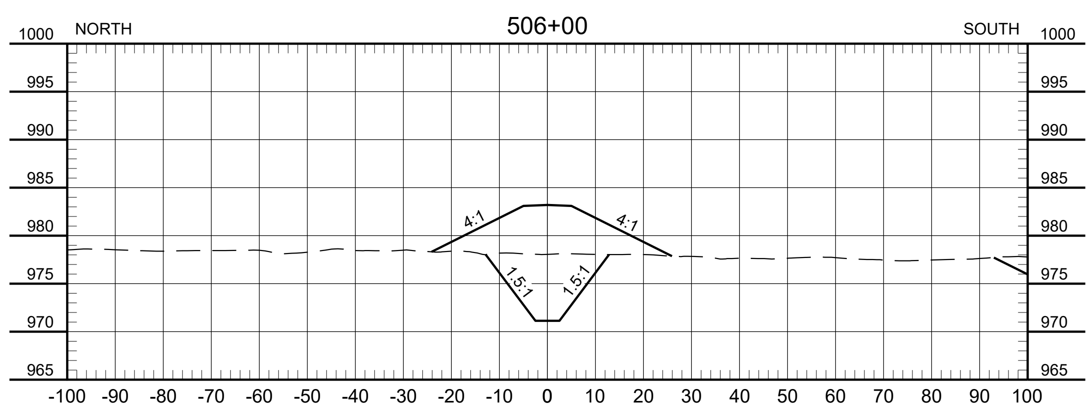
EMBANKMENT
PLAN AND PROFILE

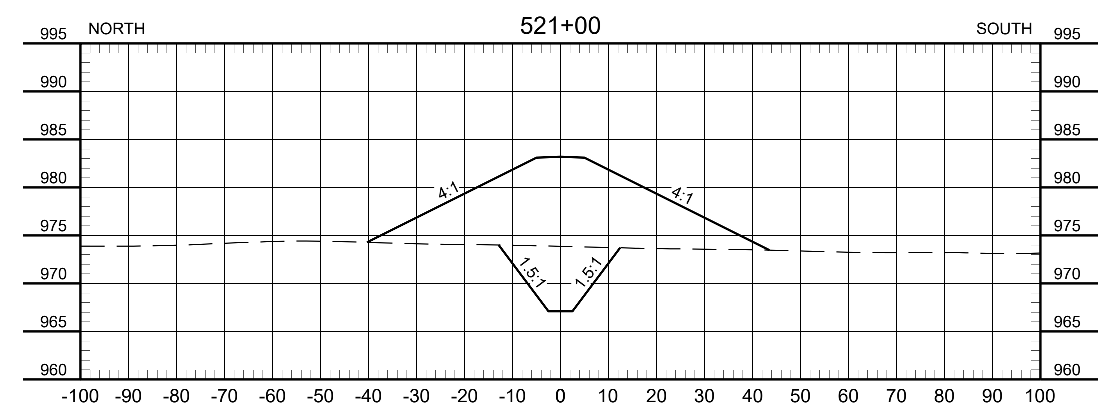
PROJECT NO. 8150-0002

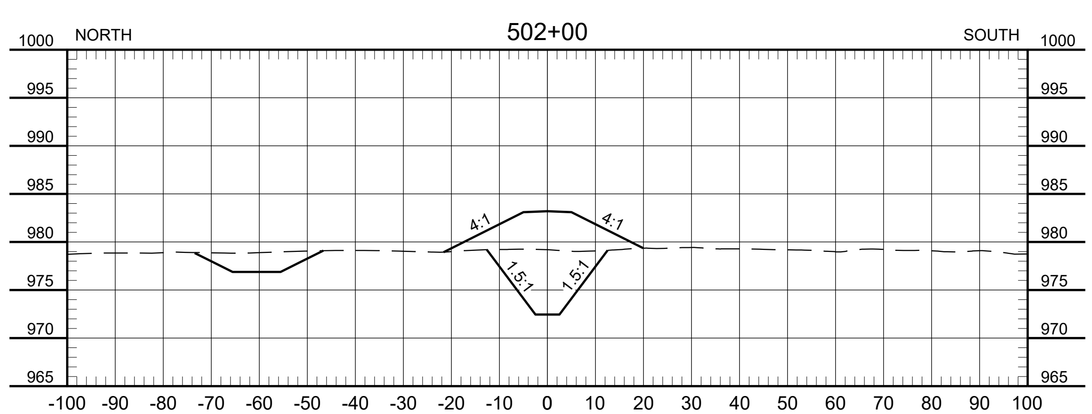
SHEET
C-3303

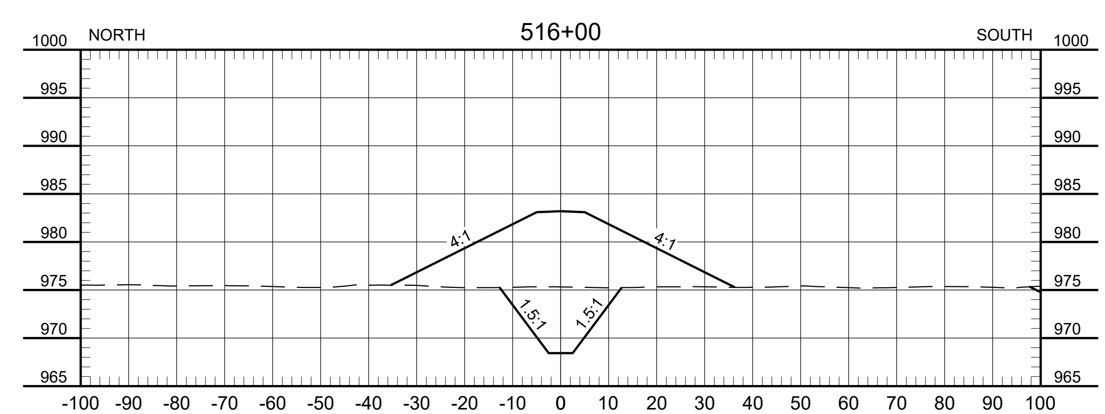












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NORTH BRANCH PARK RIVER WATERSHED
CART CREEK SITE 1 DETAILED REVIEW
PARK RIVER JOINT WATER RESOURCE DISTRICT
GRAFTON, NORTH DAKOTA

EMBANKMENT SECTIONS

PROJECT NO. 8150-0002

SHEET
C-3401

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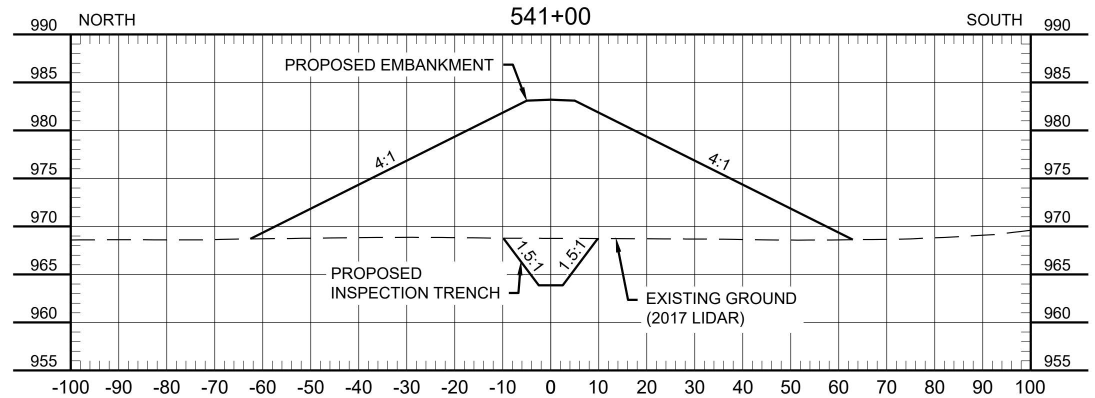

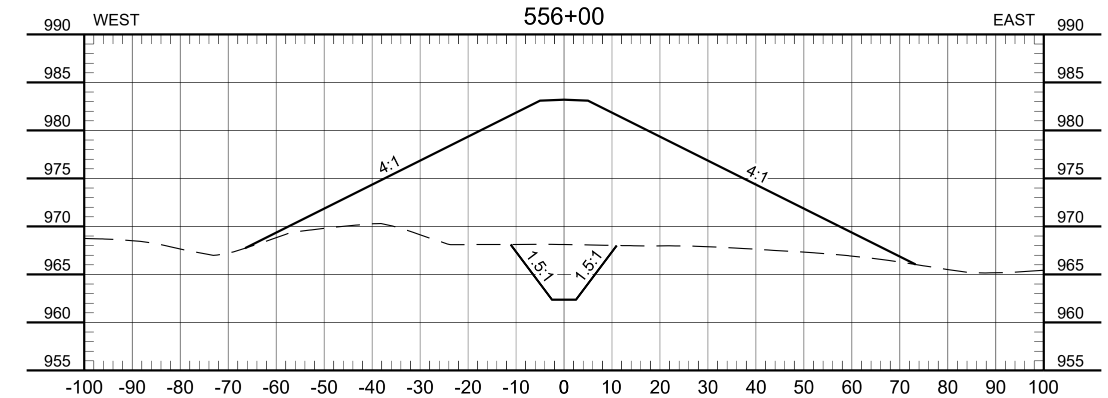

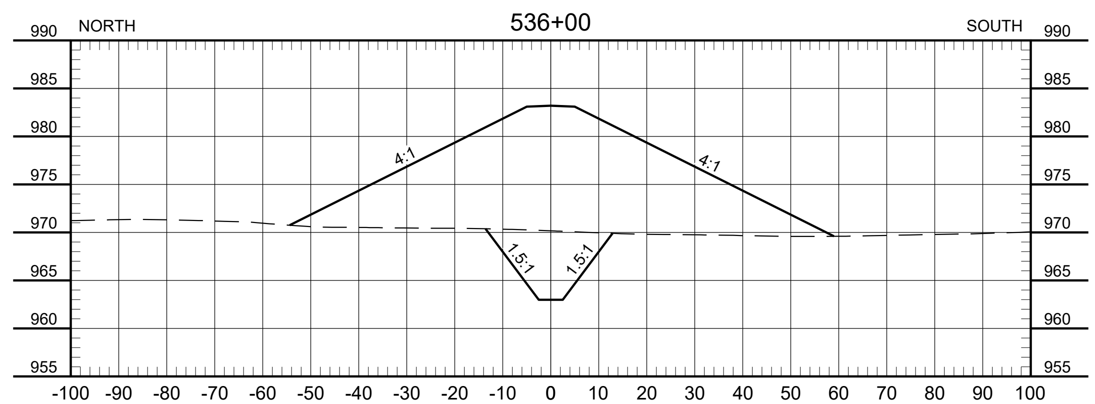

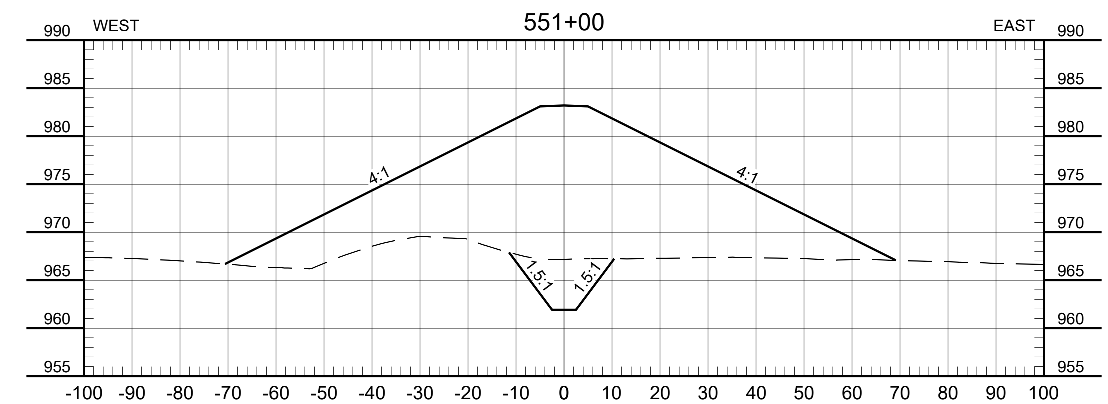

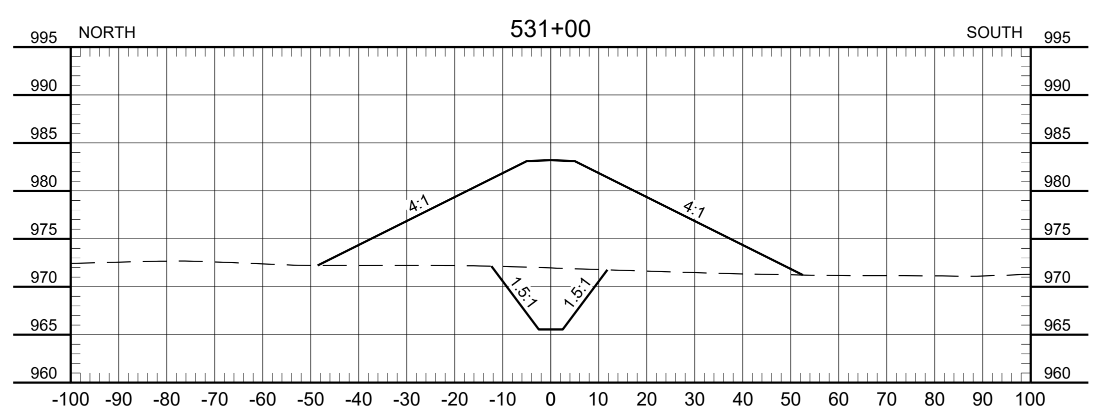

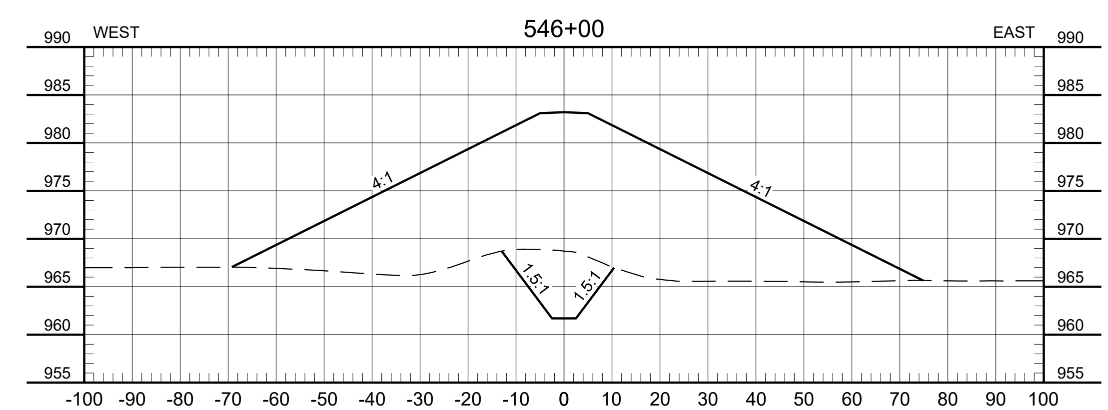

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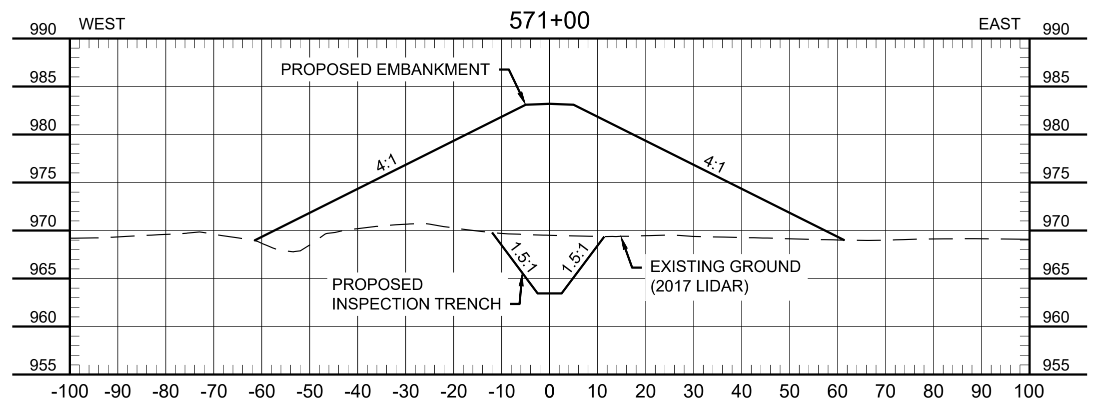
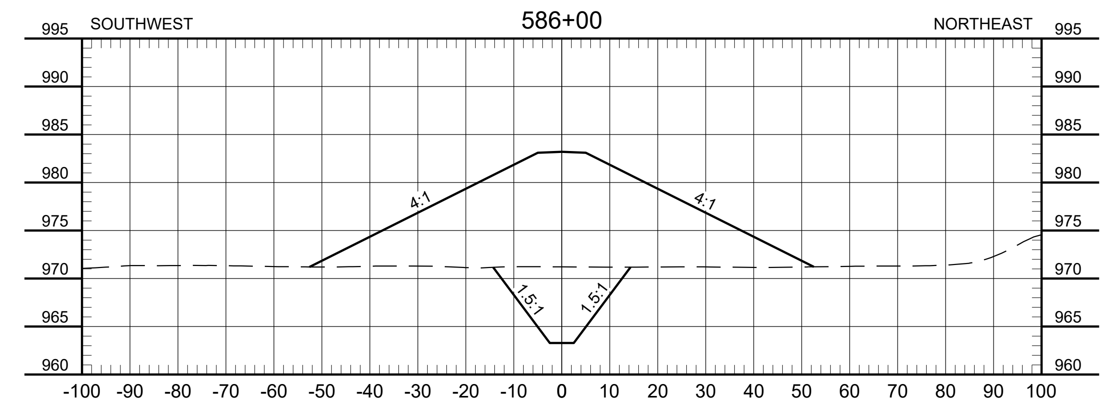
NORTH BRANCH PARK RIVER WATERSHED
CART CREEK SITE 1 DETAILED REVIEW
PARK RIVER JOINT WATER RESOURCE DISTRICT
GRAFTON, NORTH DAKOTA

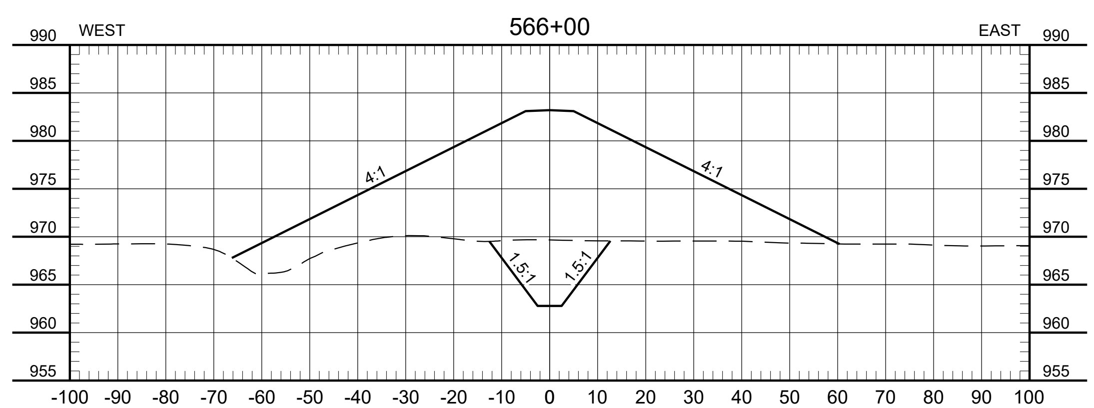
EMBANKMENT SECTIONS

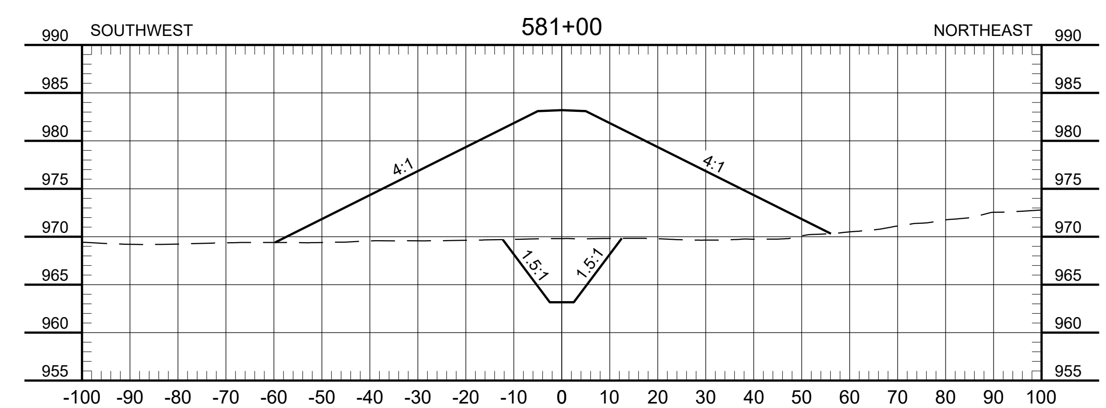
PROJECT NO. 8150-0002

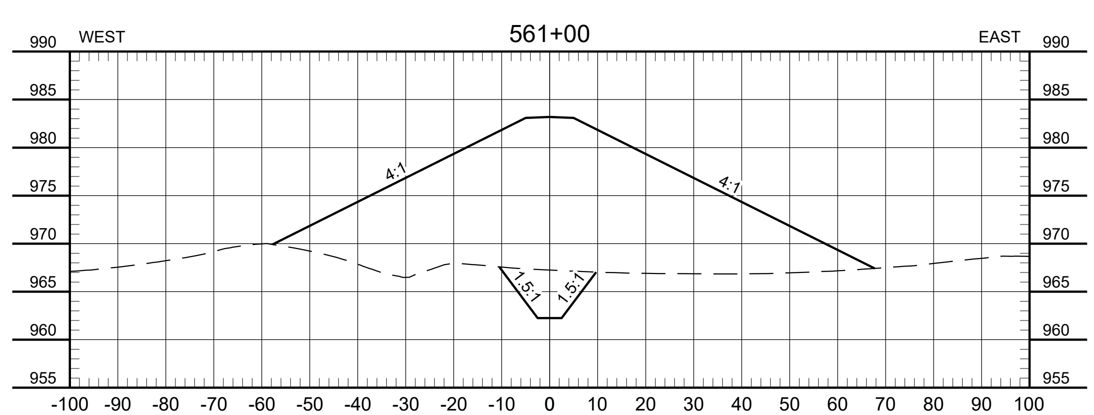
SHEET
C-3402

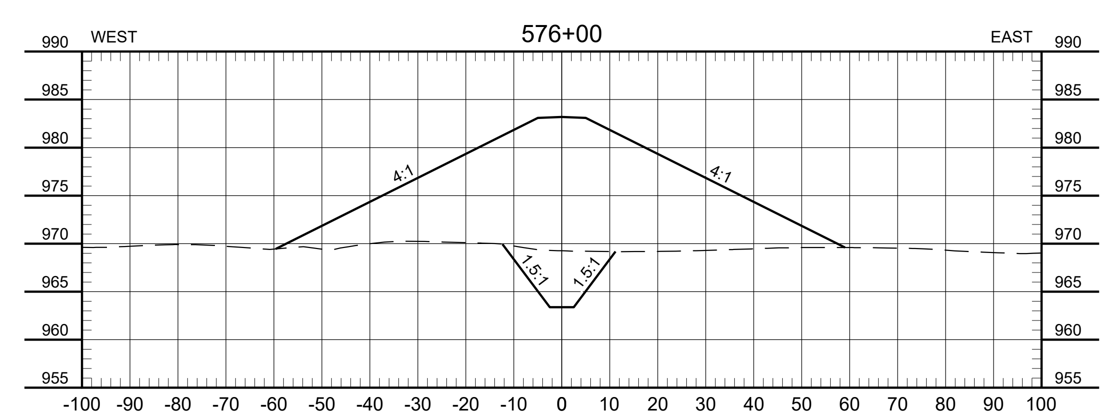












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EMBANKMENT SECTIONS

PROJECT NO. 8150-0002

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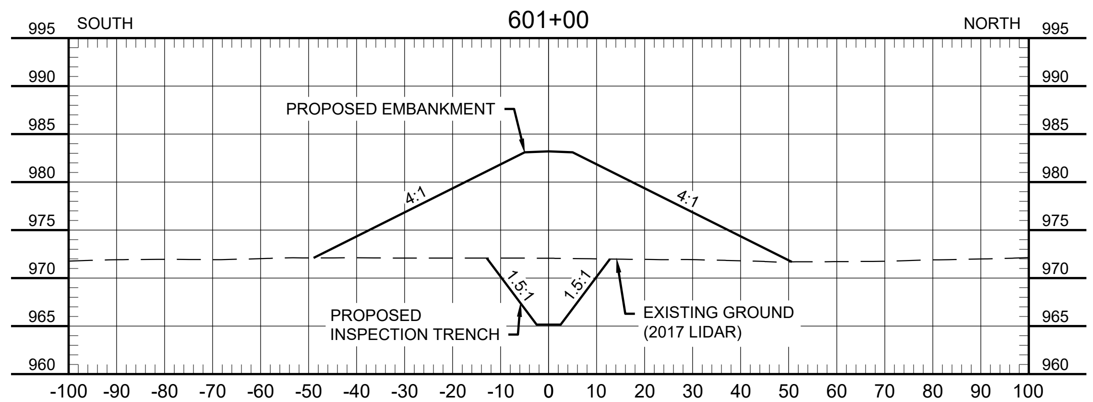

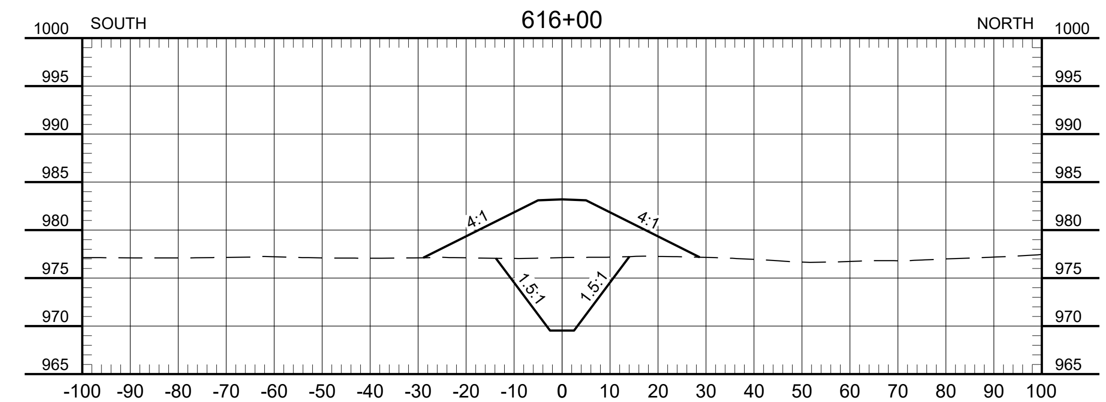

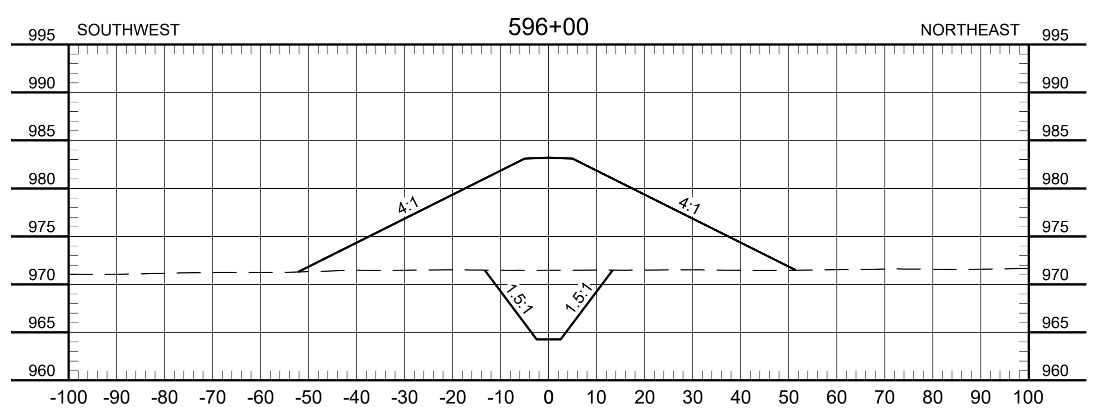

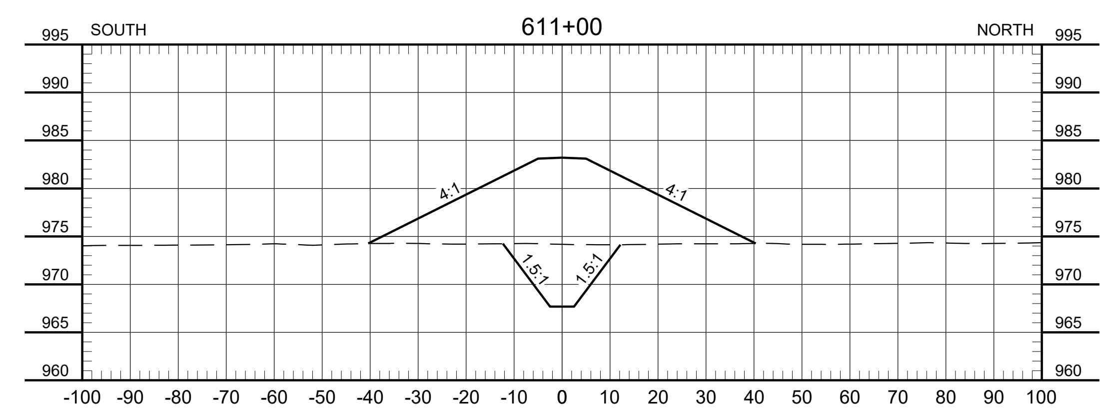

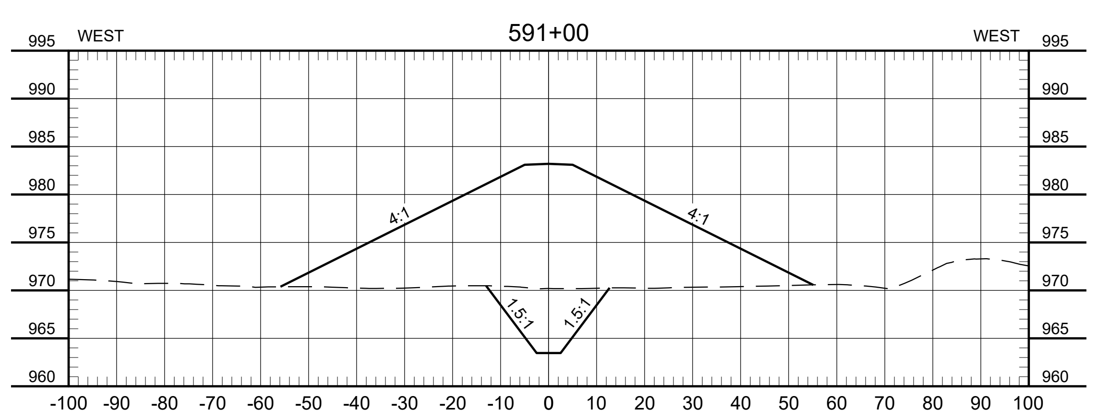

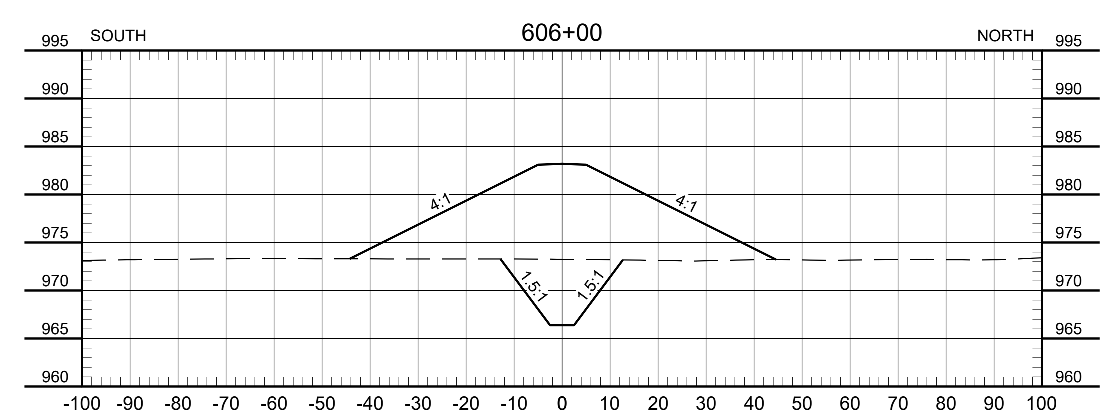

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CART CREEK SITE 1 DETAILED REVIEW
PARK RIVER JOINT WATER RESOURCE DISTRICT
GRAFTON, NORTH DAKOTA

EMBANKMENT SECTIONS
PROJECT NO. 8150-0002

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C-3404

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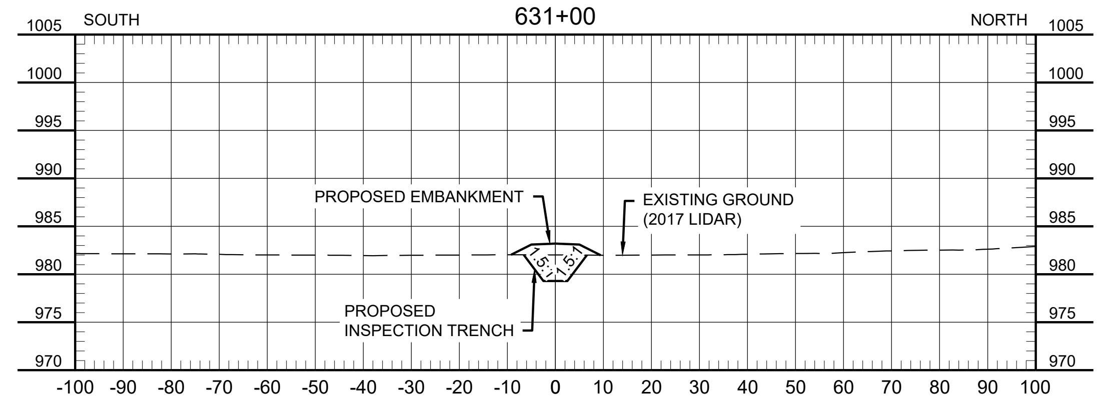

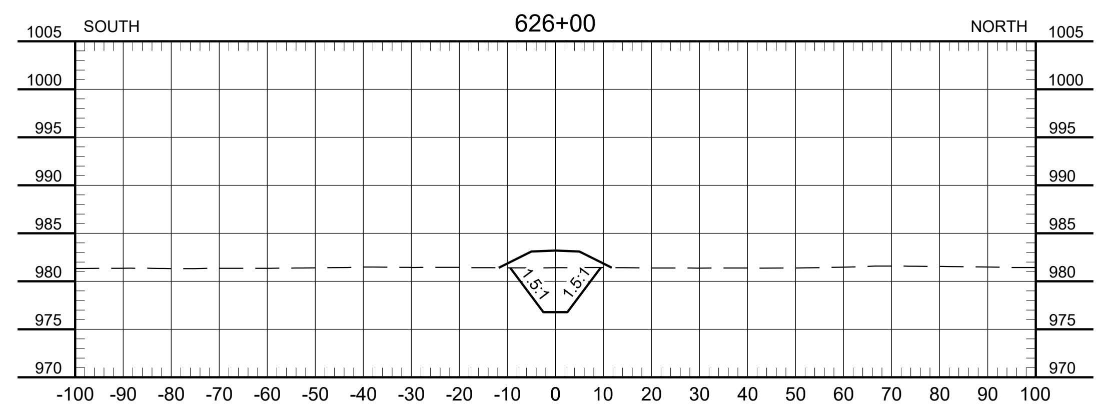

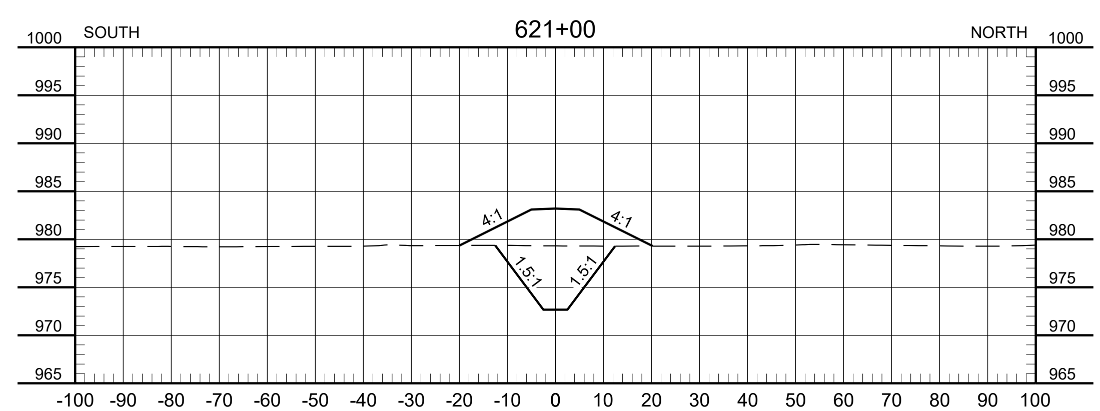

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CART CREEK SITE 1 DETAILED REVIEW
PARK RIVER JOINT WATER RESOURCE DISTRICT
GRAFTON, NORTH DAKOTA

EMBANKMENT SECTIONS
PROJECT NO. 8150-0002

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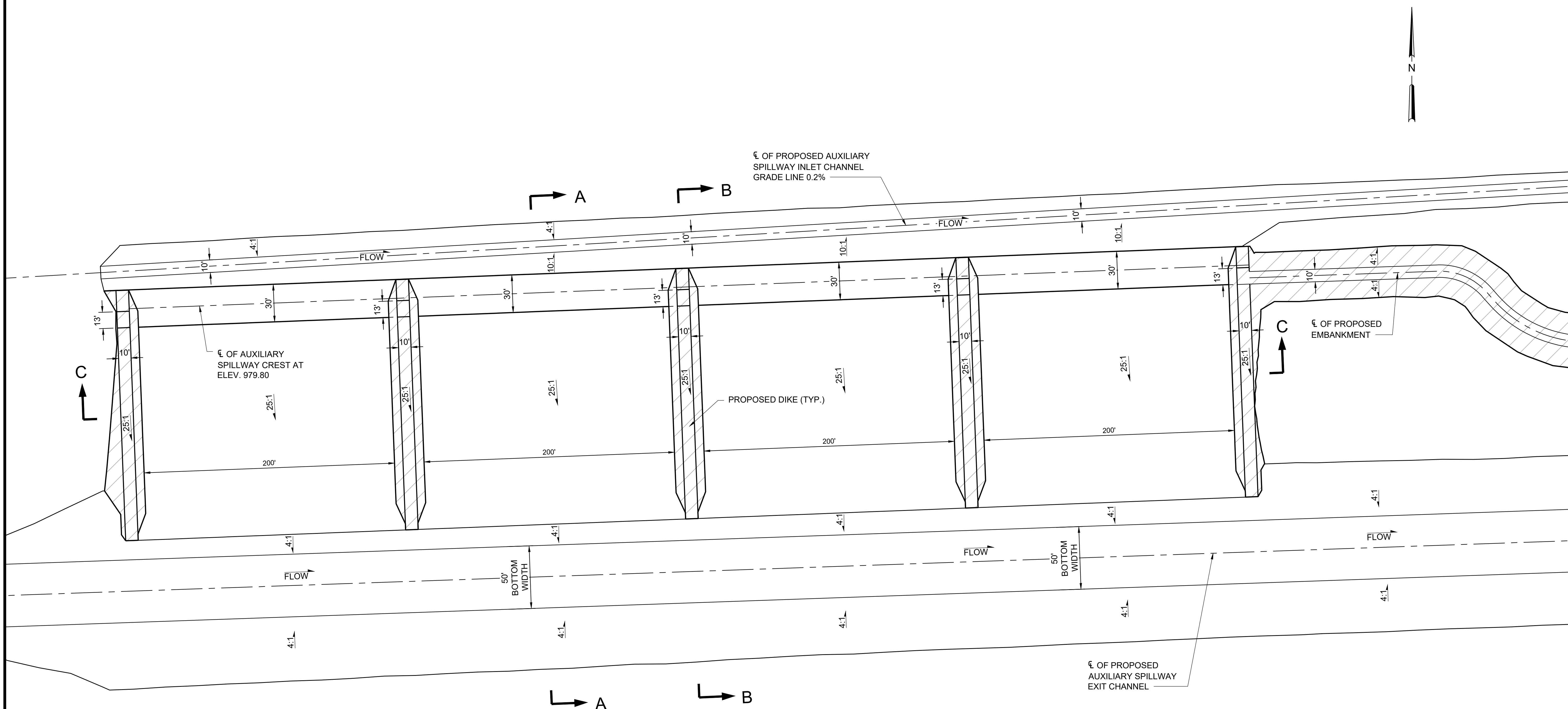

PLAN VIEW

AUXILIARY SPILLWAY

NOT TO SCALE

NOTES:

1. CROSS HATCHING INDICATES AREAS WHERE FILL IS REQUIRED.
2. EARTHEN SPILLWAYS ARE DIVIDED INTO BAYS OF 200 FOOT SECTIONS PER GUIDANCE FROM THE NATIONAL ENGINEERING HANDBOOK, PART 628, CHAPTER 50.

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NOTES:

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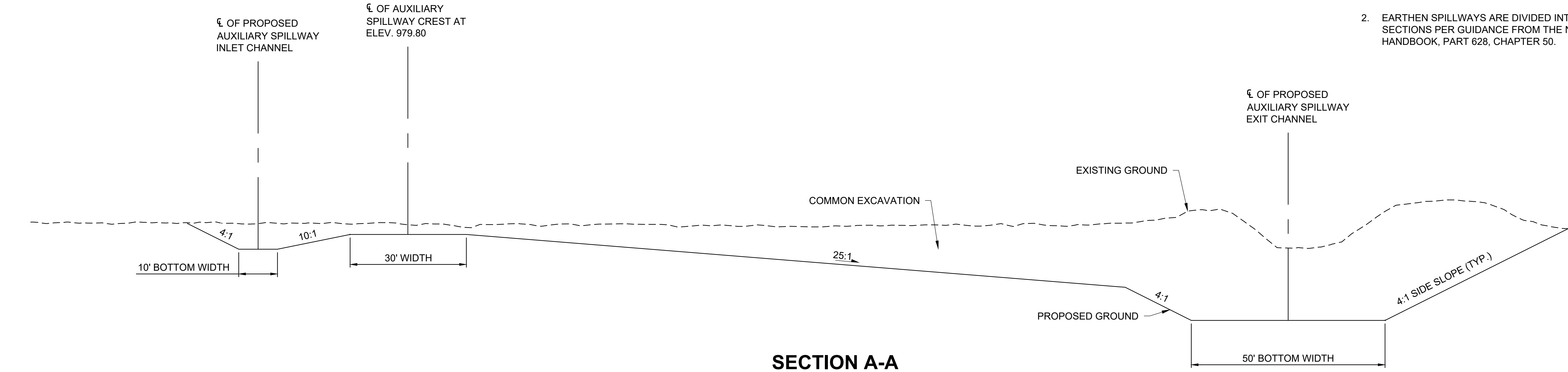

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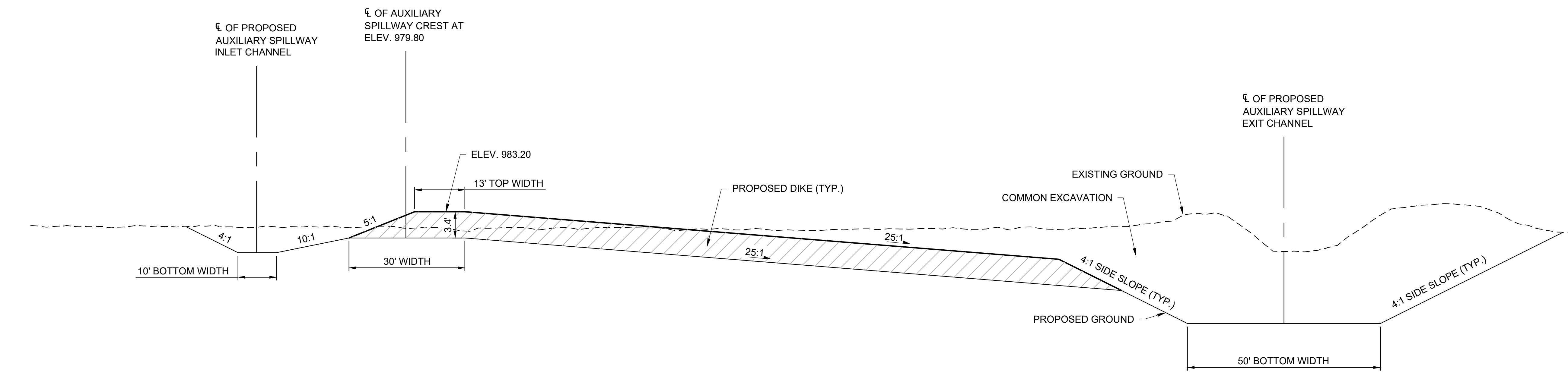

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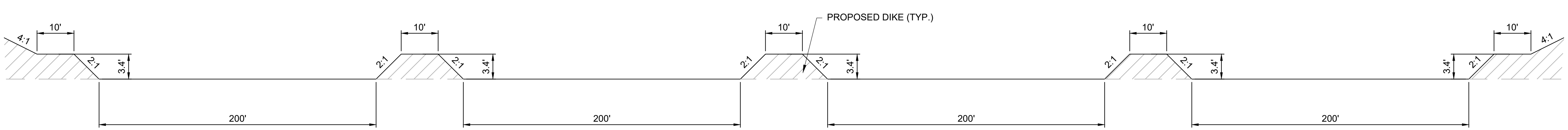

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CART CREEK SITE 1 DETAILED REVIEW
PARK RIVER JOINT WATER RESOURCE DISTRICT
GRAFTON, NORTH DAKOTA

AUXILIARY SPILLWAY EXIT CHANNEL DETAIL

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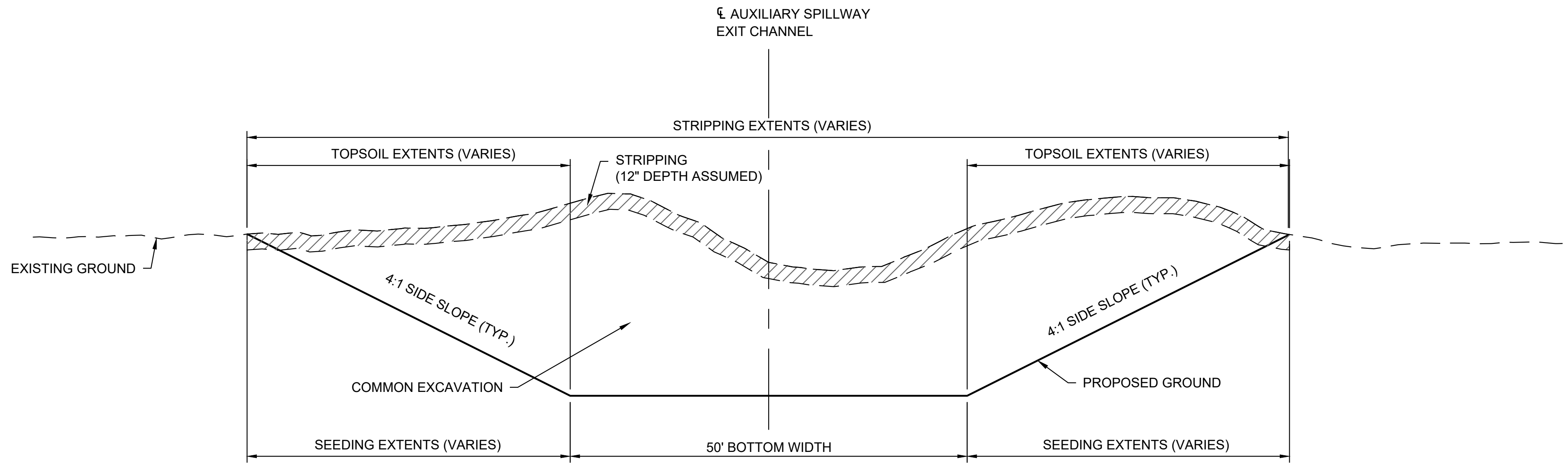

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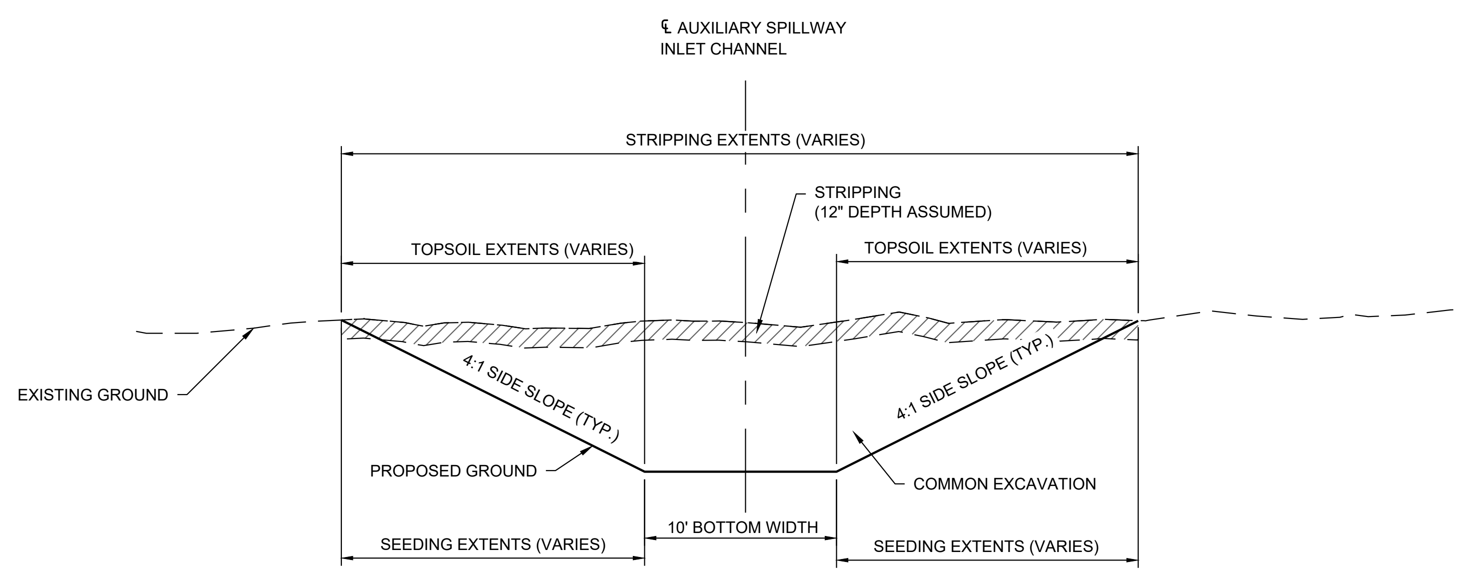

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CART CREEK SITE 1 DETAILED REVIEW
PARK RIVER JOINT WATER RESOURCE DISTRICT
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PROJECT NO. 8150-0002

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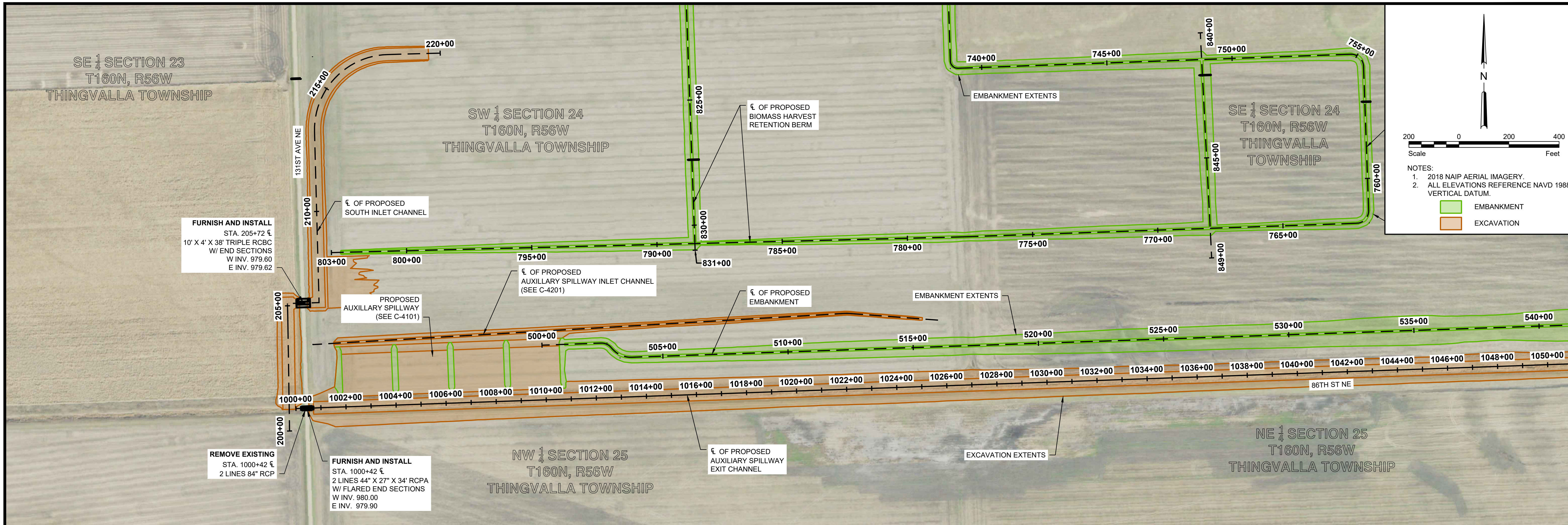

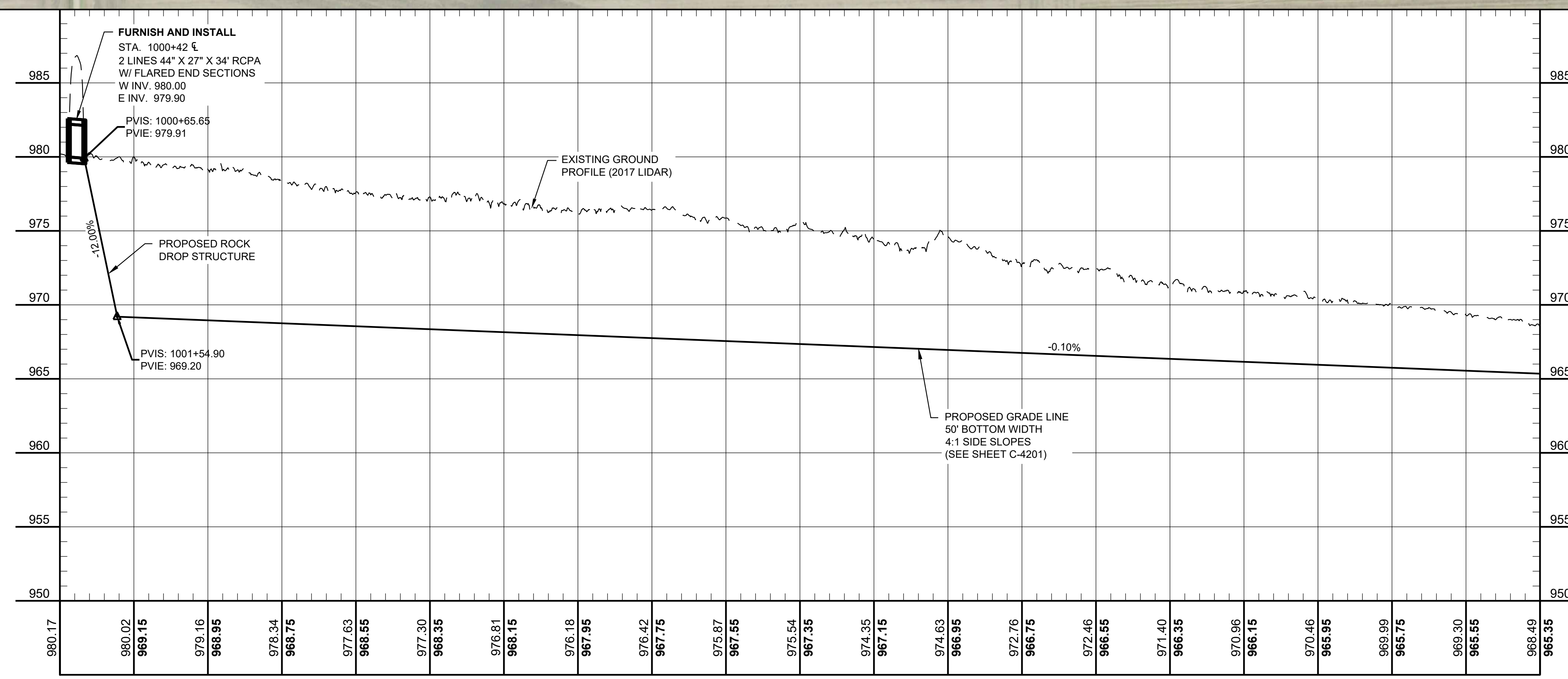

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NORTH BRANCH PARK RIVER WATERSHED
CART CREEK SITE 1 DETAILED REVIEW
PARK RIVER JOINT WATER RESOURCE DISTRICT
GRAFTON, NORTH DAKOTA

AUXILIARY SPILLWAY EXIT CHANNEL PLAN AND PROFILE
PROJECT NO. 8150-0002

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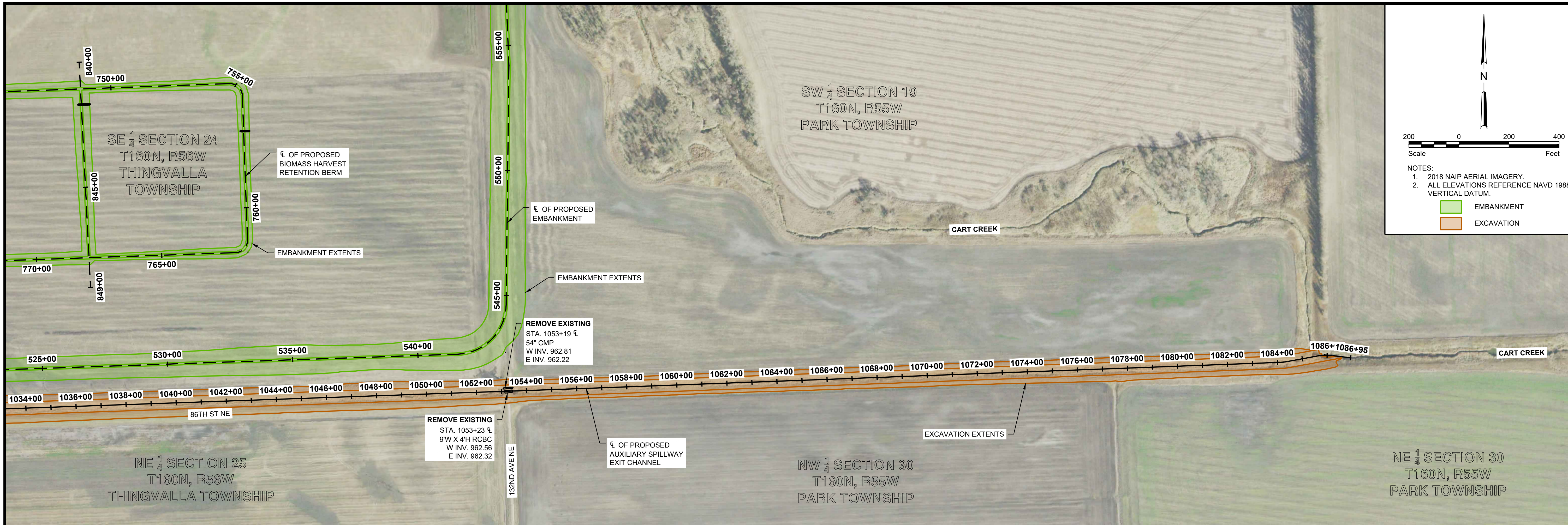

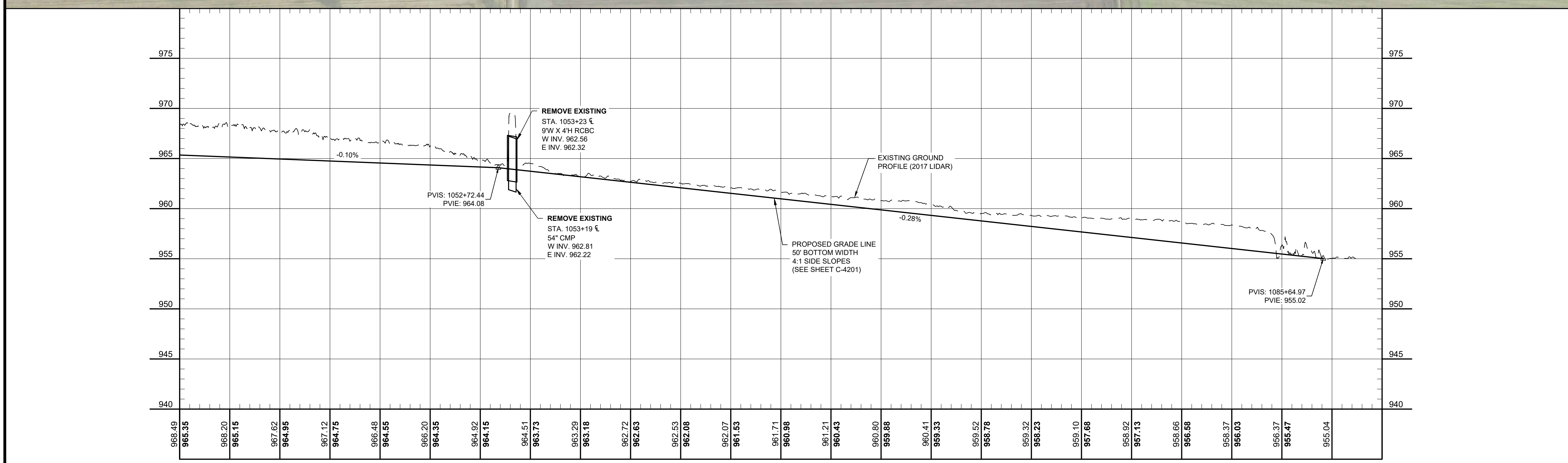

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PARK RIVER JOINT WATER RESOURCE DISTRICT
GRAFTON, NORTH DAKOTA

AUXILIARY SPILLWAY EXIT
CHANNEL PLAN AND PROFILE

PROJECT NO. 8150-0002

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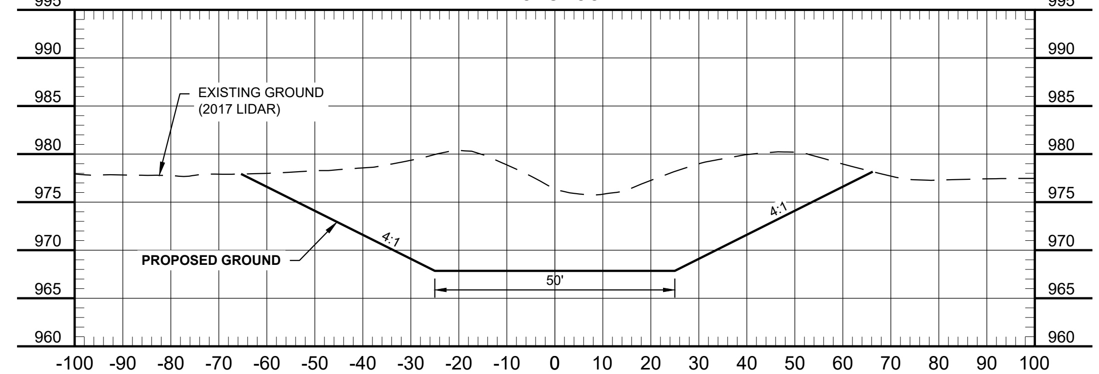
1015+00



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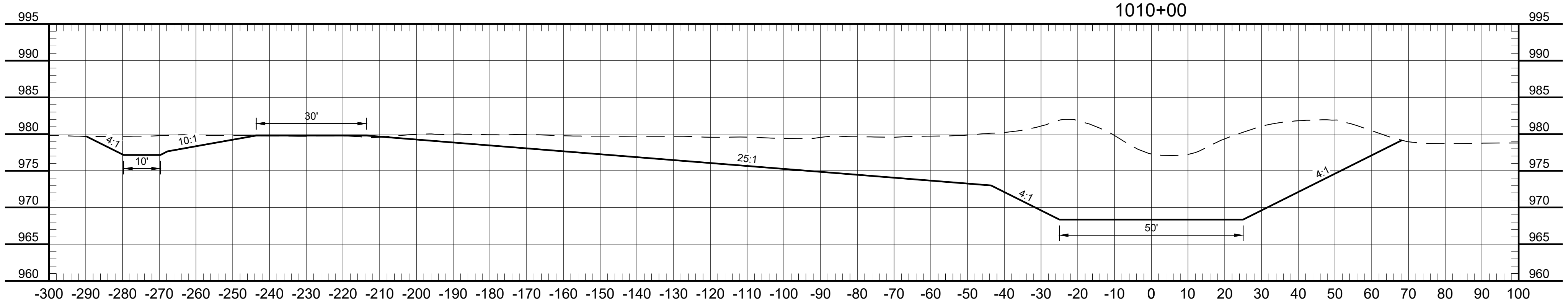

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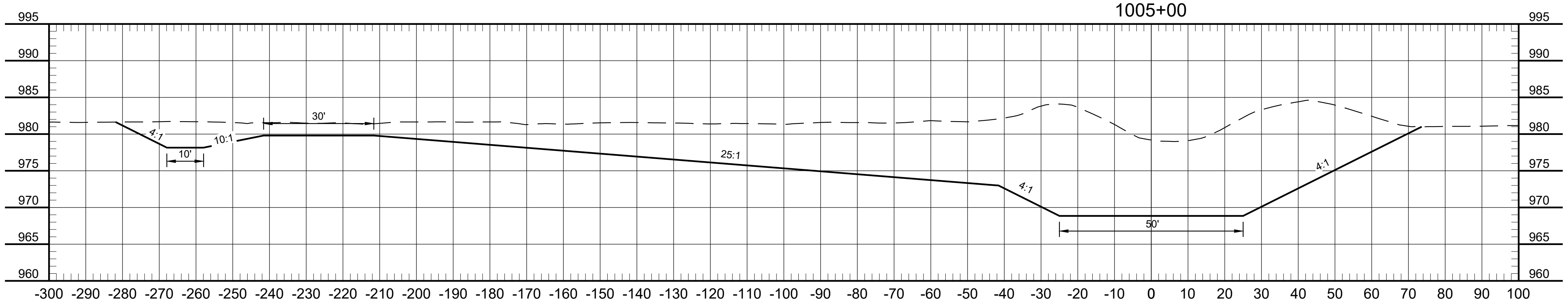

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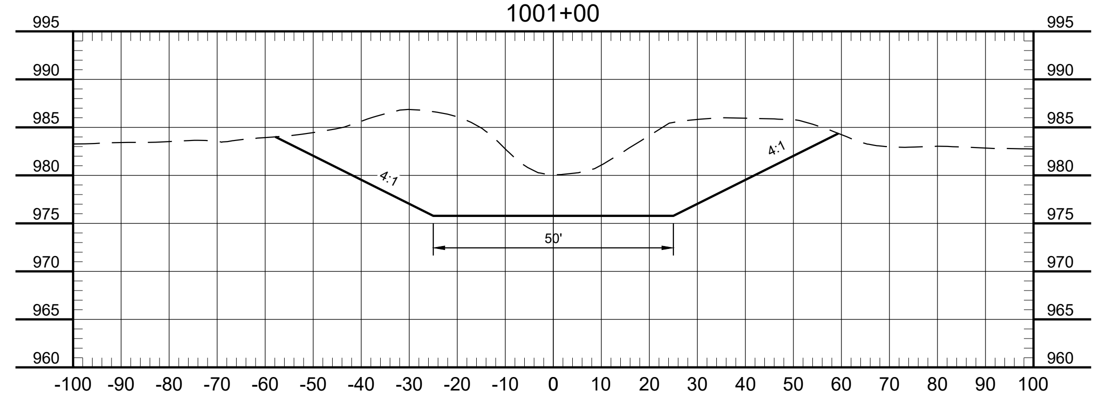

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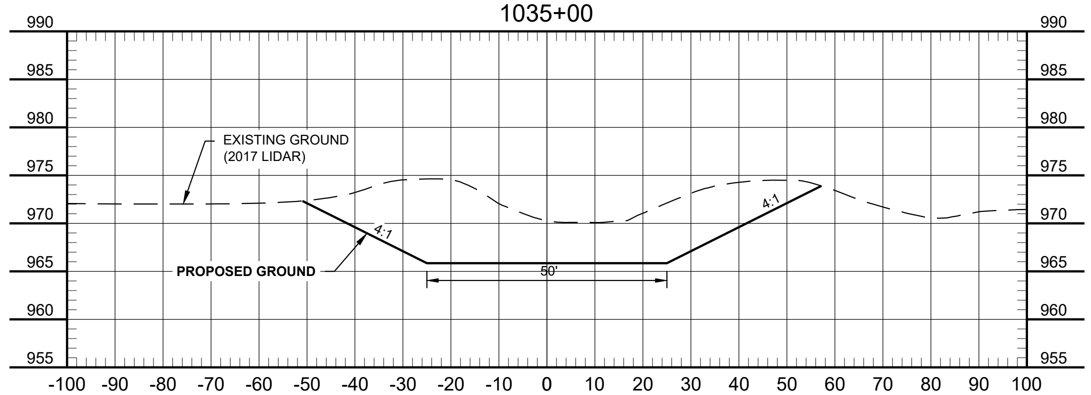

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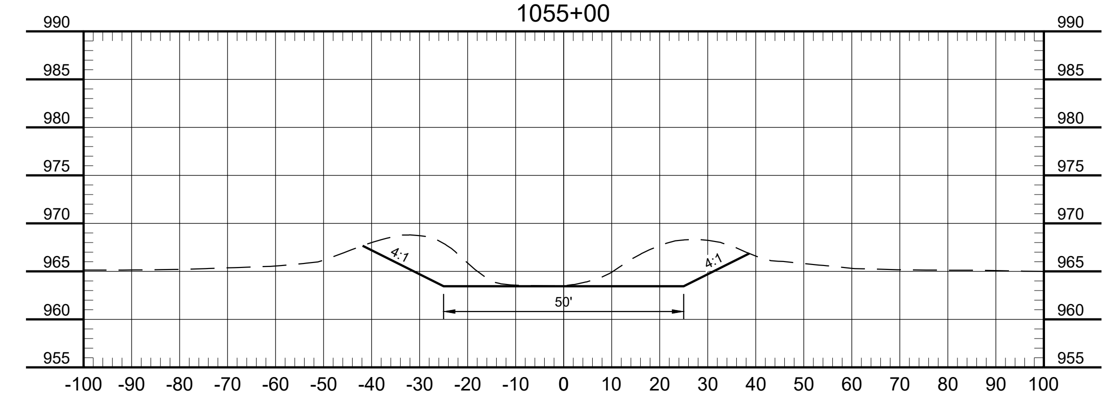

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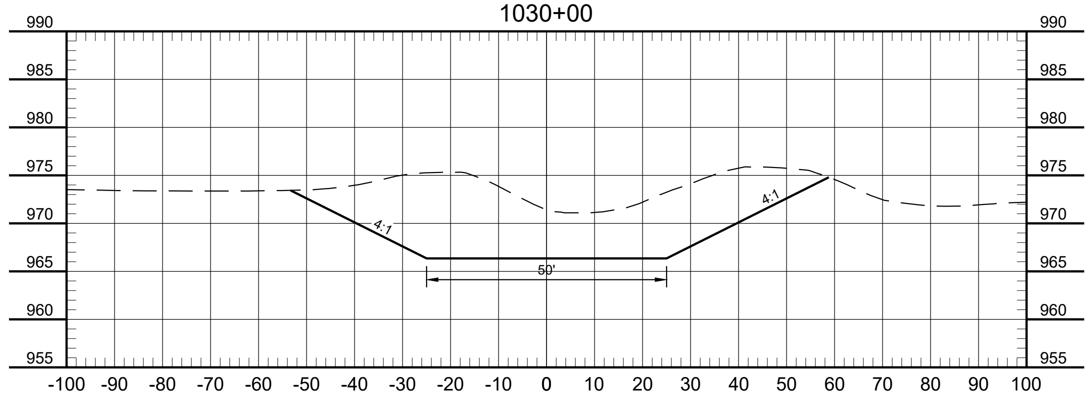

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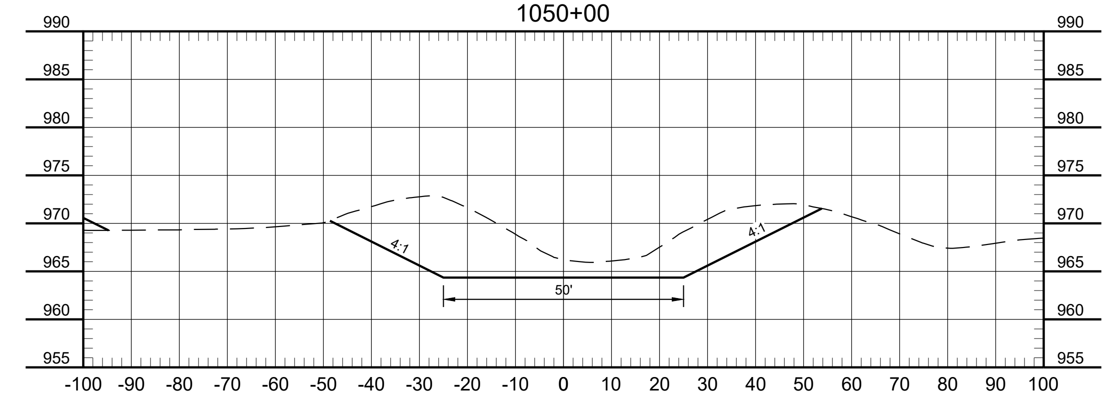

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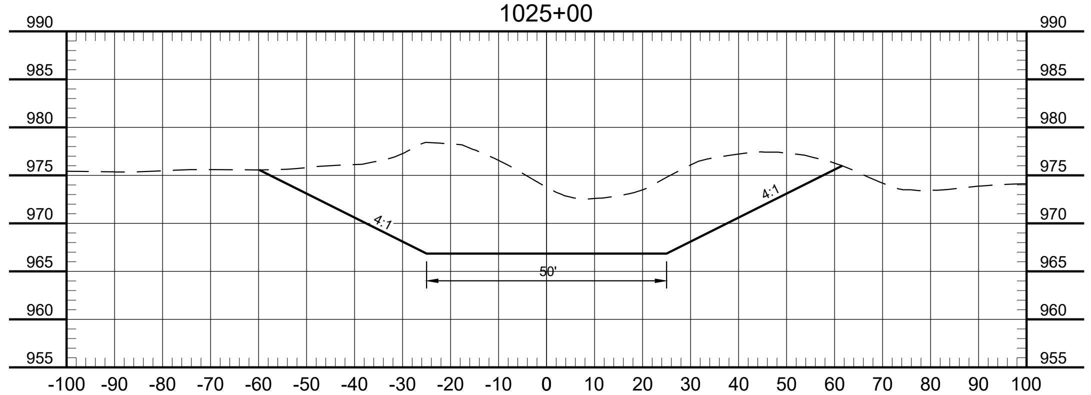

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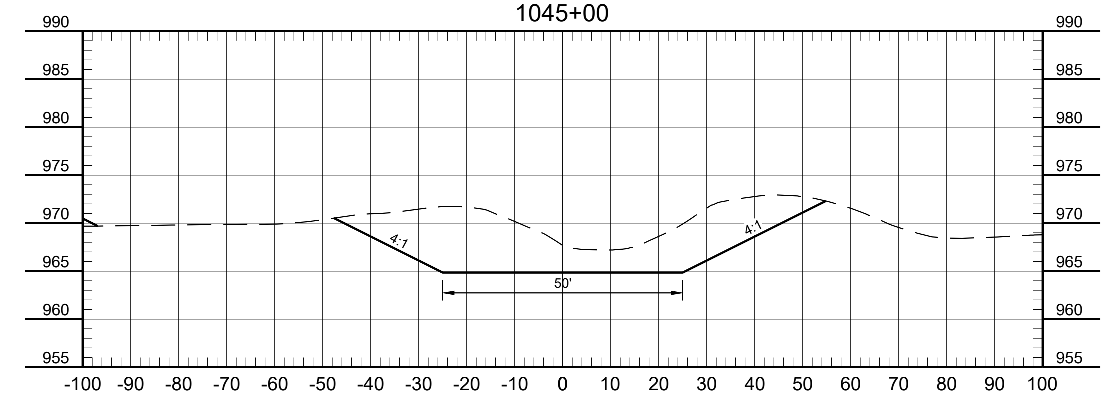

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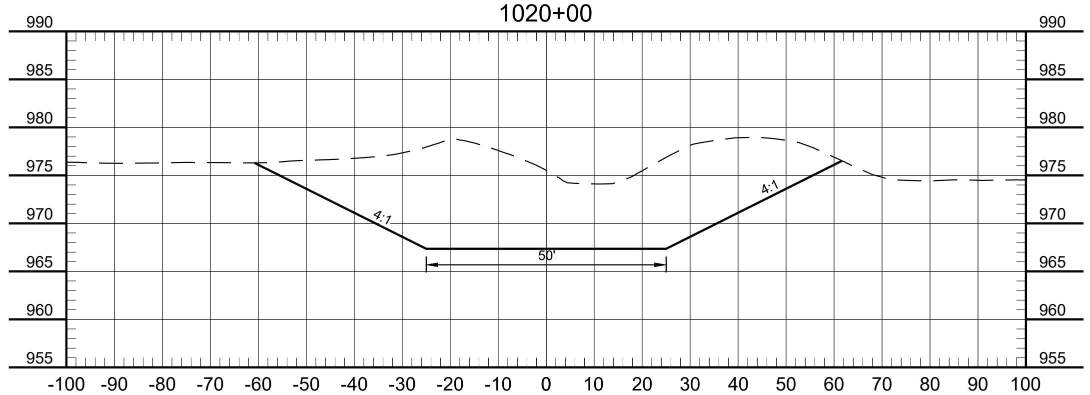

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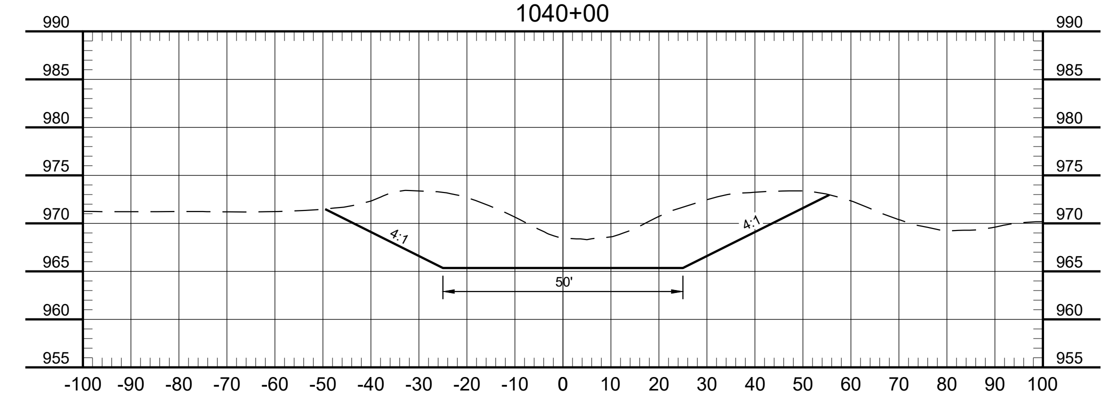

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CART CREEK SITE 1 DETAILED REVIEW
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GRAFTON, NORTH DAKOTA

AUXILIARY SPILLWAY
EXIT CHANNEL SECTIONS

PROJECT NO. 8150-0002

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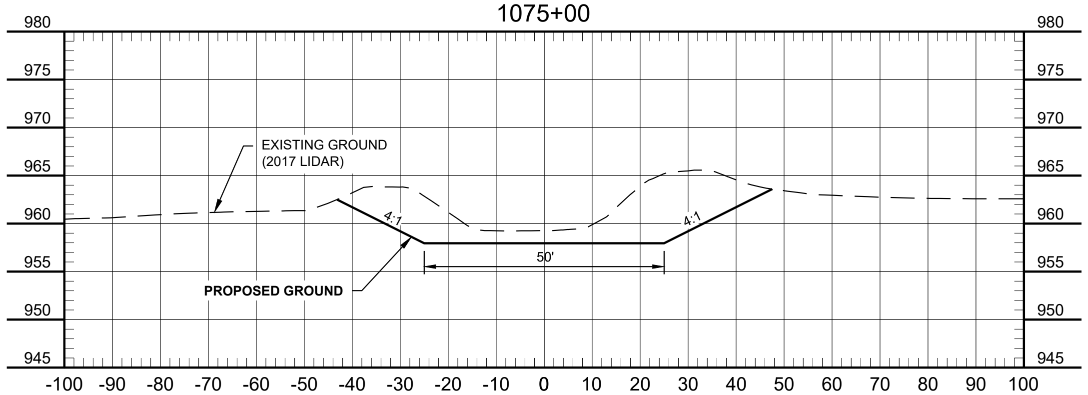

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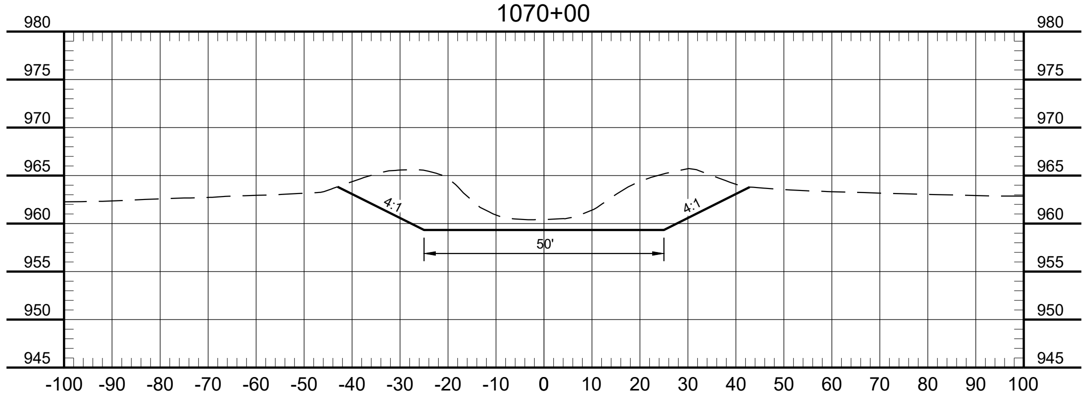

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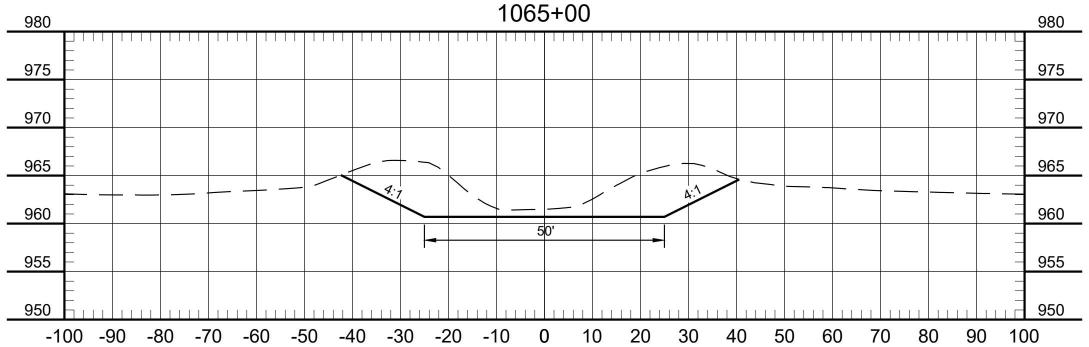

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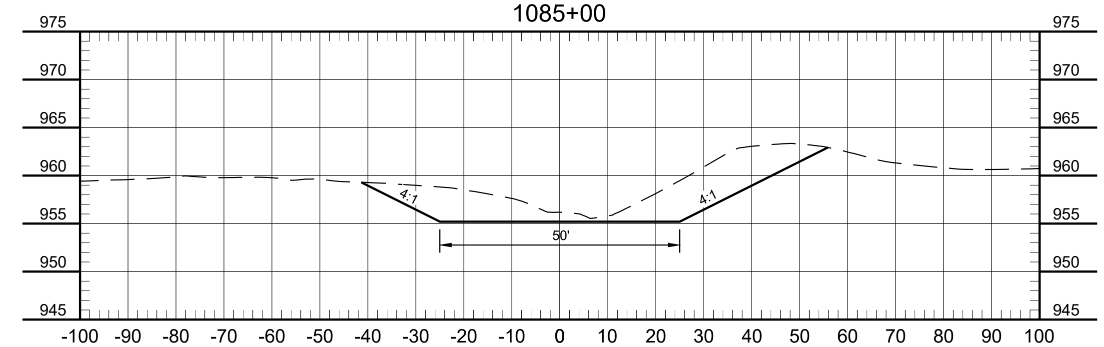

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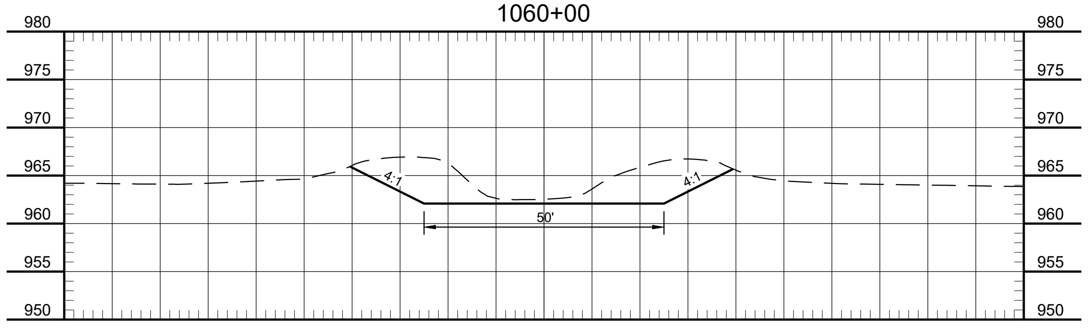

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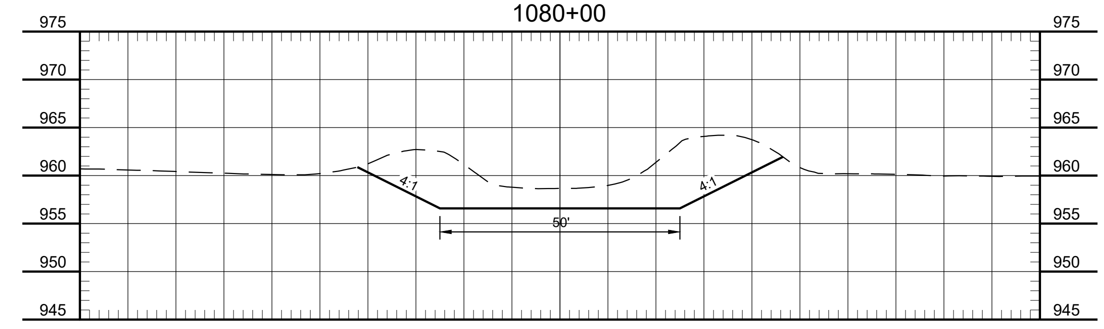

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GRAFTON, NORTH DAKOTA

AUXILIARY SPILLWAY
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PROJECT NO. 8150-0002

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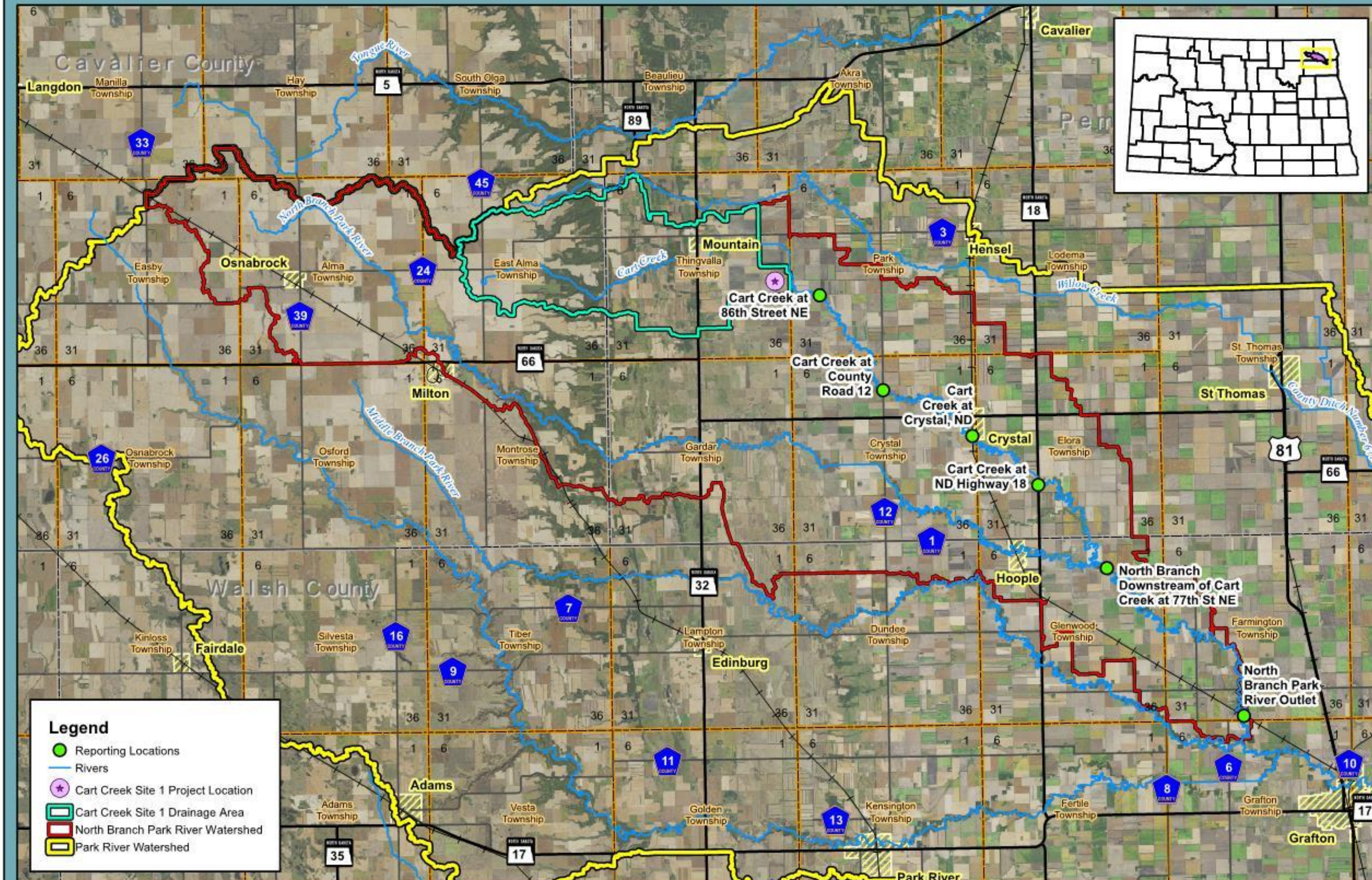
ATTACHMENT D-3-B

Synthetic Rainfall Events and Site Performance

ATTACHMENT D-3-B

Synthetic Rainfall Events and Site Performance



F-D-3-B.1

Figure D-3-B.1: Reporting Locations

North Branch Park River Watershed
Cart Creek Site 1 Concept Design Report
Park River Joint Water Resource District

0 1.75 3.5 7 Miles

Houston Engineering Inc.

***Figure D-3-B.2**: Discharge Hydrograph at 86th St NE - Cart Creek*

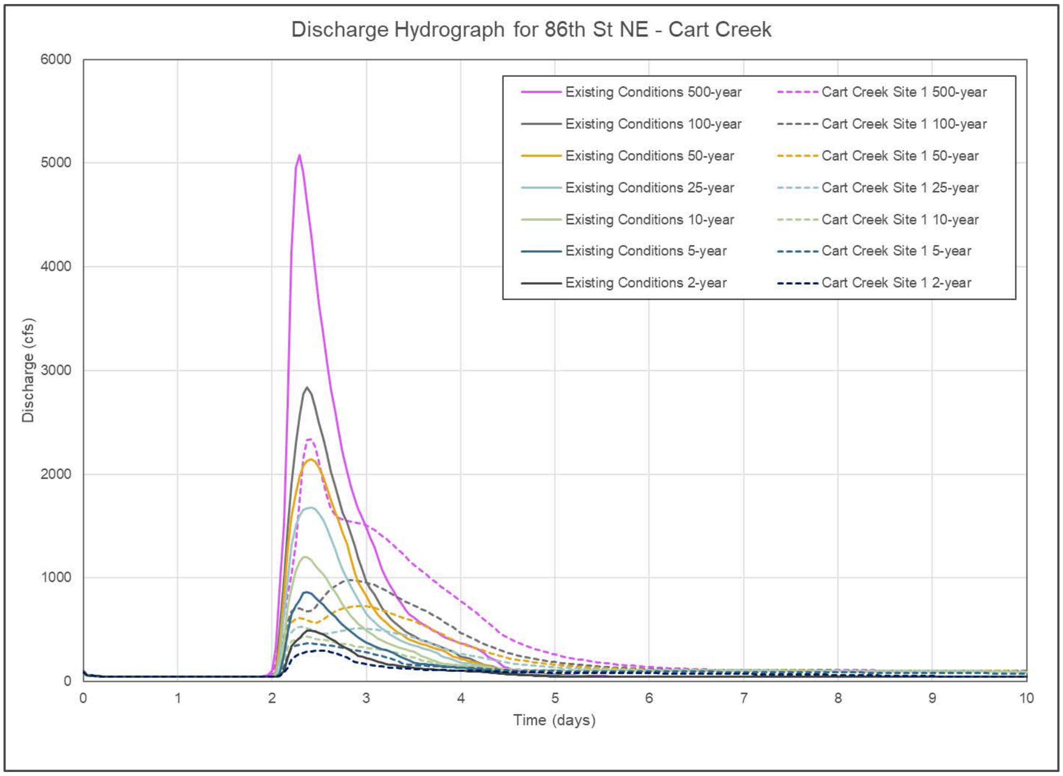


***Figure D-3-B.3:** Discharge Hydrograph at County Road 12 - Cart Creek*

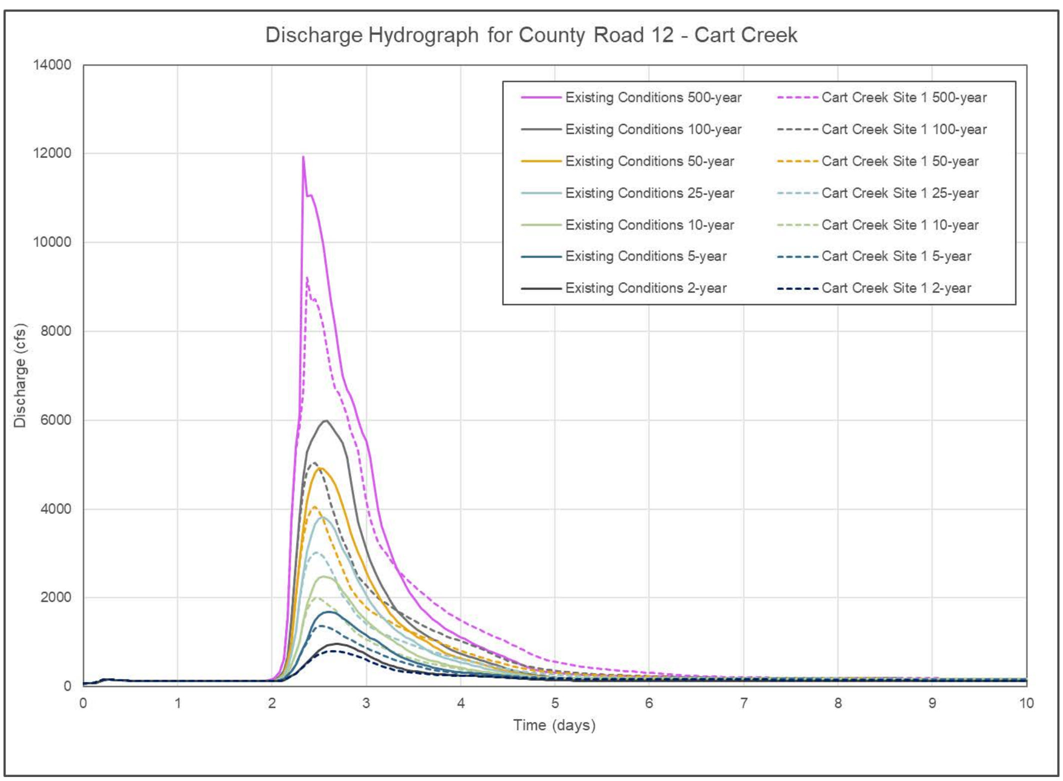


Figure D-3-B.4: *Discharge Hydrograph at Crystal, ND - Cart Creek*

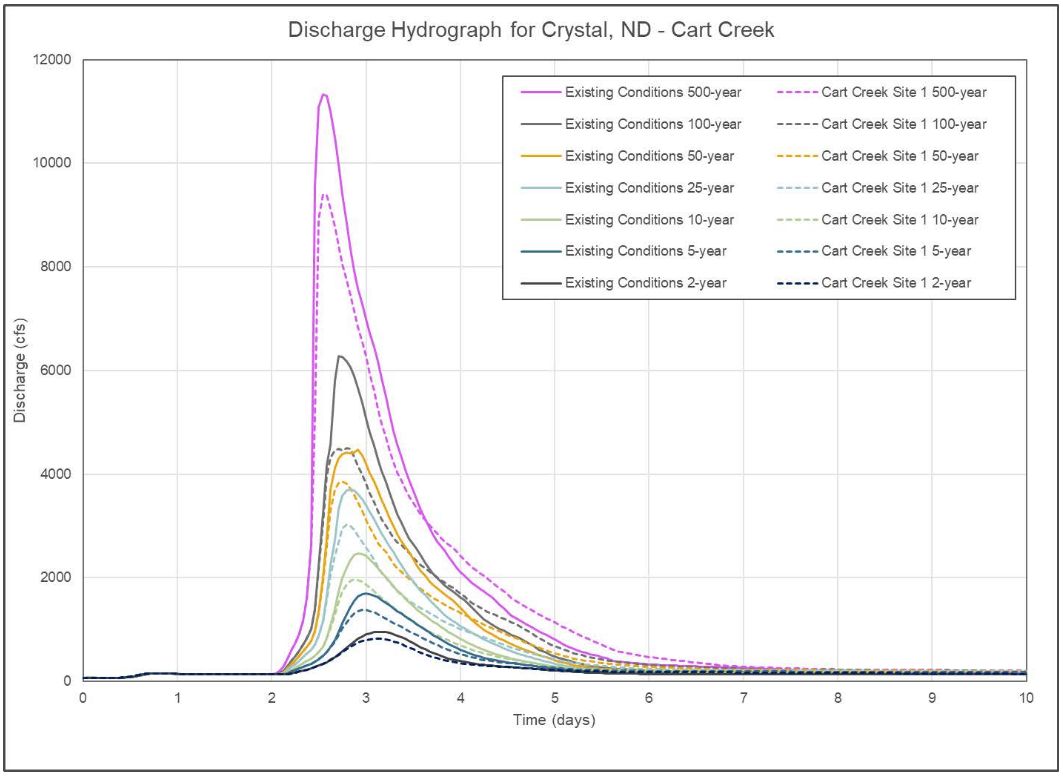


Figure D-3-B.5: *Discharge Hydrograph at Highway 18 - Cart Creek*

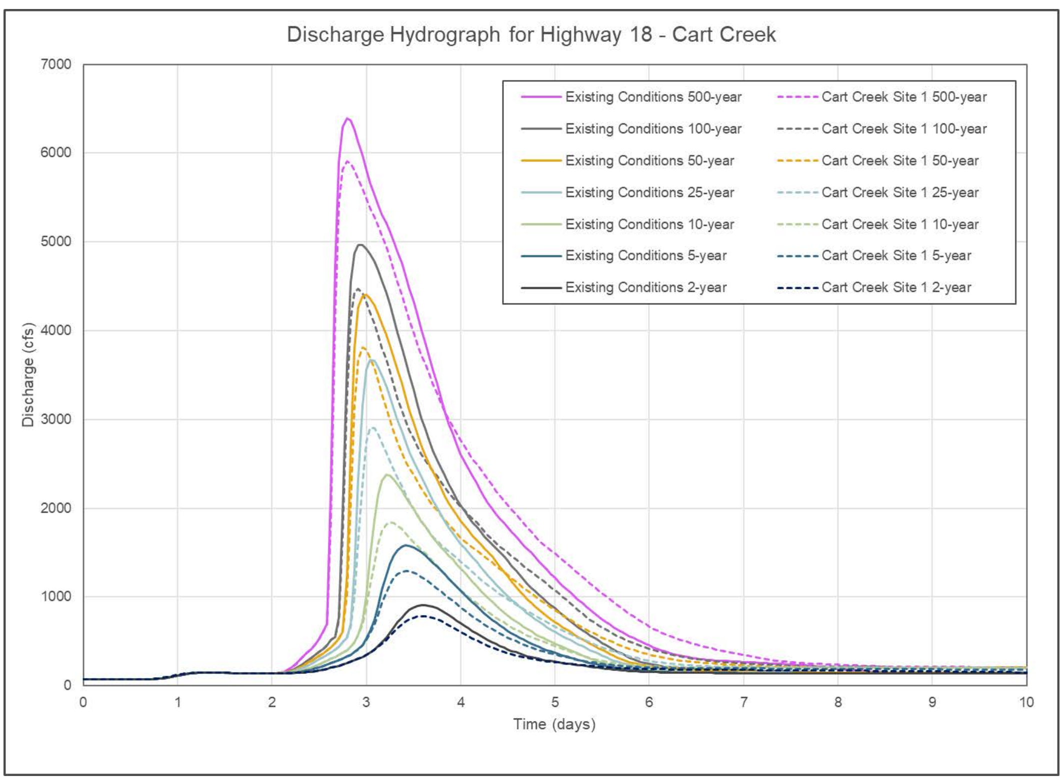


Figure D-3-B.6: *Discharge Hydrograph at 77th St NE - North Branch Downstream of Cart Creek*

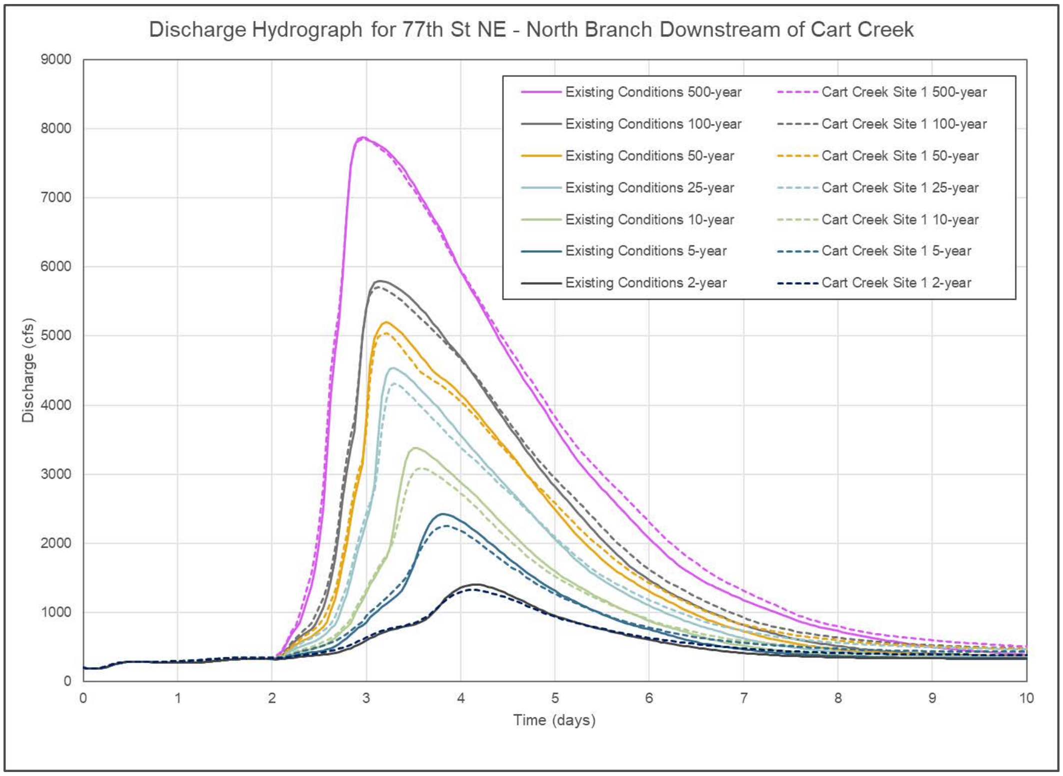


Figure D-3-B.7: *Discharge Hydrograph at North Branch Outlet (Channel Only)*

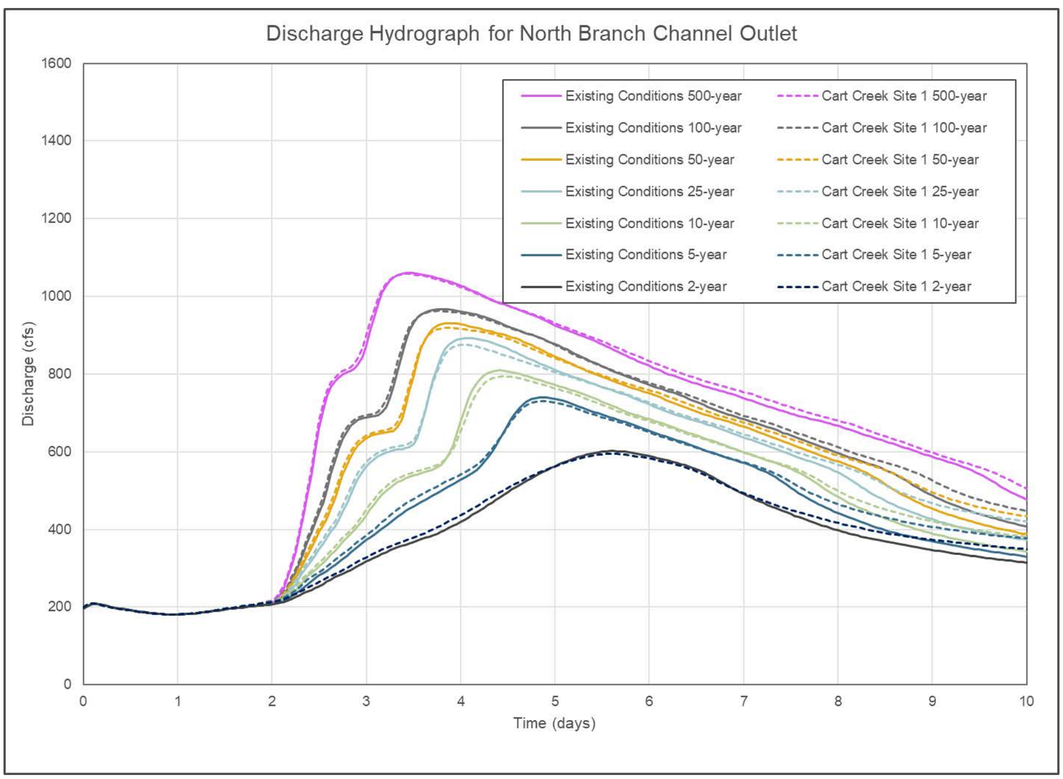


Figure D-3-B.8: *Discharge Hydrograph at North Branch Outlet (Including Breakouts)*