North Dakota State Water Commission
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July 28, 2015

Mr. Robert Flath
LaMoure County Commission
211 S. Main
PO Box 278
LaMoure, ND 58458

LaMoure County Study – James River Investigation Agreement

Dear Mr. Flath,

Enclosed is a written report that summarizes the findings of the James River Investigation conducted in LaMoure County and fulfills the responsibilities of the State Water Commission, as stated in the agreement between the LaMoure County Commission and the State Water Commission, dated June 30, 2015.

The State Water Commission examined the erosion of the James River stream banks through LaMoure County Memorial Park, examined possible mitigation and prevention alternatives, and prepared cost estimates for mitigation alternatives. The findings of the investigation are presented in the investigation report.

If you have any questions, or would like to meet to discuss the results please contact Chris Korkowski at 701-328-2762.

Sincerely,

James T. Fay, P.E.
Investigations Section Chief

JTF:pdh/2047
Enclosures

LaMoure County Memorial Park Erosion Control Investigation

LaMoure County, North Dakota

SWC Project #2047
North Dakota State Water Commission
900 East Boulevard
Bismarck, ND 58505-0850

Prepared for:
LaMoure County Commission

June 2015

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1. Introduction

LaMoure County Memorial Park is a recreational area located near the City of Grand Rapids in LaMoure County, North Dakota. Over the last several years, high-sustained flows have increased the rate at which the stream banks have been eroding in the park. The increase in erosion has jeopardized the primary park entrance

The LaMoure County Commission (County) requested the North Dakota State Water Commission (SWC) to conduct an investigation to determine possible solutions or measures that could be taken to reduce or prevent erosion on the parks banks. The SWC and County entered a Study Agreement in March 2014 (Appendix A). This report presents the results of the study and identifies alternatives for the County to implement.

2. Site Location

LaMoure County Memorial Park is located in central LaMoure County in southeast North Dakota, northeast of the city of Grand Rapids. The park is located in Sections 32 and 33 of Township 135 North, Range 61 West and Sections 4 and 5 of Township 134, Range 61 West.

Figure 1. Site Location

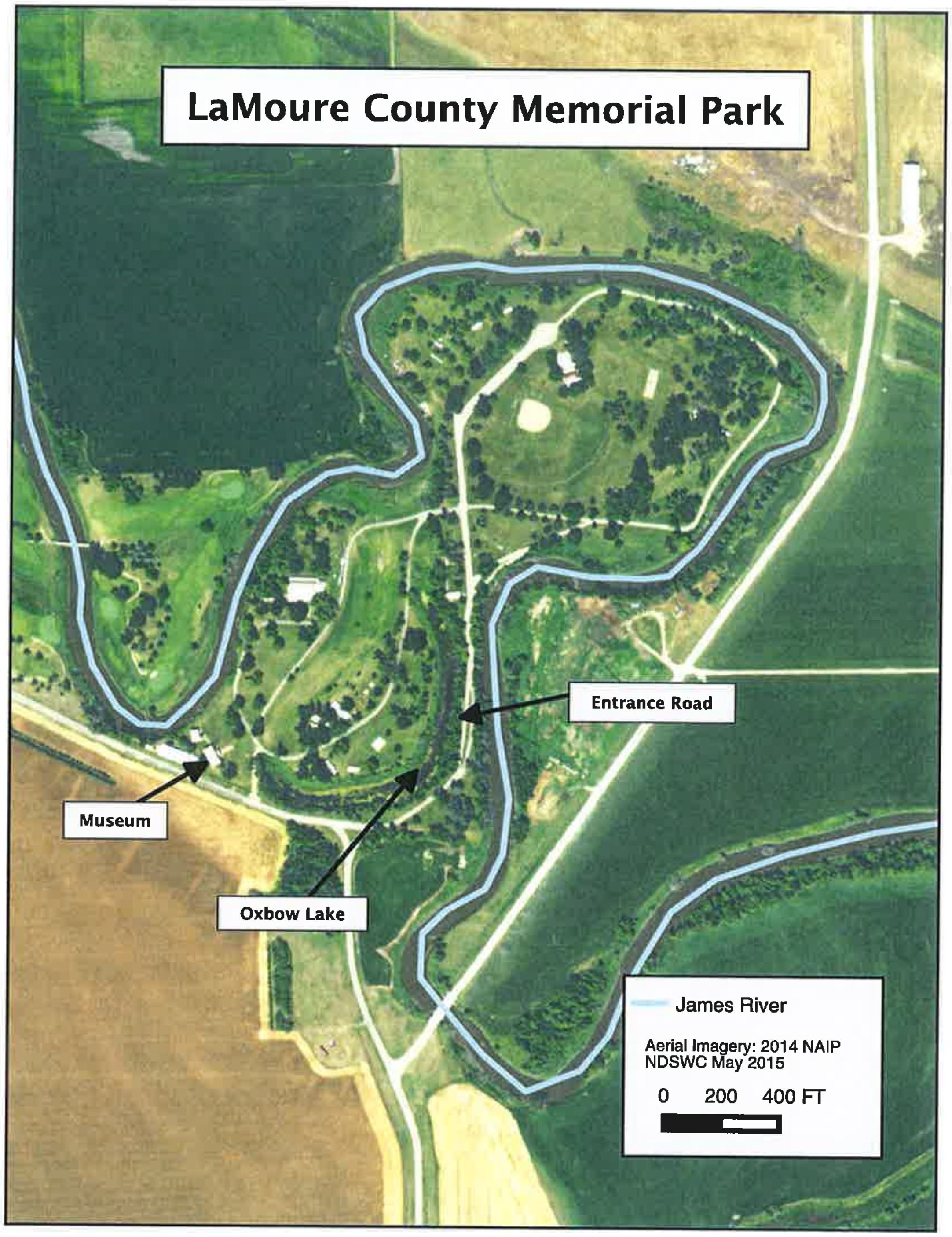

Figure 2. Site location (2)

3. Background

The entrance into the park sits between the James River and an oxbow lake (Figure 2). Currently the James River is eroding the bank near the entrance road, putting access to the park at risk. The river is also eroding several other banks along the park, including a stream bank near the county's museum.

The steep bank near the entrance road has already caused the park to shut down a small section of the roadway in order to keep park users safe.

While on a tour of the park, the County raised concern about the steep banks near the county's museum. LaMoure County Memorial Park is typically host to several large gatherings over the summer months. During these gatherings park staff place a temporary fence near the museum to keep park users away from the steep bank.

If current trends continue, the park's entrance road will have to be shut down and the museum may need to be moved.

4. Geomorphology

The James River is a meandering river. The river meanders maintain a sinusoidal pattern in order to maintain its energy grade. The sinuosity of the river channel creates a wide flood plain with a variation of sediment. Soil particles along the James River are typically composed of clay to sand particles that erode and deposit in a predictable process: the river's adjustments to maintain its energy grade cause the river to remove sediments to keep the stream length. Figure 2 is a depiction of how a typical meander of a sinusoidal river erodes and deposits sediment material. The process causes the outside bends of meanders to erode away, while the inside bends typically gain new material. The area along the outside bends are deeper due to the sediment being removed, these deep areas are referred to as pools. The inside bends of the river are referred to as point bars. Point bars are the areas of the meander that gain new sediment. On each end of the bends in a meander shallow areas form, known as riffles. The deepest path, known as the thalweg, is the area with the largest erosion potential due to fast current. The geomorphic features can be identified using the same process depicted in Figure 3 and by viewing the elevations and aerial imagery of an area. Figure 4 is a map of the James River's geomorphologic features through LaMoure County Memorial Park.

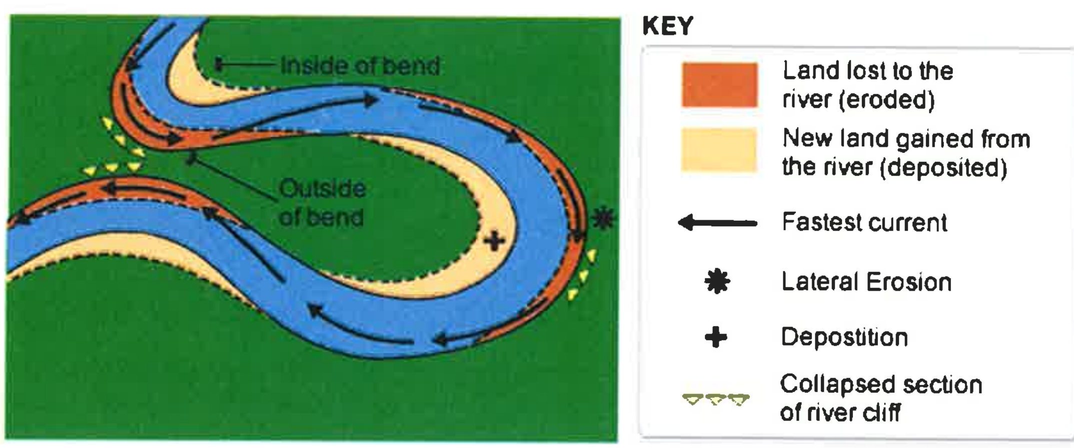

Figure 3. Meandering river sediment distribution.

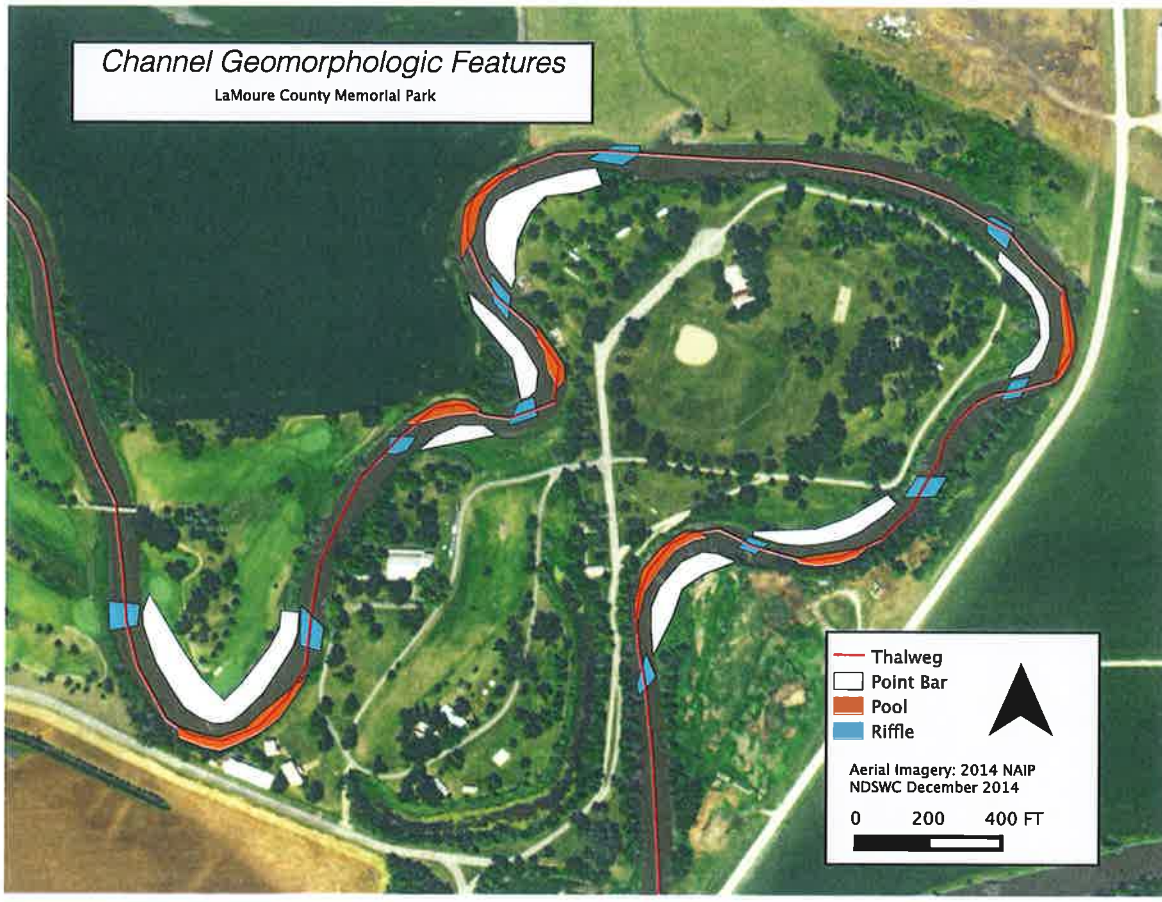

Figure 4. James River geomorphologic features.

Pools, riffles, and point bars also help identify what type of meander is forming. Reaches are often classified by their degree of meander or by their meander classification. The Modified Brice Classification System (MBCS) can be used to determine a reach's meander classification. The reach of the James River near LaMoure County Memorial Park is wider at its bends with point bars on each bend. Using MBCS the reach can be classified under the G2 category. The G2 category of MBCS describes the reach as a two phase, bimodal bank-full sinuosity that is wider at the bends. A G2 category reach is normally formed by bank-full flow or extremely large flood events. The meanders in a G2 category reach typically have excessive movement of the banks and can have extremely variable channel migration. The extreme variability of the reach can be verified from the oxbow lakes along the James River from Jamestown to the South Dakota border. The reach classification, G2, identified that bank-full and large flow events form this type of reach and can help identify factors contributing to bank retreat.

5. Factors Contributing to Bank Retreat

In order to identify stream bank erosion mitigation solutions, the cause of the erosion had to be determined. The meander classification identified that bank-full and extremely large flows are what form this particular type of reach.
Stream bank erosion can be caused by different processes including high channel velocities, excess shear stress on the stream bank, subaerial processes, and mass failure of the stream bank. These processes will be discussed below.

Two of these four processes must be evaluated using a hydraulic model of the area in question. Two-dimensional hydraulic models can determine the applied shear stress the water surface exerts on the stream bank and calculate the channel velocities in the problem area.

5.1 Channel Velocity

Channel velocities can play an important role in forming a river channel. As channel velocities increase so does the river's momentum. Increased channel momentum increases the hydraulic shear stress a river places on its banks, increasing erosion. The NRCS "Stream Restoration Planning and Design Fluvial System Stabilization and Restoration Field Guide" describes bank-full flows to be major channel forming events.

> "*Bank-full flow is often considered to be synonymous with channel-forming discharge in stable channels, and is used in some channel classification systems, as well as for an initial determination of main channel dimensions, plan and profile. In many situations, the channel velocity approaches maximum velocity at bank-full stage. In some cases, on wide, flat floodplains, it has been observed that the channel velocity can drop as the stream overtops its bank, and spills onto the floodplain." (NRCS, 2011)*

Channel velocities can be used to determine if erosion is taking place if the permissible velocity of soil type is exceeded. Figure 5 is a list of mean permissible velocities of a channel based on channel materials from the NRCS's National Engineering Handbook (NRCS, 2007).

Channel material	Mean channel velocity (ft/s)	(m/s)
Fine sand	2.0	0.61
Coarse sand	4.0	1.22
Fine gravel	6.0	1.83
Earth		
Sandy silt	2.0	0.61
Silt clay	3.5	1.07
Clay	6.0	1.83
Grass-lined earth (slopes <5%)		
Bermudagrass		
Sandy silt	6.0	1.83
Silt clay	8.0	2.44
Kentucky bluegrass		
Sandy silt	5.0	1.52
Silt clay	7.0	2.13
Poor rock (usually sedimentary)	10.0	3.05
Soft sandstone	8.0	2.44
Soft shale	3.5	1.07
Good rock (usually igneous or hard metamorphic)	20.0	6.08

Figure 5. Permissible channel velocities in riparian areas (NRCS, 2007).

5.2 Excessive Shear Stress

A soil's plasticity is the ability of its particles to adhere to one another. It is measured by its plasticity index which is defined as the difference between a soil's liquid limit and its plastic limit. The plasticity index is important in classifying fine-grained soils. The plasticity index of a soil can be related to the shear stress a soil could endure without eroding from a stream bank (Clark, 2007).

Excess shear stress is a contributor to erosion of stream banks that have non-plastic soils. The excess shear stress equation approximates the amount of soil particles detached from the stream bank due to hydraulic forces, also known as fluvial entrainment. The excessive shear stress equation can be used to approximate the amount of erosion taking place in cohesive soils (Equation 1, Clark, 2007).

$$\varepsilon = k_d*(\tau_a - \tau_c)^a \qquad \text{(Eq. 1)}$$

ε = erosion rate (m/s)
a = exponent typically assumed to be 1
k_d = erodibility coefficient (m^3/N*s)
τ_a = applied shear stress on the soil boundary (Pa)
τ_c = critical shear stress (Pa)

Equation 2 is the empirical equation developed from a flume study to compute the critical shear stress of a soil using the soil's plasticity index (Equation 2, Clark, 2007). The critical shear stress of a soil was derived to be inversely related to a soils erodibility coefficient (Equation 3, Clark, 2007).

$$\tau_c = 0.16*(I_w)^{0.84} \qquad \text{(Eq. 2)}$$

τ_c = critical shear stress (Pa)
I_w = plasticity index

$$k_d = 0.2*(\tau_c)^{-0.5} \qquad \text{(Eq. 3)}$$

k_d = erodibility coefficient (cm^3/N*s)
τ_c = critical shear stress (Pa)

5.3 Subaerial Processes

Subaerial processes are climate-controlled conditions that reduce soil strength. Frost heave is the main component of subaerial processes and typically is only a major contributor to a stream's erosion process if erosion is taking place in the upper reaches of a river system (Wynn, 2004). Subaerial processes control erosion in the upper reaches of a stream basin due to generally lower discharges in the upper reaches. In other cases, subaerial processes are minor processes that occur if another form of erosion is taking place.

5.4 Mass Failure of Stream Banks

Mass wasting occurs when the weight of the bank is greater than the shear strength of the soil (Clark, 2007). Mass wasting occurs from increases in bank height and bank angle due to fluvial entrainment. This process typically takes place after large flood events and is a separate component from fluvial entrainment. Fluvial entrainment and mass failure work together to complete the geomorphological process and define a stream's banks. Mass failure tends to occur near pools on meandering rivers due to the sharp change in elevation.

6. Hydraulic and Hydrologic Analysis

6.1 Flood Frequency Analysis

The United States Army Corps of Engineers (USACE) completed a steady flow hydraulic model and flood frequency analysis for the James River as part of the James River Feasibility Study. Table 1 is the flood frequency analysis derived by the USACE for LaMoure County Memorial Park.

Table 1. Flood frequency analysis for LaMoure County Memorial Park.

Frequency Event (Year)	Percent Chance of Reoccurrence	Flow (cfs)
2	50.0%	1,310
5	20.0%	3,330
10	10.0%	5,090
25	4.0%	8,770
50	2.0%	10,240
100	1.0%	11,620

The flood frequency analysis completed by the USACE is an important part in calibrating a hydraulic model for the James River near Grand Rapids. Since this area does not have a stream gage, the flood frequency analysis could be used as a tool to calibrate future models.

6.2 Hydraulic Modeling

Two-dimensional hydraulic modeling can calculate applied shear stress across a channel due to its ability to have independent water surfaces on each node of a grid. The International River Interface Cooperative's (iRiC) solver System for Transport and River Modeling (SToRM) was chosen to model the hydraulic effects of the James River.

SToRM is a two-dimensional solver that uses an unstructured grid to compute the momentum equation over a Digital Elevation Model (DEM). SToRM was used for the hydraulic analysis due to its ability to determine bed shear stress, map channel and over bank velocities, and its ability to identify the thalweg of the river system.

SToRM uses inflow and outflow boundary conditions to run the momentum equation over the unstructured grid. Tables 2 and 3 show the inflow and outflow boundary conditions used to run the SToRM model. The boundary conditions were created using water surface elevations and steady flow information from the HEC-RAS model developed for the James River Feasibility Study.

Table 2. SToRM Inflow Boundary Conditions.

Frequency Event	Flow (cfs)	W.S. Elevation (ft)
2	1,310	1,308.09
5	3,330	1,312.99
10	5,090	1,314.98
25	8,770	1,317.38
50	10,240	1,318.04
100	11,620	1,318.53
200	12,880	1,318.9
500	14,000	1,319.19

Table 3. SToRM Outflow Boundary Conditions.

Frequency Event	Flow (cfs)	W.S. Elevation (ft)
2	1,310	1,307.58
5	3,330	1,312.41
10	5,090	1,314.38
25	8,770	1,316.61
50	10,240	1,317.1
100	11,620	1,317.63
200	12,880	1,318.04
500	14,000	1,318.35

7. Erosion Analysis

7.1 Channel Velocity Analysis

Channel velocities for the James River were computed over several frequency events using SToRM. The velocities for each frequency event computed in SToRM were converted to rasters. The largest velocity computed for the SToRM model was then used as the control for the erosion control design. The largest velocity computed from the SToRM model was nearly 3.5 ft/s and occurred during the 100-year event. The highest velocity during bank-full conditions (2-year event) was found to be 1.8 ft/s.

7.2 Excess Shear Stress Analysis

Erosion rates for the banks of the James River in LaMoure County Memorial Park were developed using the excess shear stress equation (Equation 1). Plasticity indexes to compute the critical shear stress of the soil were given in the SSURGO horizon tables. After the critical shear stress for each soil category was computed, the applied shear stress for each frequency event from SToRM was rasterized. The erosion rates were then computed over analysis units placed along the banks of the James River (Figure 6). Each of the analysis units were cut using the SSURGO soil type boundaries and by creating analysis units over areas of interest based on site photos from Appendix B.

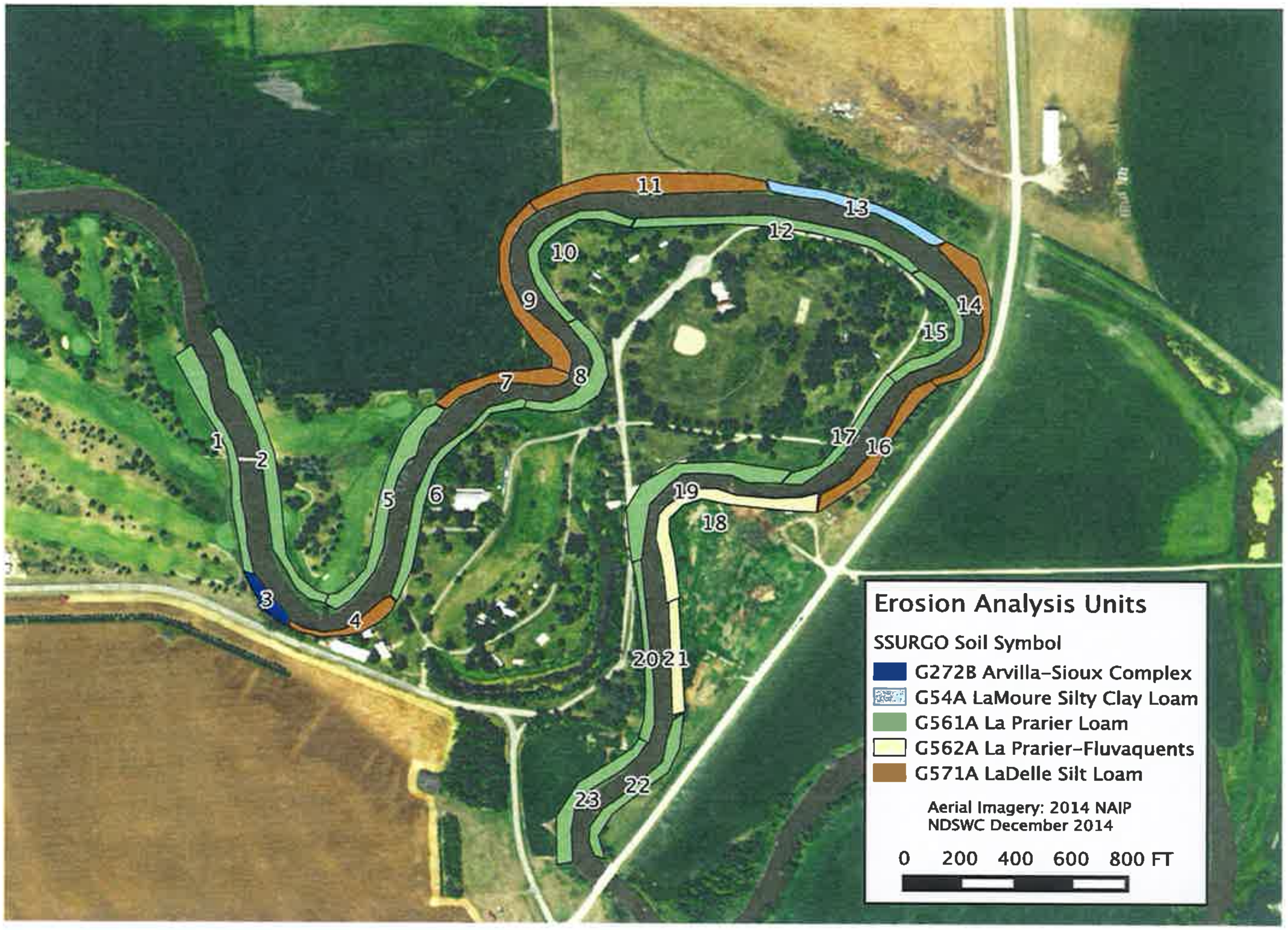

Figure 6. Erosion analysis units in LaMoure County Memorial Park

The erosion rates calculated for each frequency event should be used only as a numeric to view severity of possible events. The computed erosion rates do not factor in vegetative protection, changes in soil composition, or root adhesion. Table 4 is the calculated erosion rates for each analysis unit in LaMoure County Memorial Park.

Table 4. Erosion rate predictions for LaMoure County memorial park.

Analysis Unit	2YR cm/day	10YR cm/day	25YR cm/day	50YR cm/day	100YR cm/day
1	4.648	5.173	8.329	10.133	129.926
2	6.807	7.029	18.277	22.827	81.668
3	1.304	1.091	1.453	1.930	47.146
4	3.043	1.610	10.829	12.358	67.152
5	5.008	5.151	6.732	6.827	14.621
6	8.654	8.378	15.821	16.801	73.596
7	5.886	5.907	8.942	9.323	54.796
8	2.559	2.079	10.803	10.293	50.033
9	6.572	6.152	4.020	2.425	11.519
10	6.645	4.944	5.091	3.613	34.283
11	3.032	1.890	2.802	2.425	9.255
12	7.876	7.895	3.341	2.435	26.032
13	4.488	4.870	2.779	2.289	5.264
14	0.000	0.000	4.500	5.886	45.097
15	6.211	5.450	2.182	1.885	7.564
16	1.474	0.000	3.051	3.125	20.483
17	9.173	8.963	3.538	2.820	9.827
18	5.811	4.832	3.538	4.013	27.534
19	2.244	1.878	6.441	4.437	11.940
20	6.340	4.769	8.395	9.934	41.379
21	8.140	6.061	10.626	12.406	22.214
22	7.213	5.347	16.980	22.183	101.570
23	3.542	1.824	7.472	10.635	115.310

7.3 Mass Wasting Analysis

The excess shear stress equation accounts for mass wasting caused by a given event over certain durations. Since the excess shear stress equation does not factor in vegetation, it is important to examine the area and bank slopes to determine which areas are more likely to be eroding. The bank slopes were examined by using LIDAR and bathymetric survey to determine the elevations and slopes of the stream bank (Figure 7). Cross sections along each bank were also examined (Appendix C).

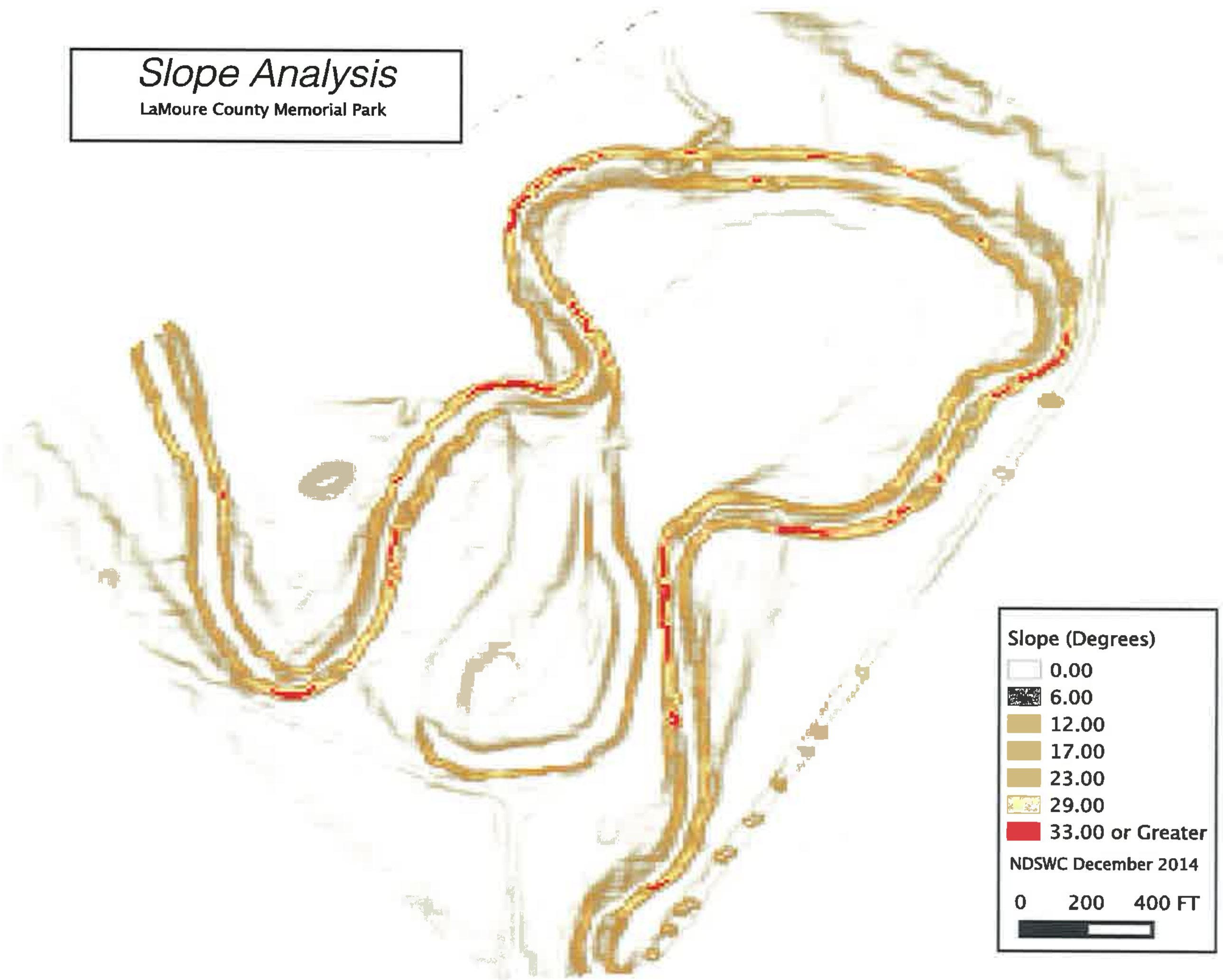

Figure 7. Slope analysis of LaMoure County Memorial Park.

7.4 Site Locations

Based on a site visit and the slope analysis, erosion rates, and geomorphology; locations for erosion protection/mitigation were determined. The site locations aligned with the pools shown in Figure 4. The site locations and site lengths in the park are displayed in Figure 8. The sites displayed in Figure 8 have little to no vegetative cover protecting them from stream bank erosion. These areas also have slopes in some cases greater than 1H:1V. Three of the most active sites are locations 1, 2, and 5. Site 1 is the bank directly next to the park's entrance road and erosion here could affect the stability of the road. (A geotechnical analysis would need to be conducted to determine the stability of the stream bank.) Site 2 is located next to the county museum and could soon affect the stability of the bank near the museum. Site 5 is located next to county road 98th Ave SE and could be affecting the roads stability (A geotechnical analysis would need to be conducted to determine the stability of the stream bank.) These sites are considered priorities since they could directly affect infrastructure and the park's primary point of entry. The other sites located within the region do not directly affect infrastructure, but have safety concerns for park users and may account for land losses to private ground.

Figure 8. Site locations.

8. Erosion Mitigation/Protection

Erosion protection structures are divided into two categories: soil bioengineering and hard engineering. Soil bioengineering techniques use vegetation to protect the stream banks from high velocities and shear stresses. Hard engineering practices consist of revetments, sheet piling, and hard armoring.

8.1 Soil Bioengineering Techniques

"Streambank soil bioengineering is defined as the use of living and nonliving plant materials in combination with natural and synthetic support materials for slope stabilization, erosion reduction, and vegetative establishment." (NRCS, 2007). Soil bioengineering provides a more aesthetic approach to stream bank protection and provides many benefits to wildlife. Improving riparian areas by selecting certain plant materials can boost the habitat of the area by providing food and cover for birds, mammals, and aquatic life. Soil bioengineering typically encompasses hard structure components to strengthen the stream bank during bank full flows. Bioengineering techniques do however slow the movement of water through the channel, reducing the energy of the stream and increasing the stage.

There is a wide variety of different soil bioengineering techniques that can be incorporated into a site area. With the incorporation of hard engineering and soil bioengineering techniques it becomes difficult to explain each option on an individual and descriptive basis. The NRCS has put together guides for selecting and viewing each of the most common soil bioengineering practices. The "Technical Supplement 14I Streambank Soil Bioengineering" guide for each soil bioengineering practices is attached in Appendix A.

8.2 Hard Structures

Hard structures increase the bank resistance to erosive forces, but do not significantly reduce the energy of the water. Hard structures redirect energy from the bank and create a more permanent change to the surrounding area. The two most common types of hard structures for decreasing erosive forces are sheet piling and riprap revetments.

8.3 No Change Alternative

A no change alternative would have many negative effects on the park. Toe erosion along site location 1 would likely lead the entrance road of the park having to be abandoned due to decreased stability within the next few years. This same erosion would likely cause similar issues with site location 5. The toe erosion along site number 2 would eventually lead to the LaMoure County

Museum having to be moved or cause the bank to collapse, damaging the museum. Any of these could happen suddenly.

8.4 Minimum Change Alternative

Closing the existing entrance road due to the erosion along site 1 and using the secondary entrance would be an option to prevent the park from having to close. This option would have minimum upfront costs but would still leave the banks exposed. This option does still cause concern for site locations 2 and 5 due to the erosion directly effecting infrastructure. The stream bank along site 2 and 5 would have to be treated or the museum and county road would have to be moved.

The minimum change alternative could also be improved by raising a section of existing road in the park. Raising the section of road would increase access in the park that would be lost after closing the primary entrance. Figure 9 depicts the suggested road raise.

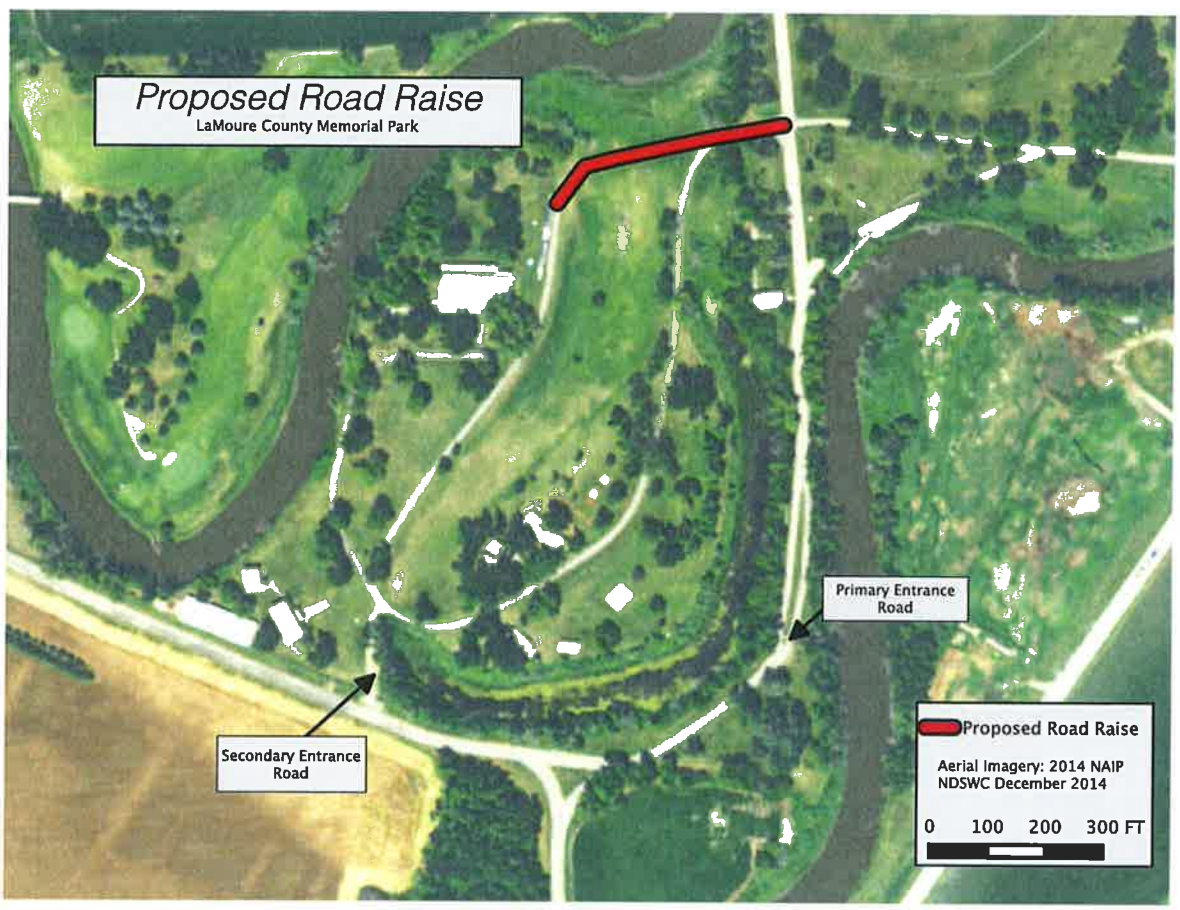

Figure 9. Proposed road raise in LaMoure County Memorial Park.

8.5 Soil Bioengineering Alternatives

Channel velocities and water-applied shear stress along with the slope of the stream bank determine which soil bioengineering techniques can be applied to a project area. Each technique can have a wide variation of costs. The soil bioengineering analysis for the sites on the James River through LaMoure County Memorial Park was governed by the maximum applied shear stress and the maximum velocity created by the 2-, 10-, 25-, 50-, and 100-year frequency events. The velocities and applied shear stresses were then compared to the permissible velocity, permissible shear stress, and the maximum slope of each technique, as described in the NRCS's "Technical Supplement 14I" (Appendix F). Tables 5 through 11 are the suggested and non-suggested soil bioengineering techniques based on the analysis described. If both initial and established requirements are met the method of stream bank restoration can be completed without extreme reshaping of the stream bank.

Site # 1	Permissible shear stress	Permissible velocity	Slope Requirements	Meets Requirements
Practice	(lb/ft^2)	(ft/s)	ft/ft	Yes/No
Live poles (Depends on the length of the poles and nature of the soil)	Initial: 0.5 to 2 Established: 2 to 5	Initial: 1 to 2.5 Established: 3 to 10	5H:1V to1H:1V See TS14I for Design Details	Initial: No Established: No
Live poles in woven coir TRM (Depends on installation and anchoring coir)	Initial: 2 to 2.5 Established: 3 to 5	Initial: 3 to 5 Established: 3 to 10	5H:1V to1H:1V See TS14I for Design Details	Initial: No Established: No
Live poles in riprap (joint planting) (Depends on riprap stability)	Initial: 3+ Established: 6 to 8	Initial: 5 to 10+ Established: 12+	5H:1V to1H:1V See TS14I for Design Details	Initial: Yes Established: Yes
Live brush sills with rock (Depends on riprap stability)	Initial: 3+ Established: 6+	Initial: 5 to 10+ Established: 12+	6H:1V to 2H:1V See TS14I for Design Details	Initial: No Established: No
Brush mattress (Depends on soil conditions and anchoring)	Initial: 0.4 to 4.2 Established: 2.8 to 8	Initial: 3 to 4 Established: 10+	4H:1V to 2H:1V See TS14I for Design Details	Initial: No Established: No
Live fascine (Very dependent on anchoring)	Initial: 1.2 to 3.1 Established: 1.4 to 3	Initial: 5 to 8 Established: 8 to 10+	5H:1V to1H:1V See TS14I for Design Details	Initial: Yes Established: Yes
Brush layer/branch packing (Depends on soil conditions)	Initial: 0.2 to 1 Established: 2.9 to 6	Initial: 2 to 4 Established: 10+	6H:1V to 2H:1V See TS14I for Design Details	Initial: No Established: No
Live cribwall (Depends on nature of fill, compaction, and anchoring)	Initial: 2 to 4 Established: 5 to 6	Initial: 3 to 6 Established: 10 to 12	1H:4V to 1H:6V See TS14I for Design Details	Initial: Yes Established: Yes
Vegetated reinforced soil slopes VRSS (depends on soil conditions and anchoring)	Initial: 3 to 5 Established: 7+	Initial: 4 to 9 Established: 10+	1H:1V or Greater See TS14I for Design Details	Initial: Yes Established: Yes
Grass turf (Depends on vegetation type and condition)	Established: 3.2	Established: 3 to 8	Up to 2H:1V See TS14I for Design Details	Initial: No Established: No
Live brush wattle fence (Depends on soil condition and depth of stakes)	Initial: 0.2 to 2 Established: 1 to 5	Initial: 1 to 2.5 Established: 3 to 10	6H:1V to 4H:1V See TS14I for Design Details	Initial: No Established: No
Vertical bundles (Depends on bank conditions, anchoring, and vegetation)	Initial: 1.2 to 3 Established: 1.4 to 3	Initial: 5 to 8 Established: 6 to 10+	Up to 1H:1V See TS14I for Design Details	Initial: Yes Established: Yes

Table 5. Site 1, soil bioengineering technique compatibility.

Site # 2 Practice	Permissible shear stress (lb/ft^2)	Permissible velocity (ft/s)	Slope Requirements ft/ft	Meets Requirements Yes/No
Live poles (Depends on the length of the poles and nature of the soil)	Initial: 0.5 to 2 Established: 2 to 5	Initial: 1 to 2.5 Established: 3 to 10	5H:1V to1H:1V See TS14I for Design Details	Initial: No Established: No
Live poles in woven coir TRM (Depends on installation and anchoring coir)	Initial: 2 to 2.5 Established: 3 to 5	Initial: 3 to 5 Established: 3 to 10	5H:1V to1H:1V See TS14I for Design Details	Initial: No Established: No
Live poles in riprap (joint planting) (Depends on riprap stability)	Initial: 3+ Established: 6 to 8	Initial: 5 to 10+ Established: 12+	5H:1V to1H:1V See TS14I for Design Details	Initial: Yes Established: Yes
Live brush sills with rock (Depends on riprap stability)	Initial: 3+ Established: 6+	Initial: 5 to 10+ Established: 12+	6H:1V to 2H:1V See TS14I for Design Details	Initial: No Established: No
Brush mattress (Depends on soil conditions and anchoring)	Initial: 0.4 to 4.2 Established: 2.8 to 8	Initial: 3 to 4 Established: 10+	4H:1V to 2H:1V See TS14I for Design Details	Initial: No Established: No
Live fascine (Very dependent on anchoring)	Initial: 1.2 to 3.1 Established: 1.4 to 3	Initial: 5 to 8 Established: 8 to 10+	5H:1V to1H:1V See TS14I for Design Details	Initial: Yes Established: Yes
Brush layer/branch packing (Depends on soil conditions)	Initial: 0.2 to 1 Established: 2.9 to 6	Initial: 2 to 4 Established: 10+	6H:1V to 2H:1V See TS14I for Design Details	Initial: No Established: No
Live cribwall (Depends on nature of fill, compaction, and anchoring)	Initial: 2 to 4 Established: 5 to 6	Initial: 3 to 6 Established: 10 to 12	1H:4V to 1H:6V See TS14I for Design Details	Initial: Yes Established: Yes
Vegetated reinforced soil slopes VRSS (depends on soil conditions and anchoring)	Initial: 3 to 5 Established: 7+	Initial: 4 to 9 Established: 10+	1H:1V or Greater See TS14I for Design Details	Initial: Yes Established: Yes
Grass turf (Depends on vegetation type and condition)	Established: 3.2	Established: 3 to 8	Up to 2H:1V See TS14I for Design Details	Initial: No Established: No
Live brush wattle fence (Depends on soil condition and depth of stakes)	Initial: 0.2 to 2 Established: 1 to 5	Initial: 1 to 2.5 Established: 3 to 10	6H:1V to 4H:1V See TS14I for Design Details	Initial: No Established: No
Vertical bundles (Depends on bank conditions, anchoring, and vegetation)	Initial: 1.2 to 3 Established: 1.4 to 3	Initial: 5 to 8 Established: 6 to 10+	Up to 1H:1V See TS14I for Design Details	Initial: Yes Established: Yes

Table 6. Site 2, soil bioengineering technique compatibility.

Site # 3	Permissible shear stress	Permissible velocity	Slope Requirements	Meets Requirements
Practice	(lb/ft^2)	(ft/s)	ft/ft	Yes/No
Live poles (Depends on the length of the poles and nature of the soil)	Initial: 0.5 to 2 Established: 2 to 5	Initial: 1 to 2.5 Established: 3 to 10	5H:1V to1H:1V See TS14I for Design Details	Initial: No Established: No
Live poles in woven coir TRM (Depends on installation and anchoring coir)	Initial: 2 to 2.5 Established: 3 to 5	Initial: 3 to 5 Established: 3 to 10	5H:1V to1H:1V See TS14I for Design Details	Initial: No Established: No
Live poles in riprap (joint planting) (Depends on riprap stability)	Initial: 3+ Established: 6 to 8	Initial: 5 to 10+ Established: 12+	5H:1V to1H:1V See TS14I for Design Details	Initial: Yes Established: Yes
Live brush sills with rock (Depends on riprap stability)	Initial: 3+ Established: 6+	Initial: 5 to 10+ Established: 12+	6H:1V to 2H:1V See TS14I for Design Details	Initial: No Established: No
Brush mattress (Depends on soil conditions and anchoring)	Initial: 0.4 to 4.2 Established: 2.8 to 8	Initial: 3 to 4 Established: 10+	4H:1V to 2H:1V See TS14I for Design Details	Initial: No Established: No
Live fascine (Very dependent on anchoring)	Initial: 1.2 to 3.1 Established: 1.4 to 3	Initial: 5 to 8 Established: 8 to 10+	5H:1V to1H:1V See TS14I for Design Details	Initial: Yes Established: Yes
Brush layer/branch packing (Depends on soil conditions)	Initial: 0.2 to 1 Established: 2.9 to 6	Initial: 2 to 4 Established: 10+	6H:1V to 2H:1V See TS14I for Design Details	Initial: No Established: No
Live cribwall (Depends on nature of fill, compaction, and anchoring)	Initial: 2 to 4 Established: 5 to 6	Initial: 3 to 6 Established: 10 to 12	1H:4V to 1H:6V See TS14I for Design Details	Initial: Yes Established: Yes
Vegetated reinforced soil slopes VRSS (depends on soil conditions and anchoring)	Initial: 3 to 5 Established: 7+	Initial: 4 to 9 Established: 10+	1H:1V or Greater See TS14I for Design Details	Initial: Yes Established: Yes
Grass turf (Depends on vegetation type and condition)	Established: 3.2	Established: 3 to 8	Up to 2H:1V See TS14I for Design Details	Initial: No Established: No
Live brush wattle fence (Depends on soil condition and depth of stakes)	Initial: 0.2 to 2 Established: 1 to 5	Initial: 1 to 2.5 Established: 3 to 10	6H:1V to 4H:1V See TS14I for Design Details	Initial: No Established: No
Vertical bundles (Depends on bank conditions, anchoring, and vegetation)	Initial: 1.2 to 3 Established: 1.4 to 3	Initial: 5 to 8 Established: 6 to 10+	Up to 1H:1V See TS14I for Design Details	Initial: Yes Established: Yes

Table 7. Site 3, soil bioengineering technique compatibility.

Site # 4	Permissible shear stress	Permissible velocity	Slope Requirements	Meets Requirements
Practice	(lb/ft^2)	(ft/s)	ft/ft	Yes/No
Live poles (Depends on the length of the poles and nature of the soil)	Initial: 0.5 to 2 Established: 2 to 5	Initial: 1 to 2.5 Established: 3 to 10	5H:1V to1H:1V See TS14I for Design Details	Initial: No Established: No
Live poles in woven coir TRM (Depends on installation and anchoring coir)	Initial: 2 to 2.5 Established: 3 to 5	Initial: 3 to 5 Established: 3 to 10	5H:1V to1H:1V See TS14I for Design Details	Initial: No Established: No
Live poles in riprap (joint planting) (Depends on riprap stability)	Initial: 3+ Established: 6 to 8	Initial: 5 to 10+ Established: 12+	5H:1V to1H:1V See TS14I for Design Details	Initial: Yes Established: Yes
Live brush sills with rock (Depends on riprap stability)	Initial: 3+ Established: 6+	Initial: 5 to 10+ Established: 12+	6H:1V to 2H:1V See TS14I for Design Details	Initial: No Established: No
Brush mattress (Depends on soil conditions and anchoring)	Initial: 0.4 to 4.2 Established: 2.8 to 8	Initial: 3 to 4 Established: 10+	4H:1V to 2H:1V See TS14I for Design Details	Initial: No Established: No
Live fascine (Very dependent on anchoring)	Initial: 1.2 to 3.1 Established: 1.4 to 3	Initial: 5 to 8 Established: 8 to 10+	5H:1V to1H:1V See TS14I for Design Details	Initial: Yes Established: Yes
Brush layer/branch packing (Depends on soil conditions)	Initial: 0.2 to 1 Established: 2.9 to 6	Initial: 2 to 4 Established: 10+	6H:1V to 2H:1V See TS14I for Design Details	Initial: No Established: No
Live cribwall (Depends on nature of fill, compaction, and anchoring)	Initial: 2 to 4 Established: 5 to 6	Initial: 3 to 6 Established: 10 to 12	1H:4V to 1H:6V See TS14I for Design Details	Initial: Yes Established: Yes
Vegetated reinforced soil slopes VRSS (depends on soil conditions and anchoring)	Initial: 3 to 5 Established: 7+	Initial: 4 to 9 Established: 10+	1H:1V or Greater See TS14I for Design Details	Initial: Yes Established: Yes
Grass turf (Depends on vegetation type and condition)	Established: 3.2	Established: 3 to 8	Up to 2H:1V See TS14I for Design Details	Initial: No Established: No
Live brush wattle fence (Depends on soil condition and depth of stakes)	Initial: 0.2 to 2 Established: 1 to 5	Initial: 1 to 2.5 Established: 3 to 10	6H:1V to 4H:1V See TS14I for Design Details	Initial: No Established: No
Vertical bundles (Depends on bank conditions, anchoring, and vegetation)	Initial: 1.2 to 3 Established: 1.4 to 3	Initial: 5 to 8 Established: 6 to 10+	Up to 1H:1V See TS14I for Design Details	Initial: Yes Established: Yes

Table 8. Site 4, soil bioengineering technique compatibility.

Site # 5	Permissible shear stress	Permissible velocity	Slope Requirements	Meets Requirements
Practice	(lb/ft^2)	(ft/s)	ft/ft	Yes/No
Live poles (Depends on the length of the poles and nature of the soil)	Initial: 0.5 to 2 Established: 2 to 5	Initial: 1 to 2.5 Established: 3 to 10	5H:1V to1H:1V See TS14I for Design Details	Initial: No Established: No
Live poles in woven coir TRM (Depends on installation and anchoring coir)	Initial: 2 to 2.5 Established: 3 to 5	Initial: 3 to 5 Established: 3 to 10	5H:1V to1H:1V See TS14I for Design Details	Initial: No Established: No
Live poles in riprap (joint planting) (Depends on riprap stability)	Initial: 3+ Established: 6 to 8	Initial: 5 to 10+ Established: 12+	5H:1V to1H:1V See TS14I for Design Details	Initial: Yes Established: Yes
Live brush sills with rock (Depends on riprap stability)	Initial: 3+ Established: 6+	Initial: 5 to 10+ Established: 12+	6H:1V to 2H:1V See TS14I for Design Details	Initial: No Established: No
Brush mattress (Depends on soil conditions and anchoring)	Initial: 0.4 to 4.2 Established: 2.8 to 8	Initial: 3 to 4 Established: 10+	4H:1V to 2H:1V See TS14I for Design Details	Initial: No Established: No
Live fascine (Very dependent on anchoring)	Initial: 1.2 to 3.1 Established: 1.4 to 3	Initial: 5 to 8 Established: 8 to 10+	5H:1V to1H:1V See TS14I for Design Details	Initial: Yes Established: Yes
Brush layer/branch packing (Depends on soil conditions)	Initial: 0.2 to 1 Established: 2.9 to 6	Initial: 2 to 4 Established: 10+	6H:1V to 2H:1V See TS14I for Design Details	Initial: No Established: No
Live cribwall (Depends on nature of fill, compaction, and anchoring)	Initial: 2 to 4 Established: 5 to 6	Initial: 3 to 6 Established: 10 to 12	1H:4V to 1H:6V See TS14I for Design Details	Initial: Yes Established: Yes
Vegetated reinforced soil slopes VRSS (depends on soil conditions and anchoring)	Initial: 3 to 5 Established: 7+	Initial: 4 to 9 Established: 10+	1H:1V or Greater See TS14I for Design Details	Initial: Yes Established: Yes
Grass turf (Depends on vegetation type and condition)	Established: 3.2	Established: 3 to 8	Up to 2H:1V See TS14I for Design Details	Initial: No Established: No
Live brush wattle fence (Depends on soil condition and depth of stakes)	Initial: 0.2 to 2 Established: 1 to 5	Initial: 1 to 2.5 Established: 3 to 10	6H:1V to 4H:1V See TS14I for Design Details	Initial: No Established: No
Vertical bundles (Depends on bank conditions, anchoring, and vegetation)	Initial: 1.2 to 3 Established: 1.4 to 3	Initial: 5 to 8 Established: 6 to 10+	Up to 1H:1V See TS14I for Design Details	Initial: Yes Established: Yes

Table 9. Site 5, soil bioengineering technique compatibility.

Site # 6	Permissible shear stress	Permissible velocity	Slope Requirements	Meets Requirements
Practice	(lb/ft^2)	(ft/s)	ft/ft	Yes/No
Live poles (Depends on the length of the poles and nature of the soil)	Initial: 0.5 to 2 Established: 2 to 5	Initial: 1 to 2.5 Established: 3 to 10	5H:1V to1H:1V See TS14I for Design Details	Initial: No Established: No
Live poles in woven coir TRM (Depends on installation and anchoring coir)	Initial: 2 to 2.5 Established: 3 to 5	Initial: 3 to 5 Established: 3 to 10	5H:1V to1H:1V See TS14I for Design Details	Initial: No Established: No
Live poles in riprap (joint planting) (Depends on riprap stability)	Initial: 3+ Established: 6 to 8	Initial: 5 to 10+ Established: 12+	5H:1V to1H:1V See TS14I for Design Details	Initial: Yes Established: Yes
Live brush sills with rock (Depends on riprap stability)	Initial: 3+ Established: 6+	Initial: 5 to 10+ Established: 12+	6H:1V to 2H:1V See TS14I for Design Details	Initial: No Established: No
Brush mattress (Depends on soil conditions and anchoring)	Initial: 0.4 to 4.2 Established: 2.8 to 8	Initial: 3 to 4 Established: 10+	4H:1V to 2H:1V See TS14I for Design Details	Initial: No Established: No
Live fascine (Very dependent on anchoring)	Initial: 1.2 to 3.1 Established: 1.4 to 3	Initial: 5 to 8 Established: 8 to 10+	5H:1V to1H:1V See TS14I for Design Details	Initial: Yes Established: Yes
Brush layer/branch packing (Depends on soil conditions)	Initial: 0.2 to 1 Established: 2.9 to 6	Initial: 2 to 4 Established: 10+	6H:1V to 2H:1V See TS14I for Design Details	Initial: No Established: No
Live cribwall (Depends on nature of fill, compaction, and anchoring)	Initial: 2 to 4 Established: 5 to 6	Initial: 3 to 6 Established: 10 to 12	1H:4V to 1H:6V See TS14I for Design Details	Initial: Yes Established: Yes
Vegetated reinforced soil slopes VRSS (depends on soil conditions and anchoring)	Initial: 3 to 5 Established: 7+	Initial: 4 to 9 Established: 10+	1H:1V or Greater See TS14I for Design Details	Initial: Yes Established: Yes
Grass turf (Depends on vegetation type and condition)	Established: 3.2	Established: 3 to 8	Up to 2H:1V See TS14I for Design Details	Initial: No Established: No
Live brush wattle fence (Depends on soil condition and depth of stakes)	Initial: 0.2 to 2 Established: 1 to 5	Initial: 1 to 2.5 Established: 3 to 10	6H:1V to 4H:1V See TS14I for Design Details	Initial: No Established: No
Vertical bundles (Depends on bank conditions, anchoring, and vegetation)	Initial: 1.2 to 3 Established: 1.4 to 3	Initial: 5 to 8 Established: 6 to 10+	Up to 1H:1V See TS14I for Design Details	Initial: Yes Established: Yes

Table 10. Site 6, soil bioengineering technique compatibility.

Site # 7	Permissible shear stress	Permissible velocity	Slope Requirements	Meets Requirements
Practice	(lb/ft^2)	(ft/s)	ft/ft	Yes/No
Live poles (Depends on the length of the poles and nature of the soil)	Initial: 0.5 to 2 Established: 2 to 5	Initial: 1 to 2.5 Established: 3 to 10	5H:1V to1H:1V See TS14I for Design Details	Initial: No Established: No
Live poles in woven coir TRM (Depends on installation and anchoring coir)	Initial: 2 to 2.5 Established: 3 to 5	Initial: 3 to 5 Established: 3 to 10	5H:1V to1H:1V See TS14I for Design Details	Initial: No Established: No
Live poles in riprap (joint planting) (Depends on riprap stability)	Initial: 3+ Established: 6 to 8	Initial: 5 to 10+ Established: 12+	5H:1V to1H:1V See TS14I for Design Details	Initial: Yes Established: Yes
Live brush sills with rock (Depends on riprap stability)	Initial: 3+ Established: 6+	Initial: 5 to 10+ Established: 12+	6H:1V to 2H:1V See TS14I for Design Details	Initial: No Established: No
Brush mattress (Depends on soil conditions and anchoring)	Initial: 0.4 to 4.2 Established: 2.8 to 8	Initial: 3 to 4 Established: 10+	4H:1V to 2H:1V See TS14I for Design Details	Initial: No Established: No
Live fascine (Very dependent on anchoring)	Initial: 1.2 to 3.1 Established: 1.4 to 3	Initial: 5 to 8 Established: 8 to 10+	5H:1V to1H:1V See TS14I for Design Details	Initial: Yes Established: Yes
Brush layer/branch packing (Depends on soil conditions)	Initial: 0.2 to 1 Established: 2.9 to 6	Initial: 2 to 4 Established: 10+	6H:1V to 2H:1V See TS14I for Design Details	Initial: No Established: No
Live cribwall (Depends on nature of fill, compaction, and anchoring)	Initial: 2 to 4 Established: 5 to 6	Initial: 3 to 6 Established: 10 to 12	1H:4V to 1H:6V See TS14I for Design Details	Initial: Yes Established: Yes
Vegetated reinforced soil slopes VRSS (depends on soil conditions and anchoring)	Initial: 3 to 5 Established: 7+	Initial: 4 to 9 Established: 10+	1H:1V or Greater See TS14I for Design Details	Initial: Yes Established: Yes
Grass turf (Depends on vegetation type and condition)	Established: 3.2	Established: 3 to 8	Up to 2H:1V See TS14I for Design Details	Initial: No Established: No
Live brush wattle fence (Depends on soil condition and depth of stakes)	Initial: 0.2 to 2 Established: 1 to 5	Initial: 1 to 2.5 Established: 3 to 10	6H:1V to 4H:1V See TS14I for Design Details	Initial: No Established: No
Vertical bundles (Depends on bank conditions, anchoring, and vegetation)	Initial: 1.2 to 3 Established: 1.4 to 3	Initial: 5 to 8 Established: 6 to 10+	Up to 1H:1V See TS14I for Design Details	Initial: Yes Established: Yes

Table 11. Site 7, soil bioengineering technique compatibility.

The techniques in tables 5-11 that have met the permissible velocity and shear stress requirements, except slope, may be compatible if the stream bank is graded to the defined slope. Certain soil bioengineering techniques may also be limited by the infrastructure in the surrounding area. The LaMoure County Memorial Museum located just off of the stream bank on Site 2 needs to have a space sensitive treatment in order to avoid moving the museum. Vegetated reinforced soil slopes (VRSS) and live cribwalls are two soil bioengineering techniques that allow the stream bank to be steep, reducing the amount of grading needed to protect the slope.

The cost of soil bioengineering techniques varies greatly depending on the available natural resources in the project area. Availability of vegetation can play a key factor in reducing costs associated with stream bank stabilization. Depending on which of the soil bioengineering techniques are chosen, the cost of stabilizing the bank can vary significantly. Most bioengineering techniques are cheaper than creating a hard structured or stone armored revetment.

8.6 Riprap Revetment Analysis

A riprap revetment was reviewed as a hard structure bank stabilization technique for LaMoure County Memorial Park. Other hard structures, such as sheet piling, were removed from the analysis due to safety considerations of park users and the negative effects on the environment.

Stone size determination for riprap revetments in the area was computed using the Isbash Method. The Isbash method compares the critical velocity to the mean particle size of riprap. The critical velocity was determined by viewing the largest velocity from each frequency event. The largest velocity determined for this area 5ft/s, was from a 100-year frequency event. The critical velocity was then multiplied by a factor of 1.5 to add a buffer to the riprap size calculation. The critical velocity after application of the buffer was 7.5 ft/s. The critical velocity was then rounded to 8 ft/s. Equation 4 is Isbash formula for computing average particle size for riprap revetments (Equation 4, NRCS, 2007).

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Figure TS14K–2 Typical riprap section

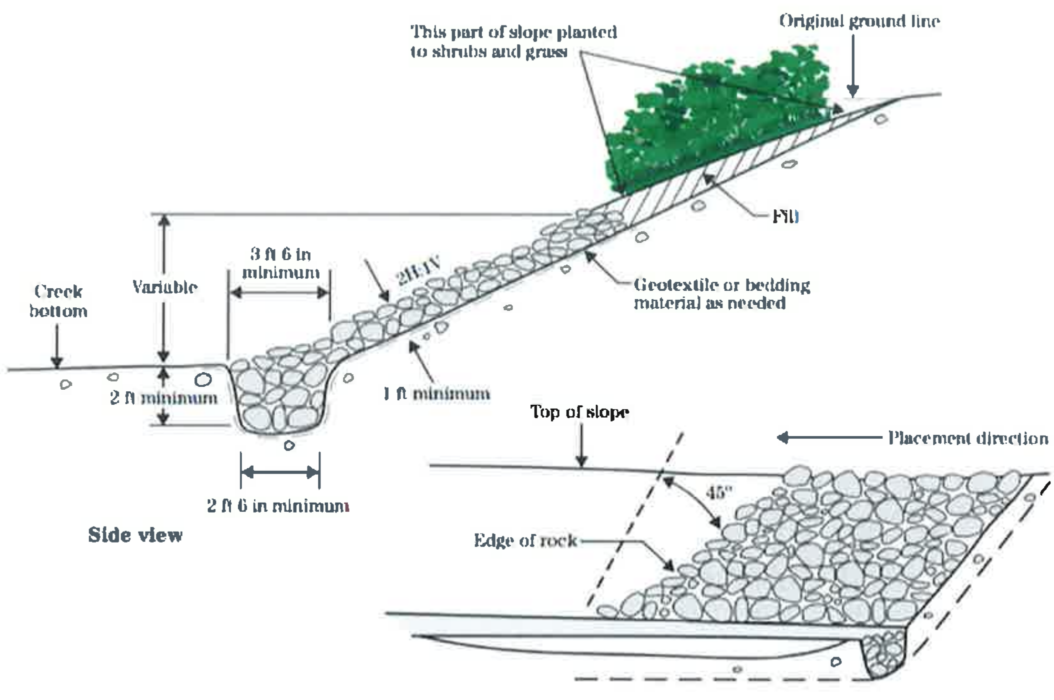


Figure 10. Typical riprap section (NRCS, 2007)

$$Vc=C*(2*g*((Ys-Yw)/Yw)))^{0.50}*(D_{50})^{0.50} \qquad \text{(Eq. 4)}$$

Vc = critical velocity (ft/s)
C = 0.86 for high turbulence
C = 1.20 for low turbulence
g = 32.2 ft/s^2
Ys = stone density (165 lb/ft^3)
Yw = water density (62.4 lb/ft^3)
D_{50} = mean stone diameter (ft)

The average particle size, D_{50}, for riprap for each site location through the park calculated from equation 4 is approximately 6-inch diameter riprap. The volume of riprap was determined for each site by determining the surface area of each bank and multiplying it by a thickness of 3 times the average particle size (1.5ft). Each site was also graded to a 2H:1V slope before determinations of volumes were made. Table 12 is a volume estimate for the amount of riprap needed for each site.

Table 12. Riprap revetment volumes.

Site	Site Length (ft)	Bank Width (ft)	Volume of Riprap (yd^3)	Volume of Riprap (tons)
1	739	45.53	1869	1246
2	721	55.00	2203	1469
3	520	43.13	1246	831
4	347	43.34	835	557
5	449	48.66	1214	809
6	526	49.46	1445	964
7	627	39.12	1363	908

A non-woven geotextile fabric would underlay the riprap revetment decreasing particle transport and support particle deposition onto the site. Table 13 is the amount of non-woven geotextile fabric underlay for the designed riprap revetment.

Table 13. Non-woven geotextile fabric underlay per site.

Site	Non-Woven Geotextile Fabric (yd^2)
1	3738.52
2	4406.11
3	2492.19
4	1670.98
5	2427.39
6	2890.77
7	2725.36

Sites 1, 2, and 5 provide challenges in creating a riprap revetment due to the infrastructure near each bank. Grading these sites to a 2H:1V may not be feasible, grouting may be necessary on these sites.

Cost estimates were developed from the computed volume of riprap. The price estimates for the site-by-site cost estimate are based off of RSMeans "Heavy Construction Estimator" and a cost estimate prepared by K2S Engineering. Tables 14 through 20 are the cost estimates to place a riprap revetment on each bank. Riprap revetments on site 2 and 5 may be unstable due to surrounding infrastructure; a further geotechnical analysis of the sites would be required. The bank excavation/grading was evaluated as a lump sum cost due to the amount of work on each site being similar. The lump sum cost of excavation was estimated from a cost estimate K2S Engineering produced for sites in the park.

LaMoure County Memorial Park: Site 1 Riprap Revetment		Unit	Unit Price	Quantity	Total Cost
Construction Costs					
1) Riprap (Placed)		cu yd	$75.00	1,869	$140,175
2) Geotextile Blanket (Placed)		sq yd	$5.00	3,739	$18,695
3) Bank Excavation/Grading		Lump Sum	$40,000		$40,000
				Subtotal	$198,870
Design Costs					
1) Design and Oversight		10% of const. cost	10%	$19,887	$218,757
Cost Summary					
Total Capital Costs Without Contingency					$218,757
Contingency (25%)				25%	$54,689
Total Cost Estimate				**Total**	$273,446

Table 14. Site 1, Riprap revetment cost estimate.

LaMoure County Memorial Park: Site 2 Riprap Revetment		Unit	Unit Price	Quantity	Total Cost
Construction Costs					
1) Riprap (Placed)		cu yd	$75.00	2,203	$165,225
2) Geotextile Blanket (Placed)		sq yd	$5.00	4,406	$22,030
3) Bank Excavation/Grading		Lump Sum	$40,000		$40,000
				Subtotal	$227,255
Design Costs					
1) Design and Oversight		10% of const. cost	10%	$22,726	$249,981
Cost Summary					
Total Capital Costs Without Contingency					$249,981
Contingency (25%)				25%	$62,495
Total Cost Estimate				**Total**	$312,475.63

Table 15. Site 2, Riprap revetment cost estimate.

LaMoure County Memorial Park: Site 3 Riprap Revetment		Unit	Unit Price	Quantity	Total Cost
Construction Costs					
1) Riprap (Placed)		cu yd	$75.00	1,246	$93,450
2) Geotextile Blanket (Placed)		sq yd	$5.00	2,492	$12,460
3) Bank Excavation/Grading		Lump Sum	$40,000		$40,000
				Subtotal	$145,910
Design Costs					
1) Design and Oversight		10% of const. cost	10%	$14,591	$160,501
Cost Summary					
Total Capital Costs Without Contingency					$160,501
Contingency (25%)				25%	$40,125
Total Cost Estimate				**Total**	$200,626.25

Table 16. Site 3, Riprap revetment cost estimate.

LaMoure County Memorial Park: Site 4 Riprap Revetment		Unit	Unit Price	Quantity	Total Cost
Construction Costs					
1) Riprap (Placed)		cu yd	$75.00	836	$62,700
2) Geotextile Blanket (Placed)		sq yd	$5.00	1,671	$8,355
3) Bank Excavation/Grading		Lump Sum	$40,000		$40,000
				Subtotal	$111,055
Design Costs					
1) Design and Oversight		10% of const. cost	10%	$11,106	$122,161
Cost Summary					
Total Capital Costs Without Contingency					$122,161
Contingency (25%)				25%	$30,540
Total Cost Estimate				**Total**	$152,700.63

Table 17. Site 4, Riprap revetment cost estimate.

LaMoure County Memorial Park: Site 5 Riprap Revetment		Unit	Unit Price	Quantity	Total Cost
Construction Costs					
1) Riprap (Placed)		cu yd	$75.00	1,214	$91,050
2) Geotextile Blanket (Placed)		sq yd	$5.00	2,427	$12,135
3) Bank Excavation/Grading		Lump Sum	$40,000		$40,000
				Subtotal	$143,185
Design Costs					
1) Design and Oversight		10% of const. cost	10%	$14,319	$157,504
Cost Summary					
Total Capital Costs Without Contingency					$157,504
Contingency (25%)				25%	$39,376
Total Cost Estimate				**Total**	$196,879.38

Table 18. Site 5, Riprap revetment cost estimate.

LaMoure County Memorial Park: Site 6 Riprap Revetment		Unit	Unit Price	Quantity	Total Cost
Construction Costs					
1) Riprap (Placed)		cu yd	$75.00	1,445	$108,375
2) Geotextile Blanket (Placed)		sq yd	$5.00	2,891	$14,455
3) Bank Excavation/Grading		Lump Sum	$40,000		$40,000
				Subtotal	$162,830
Design Costs					
1) Design and Oversight		10% of const. cost	10%	$16,283	$179,113
Cost Summary					
Total Capital Costs Without Contingency					$179,113
Contingency (25%)				25%	$44,778
Total Cost Estimate				**Total**	$223,891.25

Table 19. Site 6, Riprap revetment cost estimate.

LaMoure County Memorial Park: Site 7 Riprap Revetment		Unit	Unit Price	Quantity	Total Cost
Construction Costs					
1) Riprap (Placed)		cu yd	$75.00	1,363	$102,225
2) Geotextile Blanket (Placed)		sq yd	$5.00	2,725	$13,625
3) Bank Excavation/Grading		Lump Sum	$40,000		$40,000
				Subtotal	$155,850
Design Costs					
1) Design and Oversight		10% of const. cost	10%	$15,585	$171,435
Cost Summary					
Total Capital Costs Without Contingency					$171,435
Contingency (25%)				25%	$42,859
Total Cost Estimate				**Total**	$214,293.75

Table 20. Site 7, Riprap revetment cost estimate.

9. Summary

The banks of the James River through LaMoure County Memorial Park are eroding due primarily to excess shear stress. The banks will continue to erode unless treated. The treatment options summarized in Tables 5 through 11 show similarities in that vertical bundles, crib wall, joint plantings, live fascines, and vertical reinforced-soil slopes would be appropriate treatment options along with riprap revetments. Due to the large variation in costs due to the availability or lack of the natural resources needed to complete a soil bioengineering alternative, no cost estimates were calculated for the soil bioengineering techniques. However, the cost estimate per site for a riprap revetment was calculated to help determine an approximate cost per site. The cost of soil bioengineering techniques, depending on the availability of materials, is typically less expensive than riprap revetments. If certain sites aren't treated, they will continue to erode and may erode faster due to treatment of the other banks.

The stabilization of the stream banks on the James River would require several permits. The State of North Dakota would require a Sovereign Lands Permit since the project would take place on sovereign land. The federal government would require a Section 10 Permit of the Rivers and Harbors Act to build within navigable waters. The federal government would also require a Section 404 Permit of the Federal Clean Water Act to place materials within a wetland.

Infrastructure along sites 1, 2, and 5 provide many different challenges due to space limitations on slope cutbacks and stresses the infrastructures places on the stream banks. Sites 2 and 5 should have erosion protection that wouldn't require dramatic reshaping of the stream bank. These erosion protection options could be a crib wall, sheet piling, or vegetated reinforced soil slope to stabilize the banks. Site 1 should have similar protection to sites 2 and 5 if the primary entrance road is to remain open. A further geotechnical analysis of these three sites may be necessary to determine the proper treatment option. If site 1 is deemed unstable, the bank could be left alone or graded back and varying techniques could be applied.

If nothing is to be done to protect the banks of the James River in the park, it is suggested that the primary entrance road be evaluated or closed. The secondary entrance road could be used in order to keep the park open and modification to existing roads in the park could help keep the park open year round. The 'do nothing' option could eventually cause significant damage to the LaMoure County Museum, the parks primary entrance road, and county road 98th Ave. SE.

During the course of this investigation information was provided to the County on an on-going basis. Based on this information the County retained consulting services and began implementation of the most promising of the features described here in.

10. Citations

Bentrup, Gary, and J. Chris Hoag. "The Practical Streambank Bioengineering Guide." *The Practical Streambank Bioengineering Guide*. USDA Natural Resources Conservation Service, 1 May 1998. Web. 15 Dec. 2014. <http://www.nrcs.usda.gov/Internet/FSE_PLANTMATERIALS/publications/idpmcpu116.pdf>

Clark, L.A., and T.M. Wynn. "Methods For Determining Streambank Critical Shear Stress and Soil Erodibility." *Implications for Erosion Rate Predicitions*. American Society of Agricultural and Biological Engineering, 1 Jan. 2007. Web. 15 Dec. 2014. <http://www.tmdl.bse.vt.edu/uploads/File/Pub db files stream rest/Clark_Wynn_2007TransASABE.pdf>.

Wynn, Theresa. "The Effects of Vegetation on Stream Bank Erosion." Virginia Polytechnic Institue and State University, 14 May 2004. Web. 15 Dec. 2014. <http://scholar.lib.vt.edu/theses/available/etd-05282004-115640/unrestricted/Chapters1-2.pdf>.

Fripp, Jon. *Stream Restoration Planning and Design Fluvial System Stabilization and Restoration Field Guide*. Forth Worth, Texas: USDA National Resources Conservation Service, 2011. Print.

Part 654 Stream Restoration Design National Engineering Handbook. Washington, DC: USDA National Resources Conservation Service, 2007. Print.

Part 654 Stream Restoration Design National Engineering Handbook Technical Supplement 14I, Streambank Soil Bioengineering. Washington, DC: USDA National Resources Conservation Service, 2007. Print.

Appendix A
(Investigation Agreement)

SWC Project #2047
Project Manager: CKorkowski
March 2014

Investigation Agreement

1. **PARTIES.** This agreement is between the State of North Dakota (State), acting through the State Water Commission (Commission), and the LaMoure County Commission (County).

2. **PROJECT DESCRIPTION.** Commission shall conduct a study of the hydraulics of the James River system near Grand Rapids, located in LaMoure County; identify potential implications of the erosion near LaMoure County Memorial Park; and evaluate options that could be implemented to mitigate current damages caused by the river erosion near LaMoure County Memorial Park.

3. **COMMISSION'S RESPONSIBILITIES.** Commission shall:

   a. Examine hydraulics of the James River near Grand Rapids, ND.

   b. Conduct topographic surveys and field observations to collect necessary data.

   c. Identify potential implications of natural erosion in the James River near LaMoure County Memorial Park.

   d. Evaluate options that could be implemented to mitigate damages caused by erosion.

   e. Complete a written report with findings, including cost estimates.

4. **COUNTY'S RESPONSIBILITIES.** County shall:

   a. Acquire written permission from landowners for access and modification to property related to the investigation of the James River near LaMoure County Memorial Park.

   b. Pay a deposit of $700.00 to Commission.

   c. Prior to signature, inform Commission and any other relevant party regarding Project of any errors, misinterpretations, changes, modifications, miscalculations, incorrect Project descriptions, or any other information stated herein that is inaccurate.

5. **TERM.** This agreement becomes effective upon signing by both parties and shall terminate on June 30, 2015.

6. **INSURANCE.** County shall secure and keep in force during the term of this agreement from an insurance company, government self-insurance pool, or government self-retention fund authorized to do business in North Dakota, commercial general liability with minimum limits of liability of $250,000 per person and $500,000 per occurrence.

7. **BREACH.** Violation of any provision of this agreement by County constitutes breach of this agreement. A breach obligates County to reimburse Commission for all funds expended by Commission to County for Project and relieves Commission of all obligations under this agreement.

8. **AGREEMENT BECOMES VOID.** This agreement is void if not signed and returned by County within 60 dates of Commission's signature

9. **FORCE MAJEURE.** Commission will not be held responsible for delay or default caused by fire, riot, acts of God, or war.

10. **TERMINATION.**

a. Commission may terminate this agreement effective upon delivery of written notice to County, or a later date as may be stated in the notice, under any of the following conditions:
   (1) If Commission determines an emergency exists.
   (2) If funding from federal, state, or other sources is not obtained and continued at levels sufficient to provide the funds necessary to comply with this agreement. The parties may modify this agreement to accommodate a reduction in funds.
   (3) If federal or state laws or rules are modified or interpreted in a way that the services are no longer allowable or appropriate for purchase under this agreement or are no longer eligible for the funding proposed for payments authorized by this agreement.
   (4) If any license, permit, or certificate required by law, rule, or this agreement is denied, revoked, suspended, or not renewed.
   (5) If Commission determines that continuing the agreement is no longer necessary or would not produce beneficial results commensurate with the further expenditure of public funds.

b. Any termination of this agreement shall be without prejudice to any obligations or liabilities of either party already accrued prior to termination.

c. The rights and remedies of any party provided in this agreement are not exclusive.

11. **APPLICABLE LAW AND VENUE.** This agreement is governed by and construed in accordance with the laws of the State of North Dakota. Any action to enforce this agreement must be brought in the District Court of Burleigh County, North Dakota.

12. **Severability.** If any term of this agreement is declared by a court having jurisdiction to be illegal or unenforceable, the validity of the remaining terms must not be affected, and if possible, the rights and obligations of the parties are to be construed and enforced as if the agreement did not contain that term.

13. **Spoliation – Notice of Potential Claims.** County agrees to promptly notify Commission of all potential claims that arise or result from this agreement. County shall also take all reasonable steps to preserve all physical evidence and information that may be relevant to the circumstances surrounding a potential claim, while maintaining public safety, and grants to Commission the opportunity to review and inspect the evidence, including the scene of an accident.

14. **Merger.** This agreement constitutes the entire agreement between the parties. There are no understandings, agreements, or representations, oral or written, not specified within this agreement. This agreement may not be modified, supplemented, or amended in any manner except by written agreement signed by both parties.

NORTH DAKOTA STATE WATER COMMISSION	**LAMOURE COUNTY COMMISSION**
By: Todd Sando	By: Robert Flath
TODD SANDO, P.E. Chief Engineer and Secretary	ROBERT FLATH Chairman
Date: 3/3/14	Date: 3-18-14

Appendix B
(Site Photography)

Figure 1. Site 1 looking downstream.

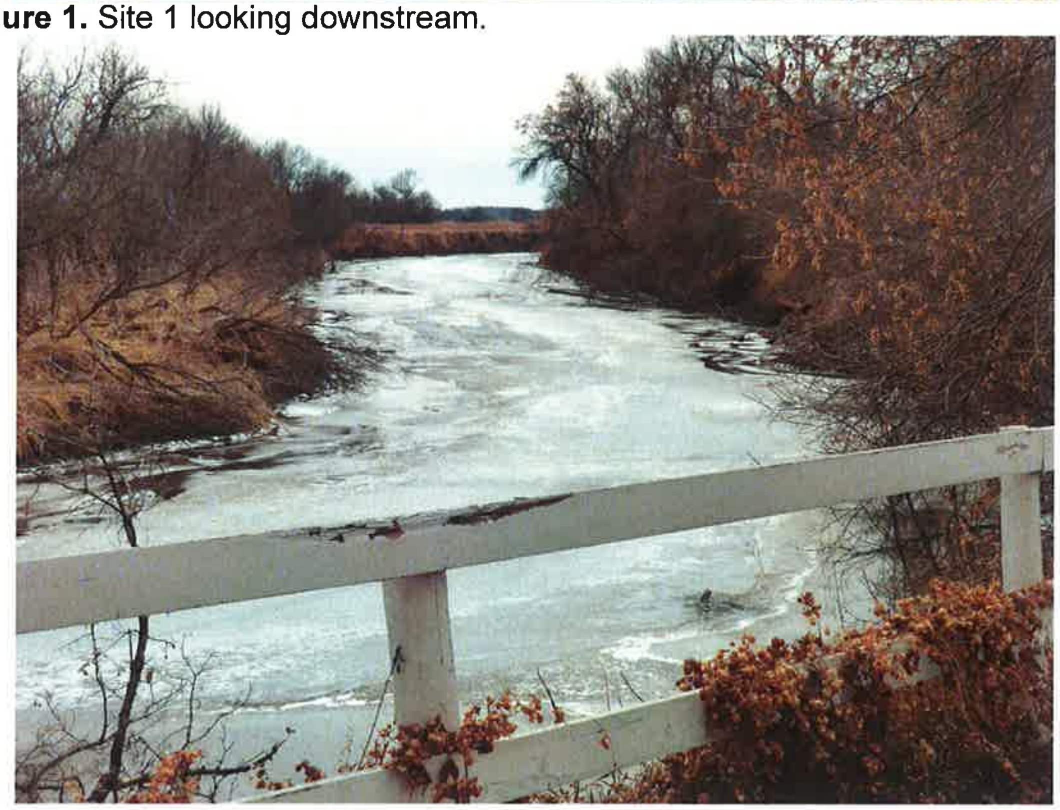


Figure 2. Site 1 looking downstream from closed road section.

Figure 3. Site 1 looking downstream (2).

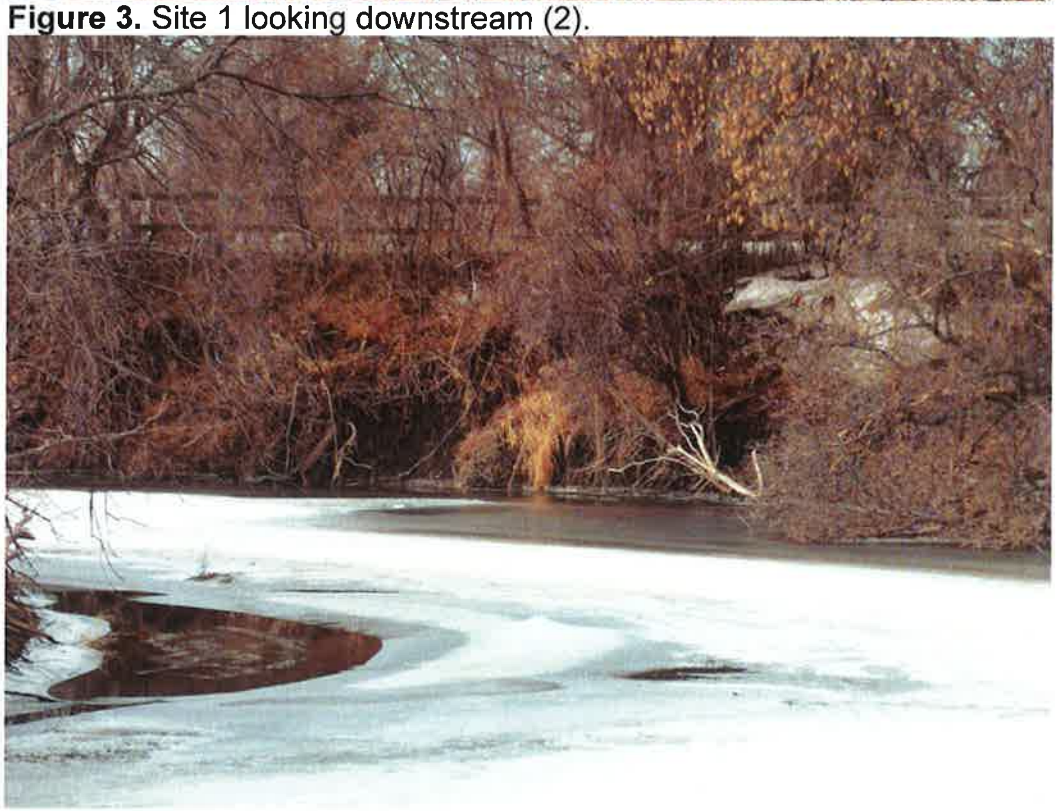


Figure 4. Site 1 looking directly toward eroding bank.

Figure 5. Site 1 looking upstream

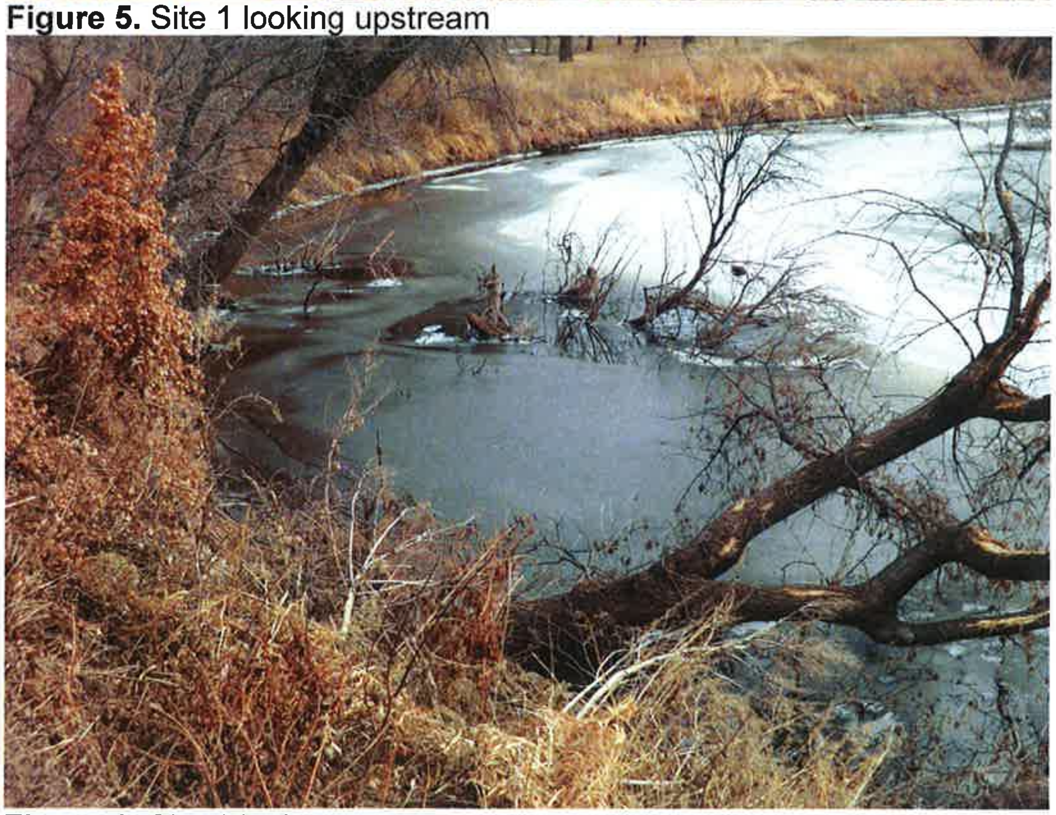


Figure 6. Site 1 looking upstream (2)

Figure 7. Site 2 looking downstream.

Figure 8. Site 2 looking upstream.

Figure 9. Site 2 looking upstream (2).

Figure 10. Site 2 looking upstream (3).

Figure 11. Site 3 looking directly toward bank.

Figure 12. Site 3 looking upstream.

Figure 13. Site 4 looking downstream.

Figure 14. Site 4 looking downstream (2).

Figure 15. Oxbow lake.

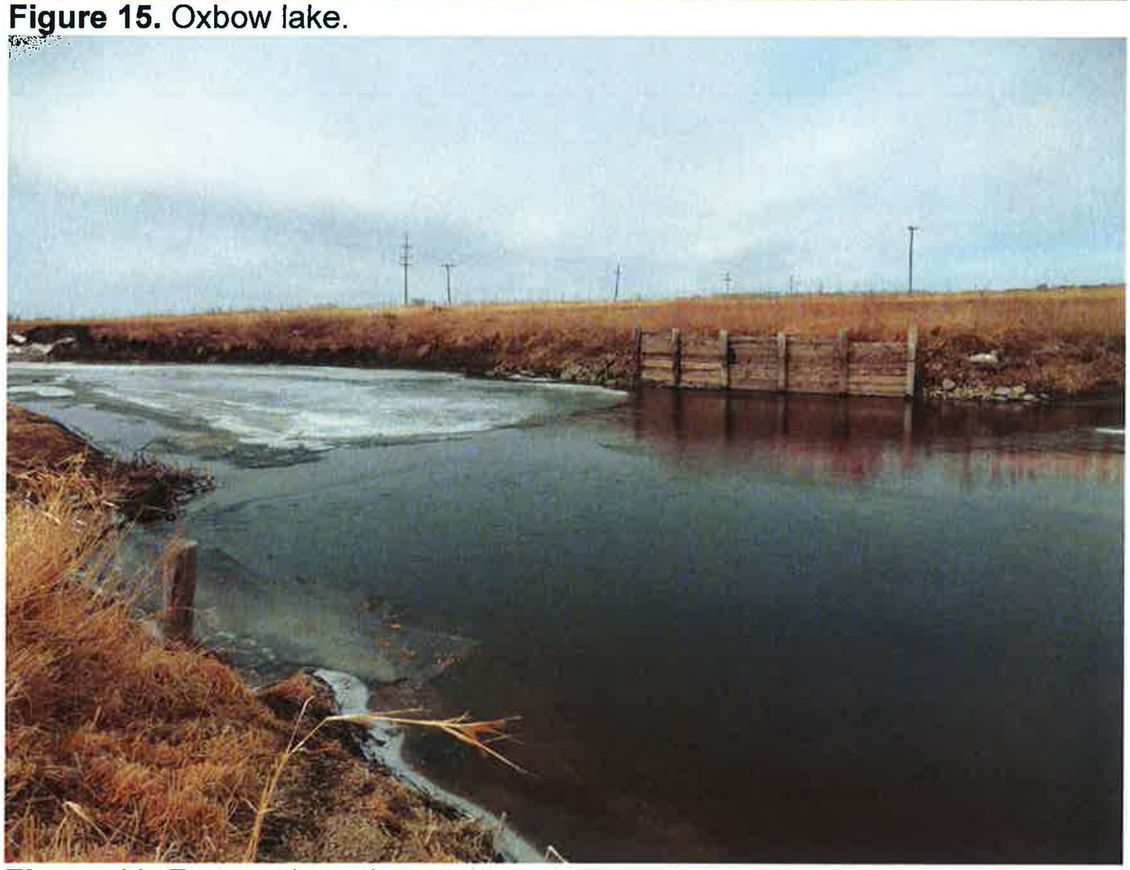


Figure 16. Former dam site.

Figure 17. Site 5 looking directly toward bank.

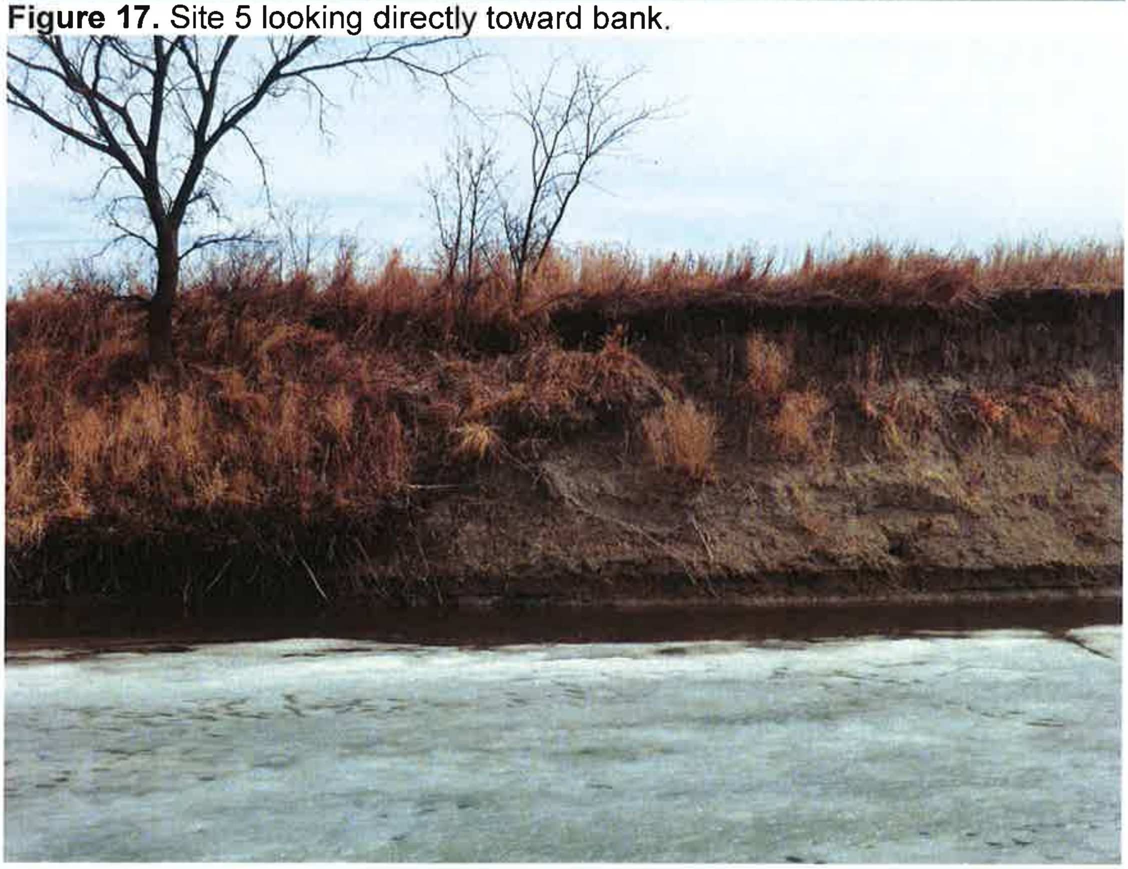


Figure 18. Site 5 looking directly toward bank (2).

Figure 19. Looking west down the primary entrance road.

Figure 20. Looking north towards the road closure.

Appendix C
(Site Cross Sections)

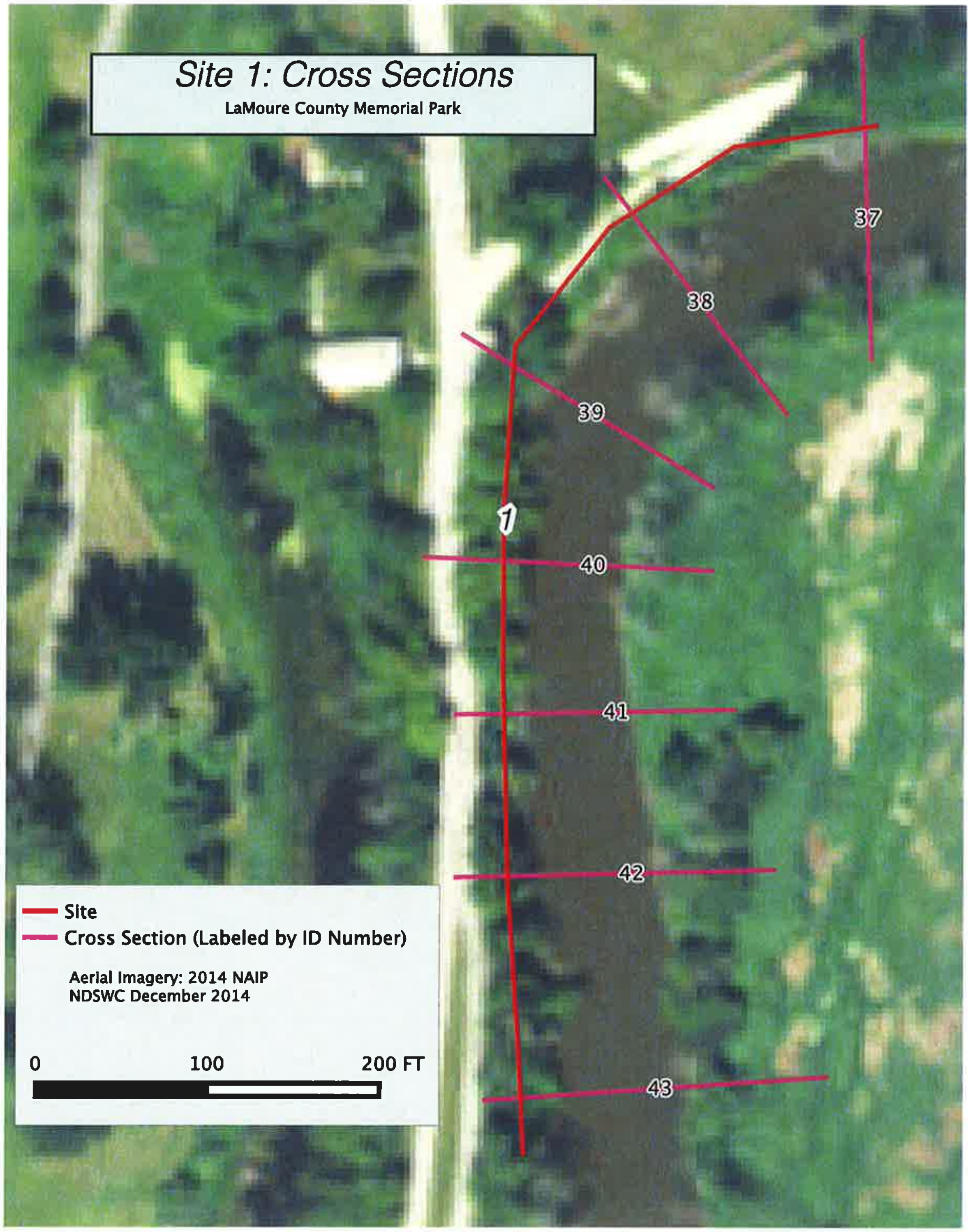


Figure 1. Site location 1.

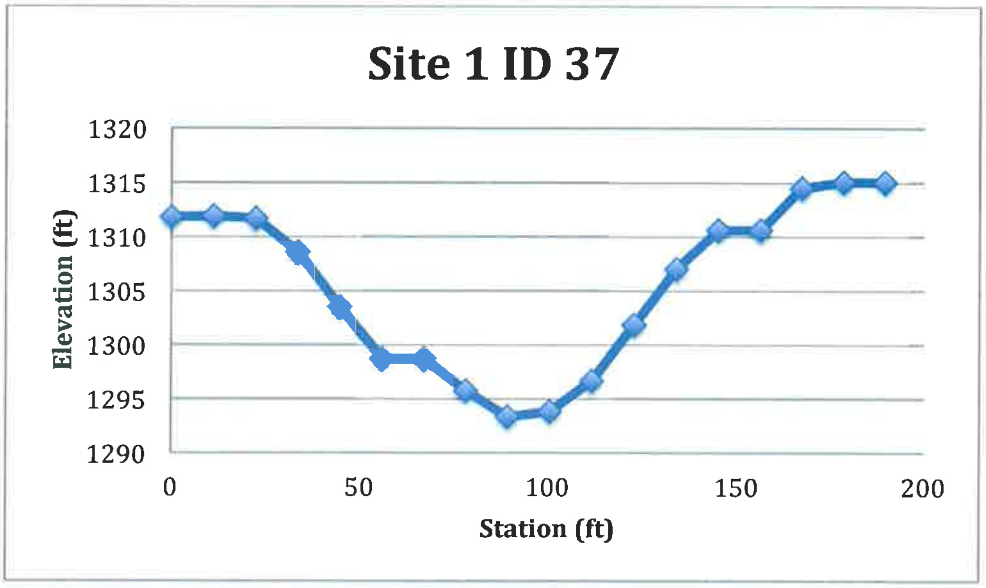


Figure 2. Site location 1, cross section ID 37.

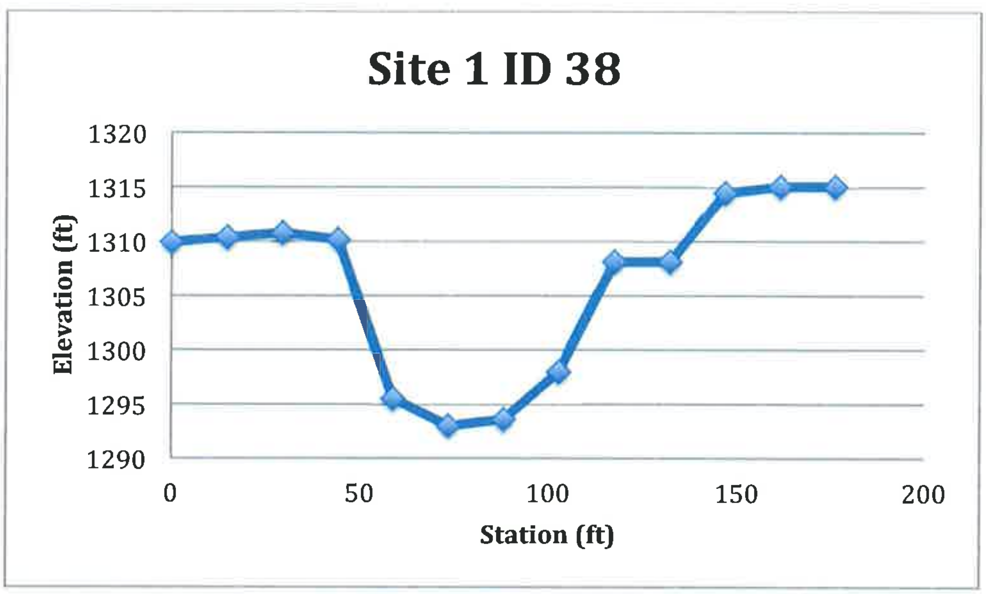


Figure 3. Site location 1, cross section ID 38.

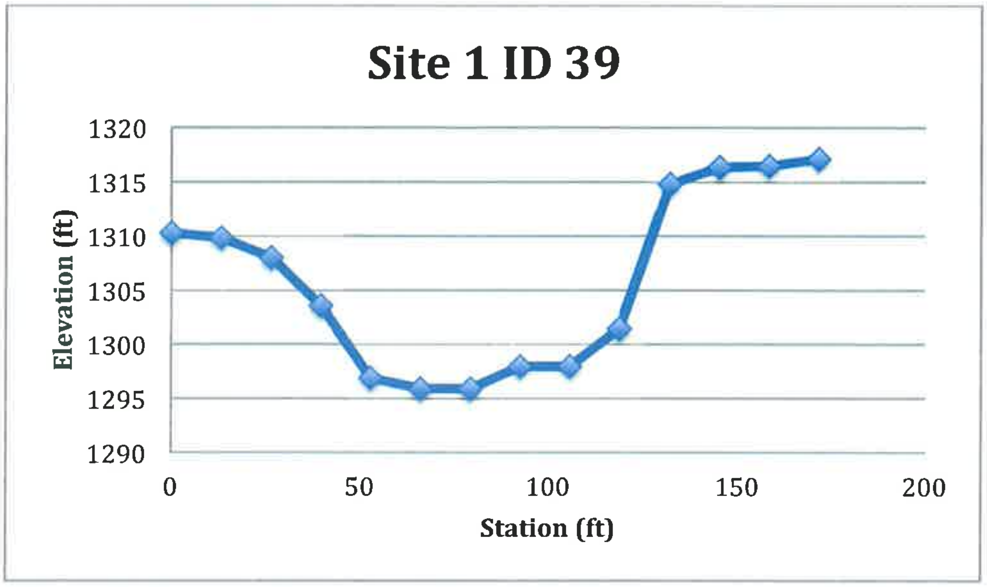


Figure 4. Site location 1, cross section ID 39.

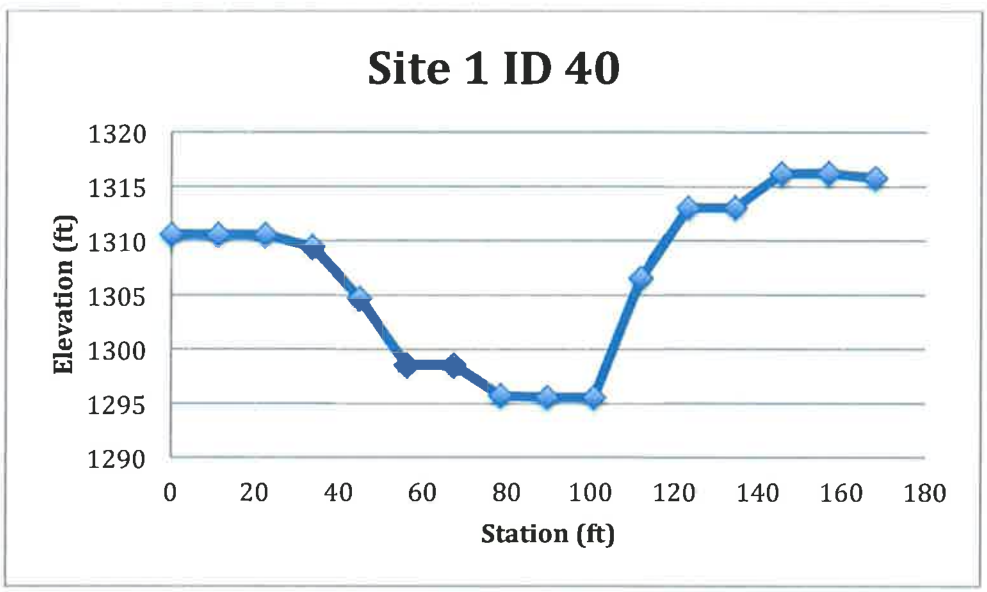


Figure 5. Site location 1, cross section ID 40.

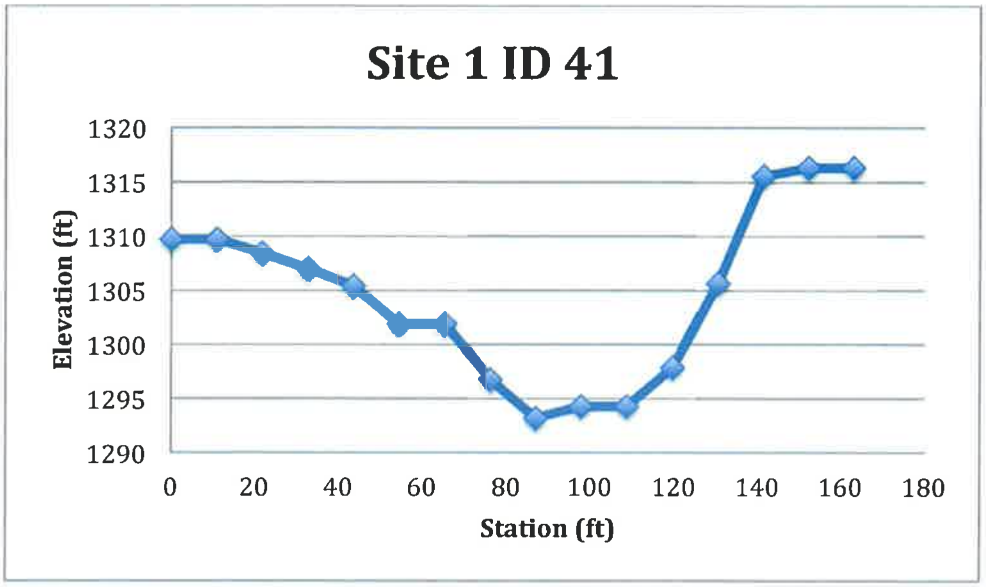


Figure 6. Site location 1, cross section ID 41.

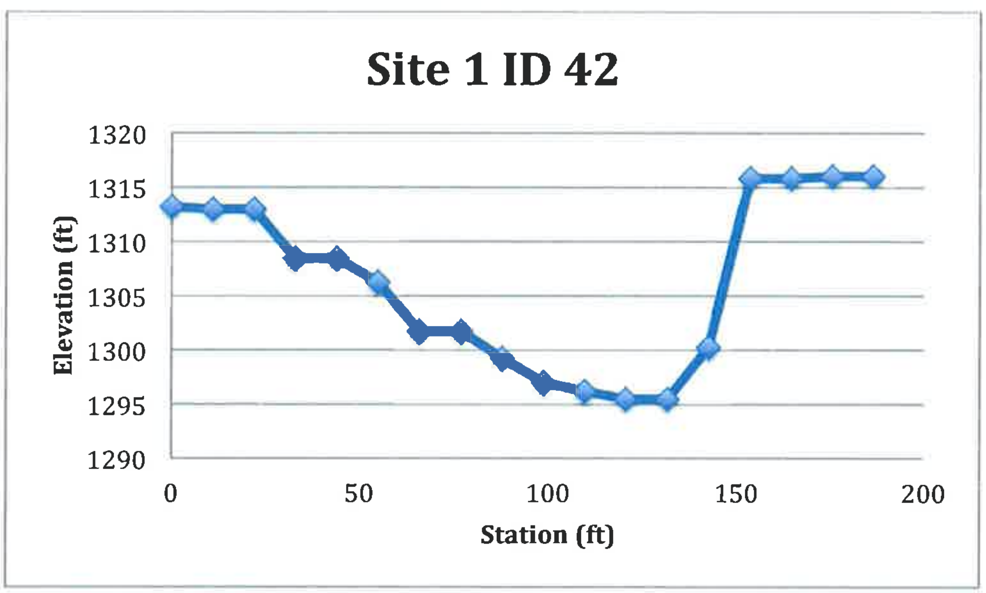


Figure 7. Site location 1, cross section ID 42.

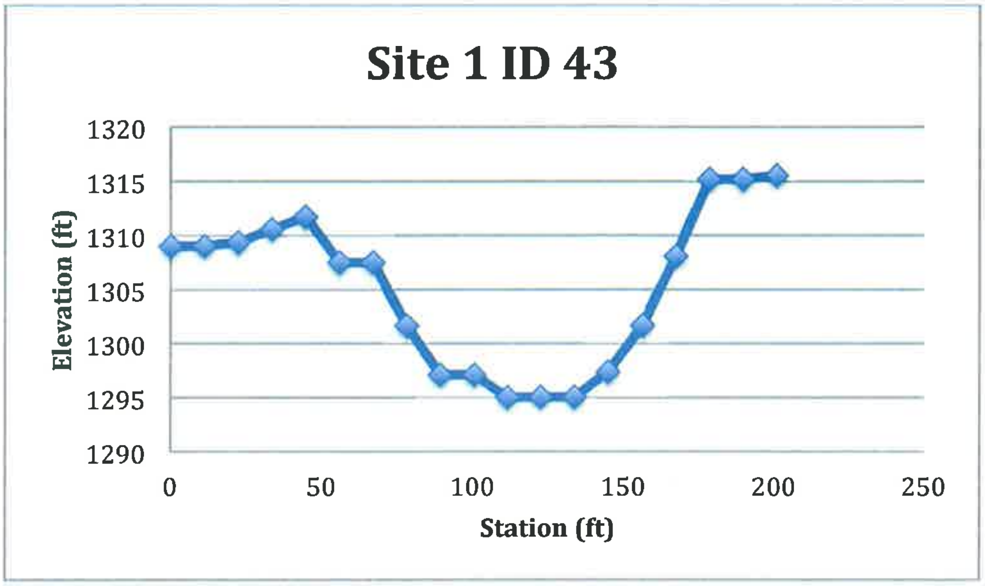


Figure 8. Site location 1, cross section ID 43.

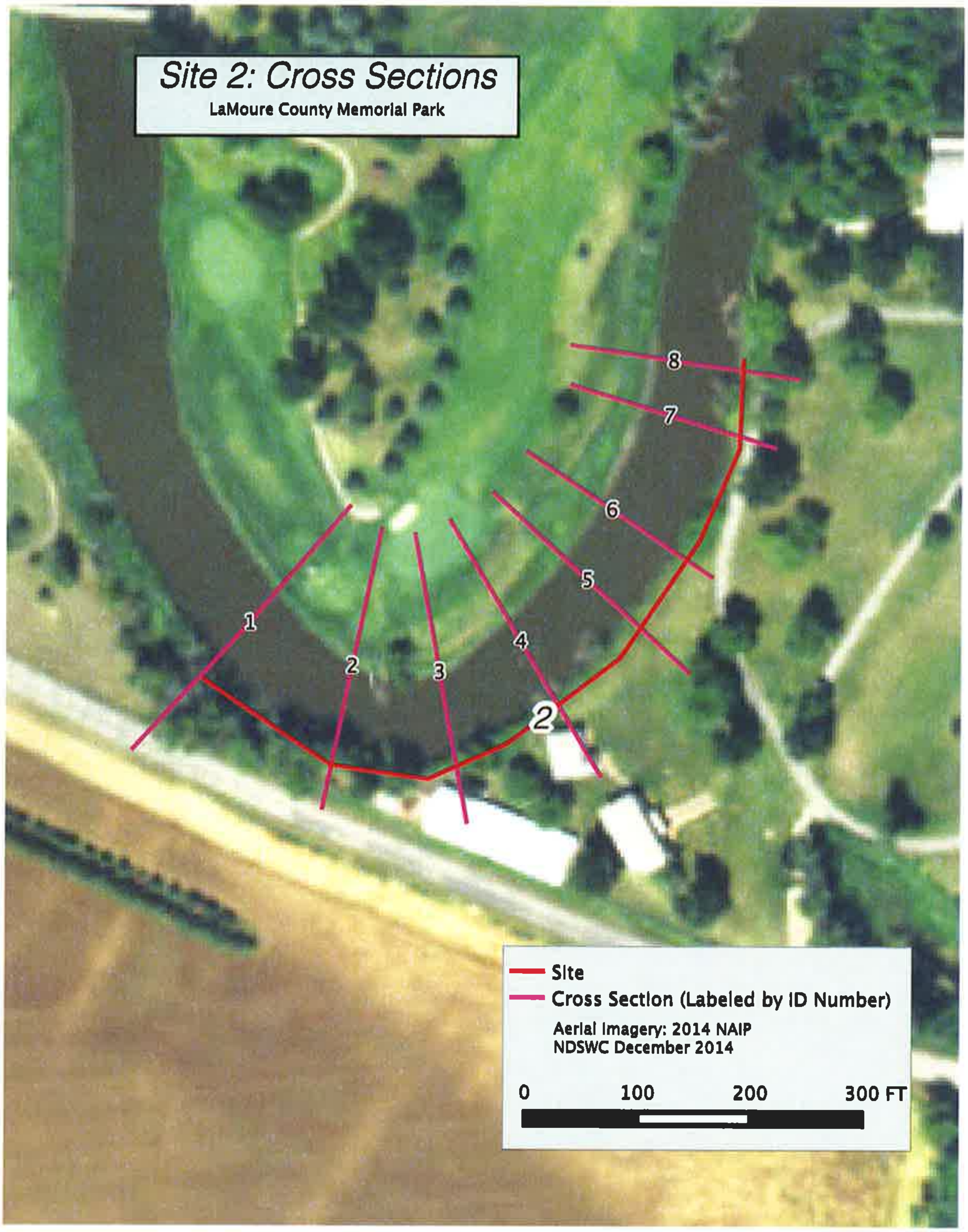


Figure 9. Site location 2.

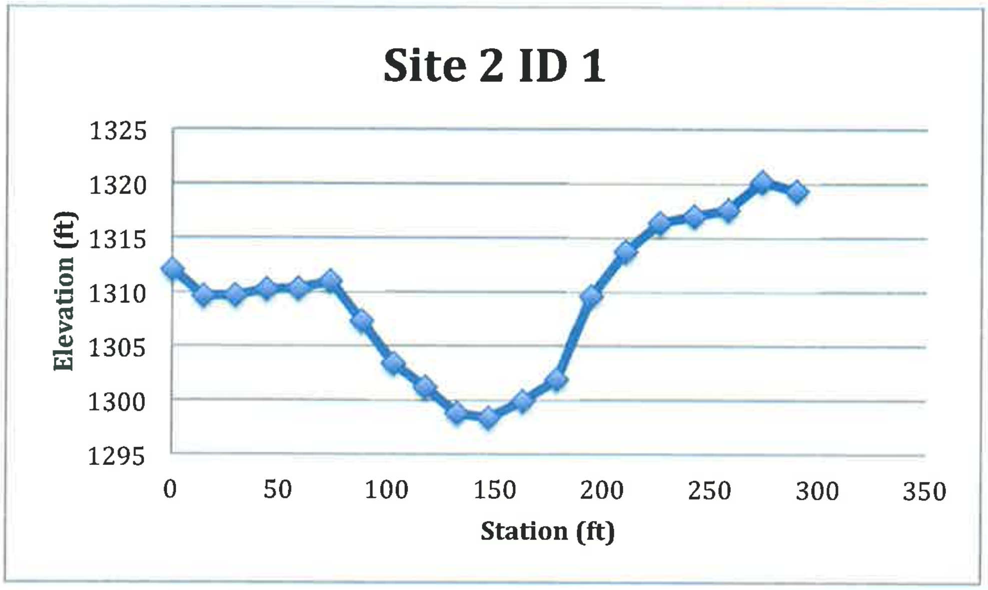


Figure 10. Site location 2, cross section ID 1.

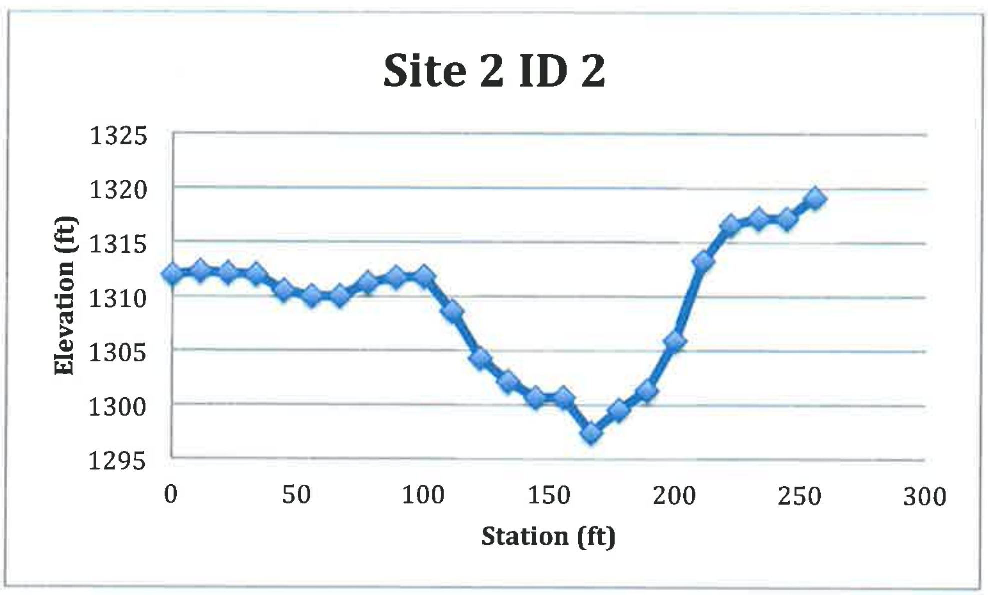
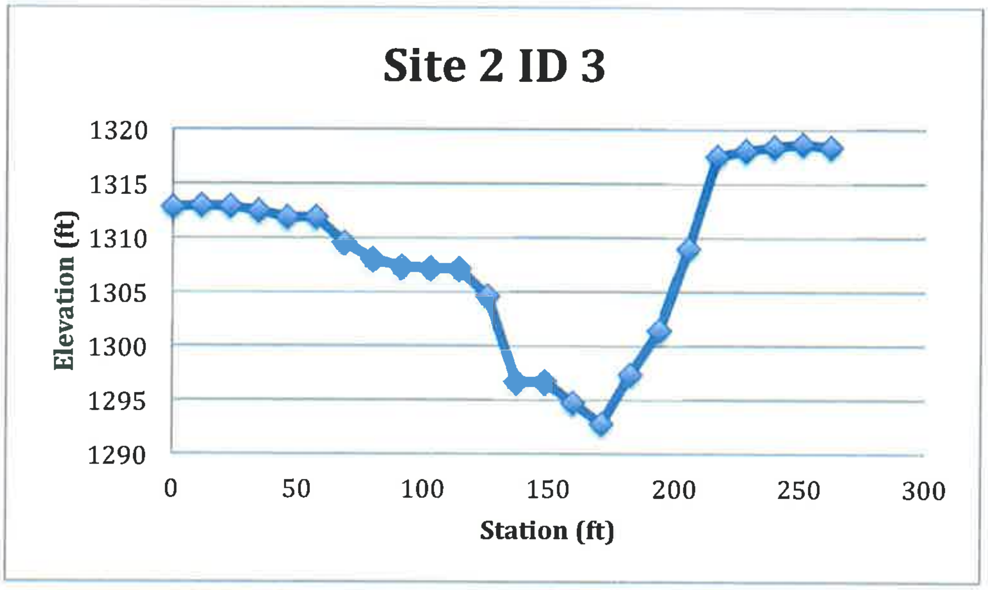


Figure 11. Site location 2, cross section ID 2.



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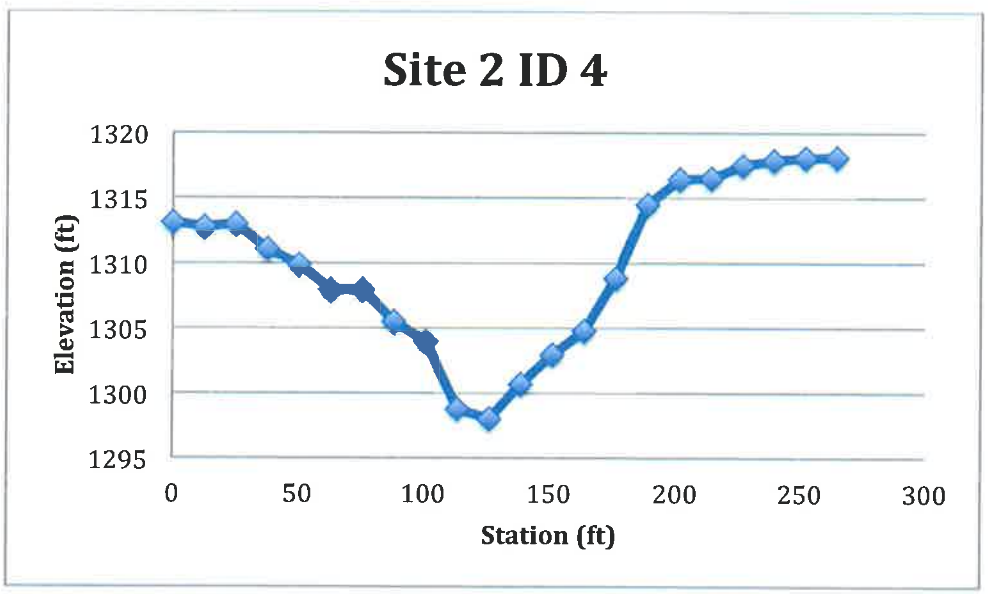


Figure 13. Site location 2, cross section ID 4.

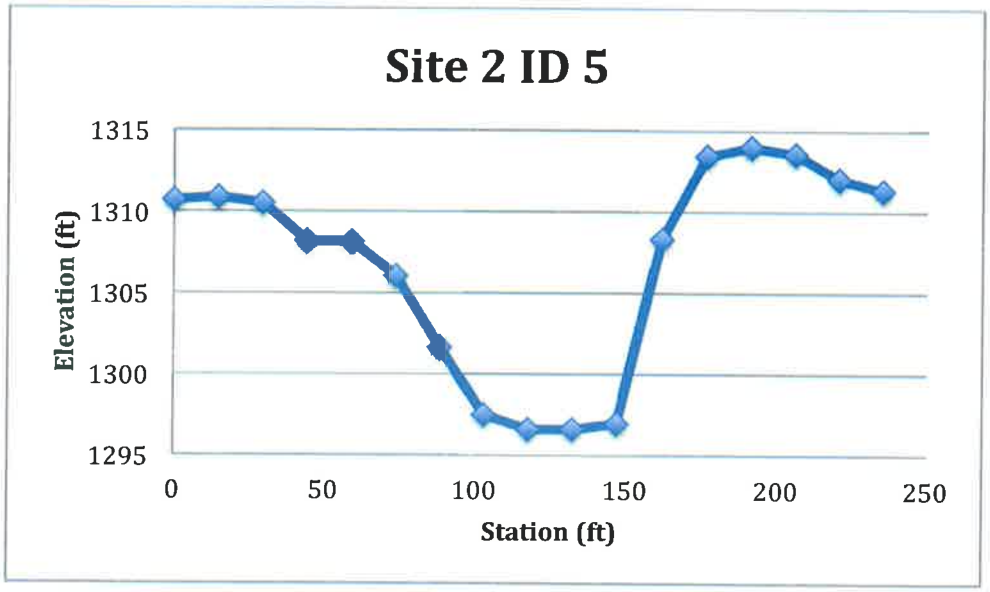


Figure 14. Site location 2, cross section ID 5.

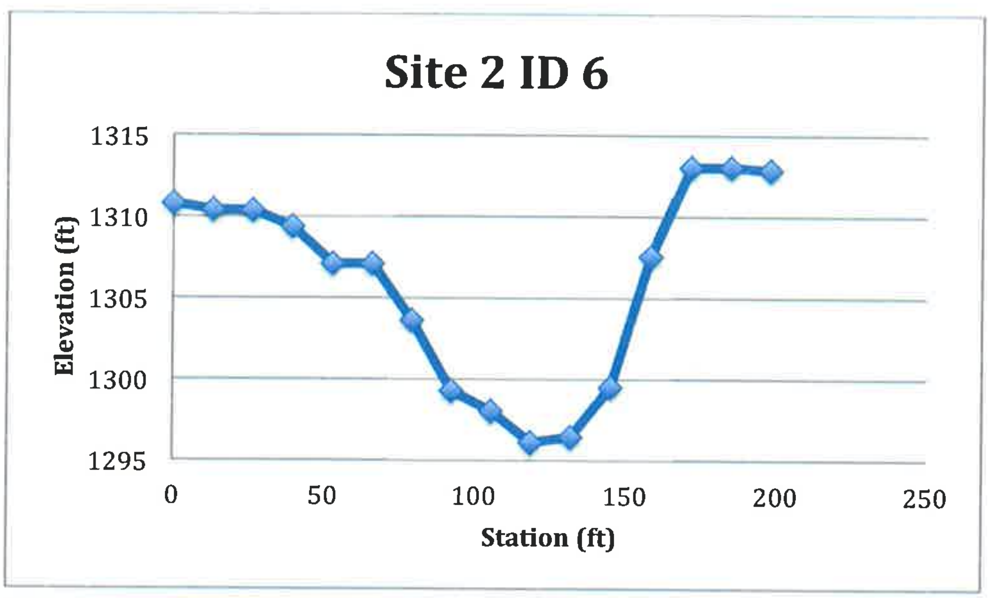


Figure 15. Site location 2, cross section ID 6.

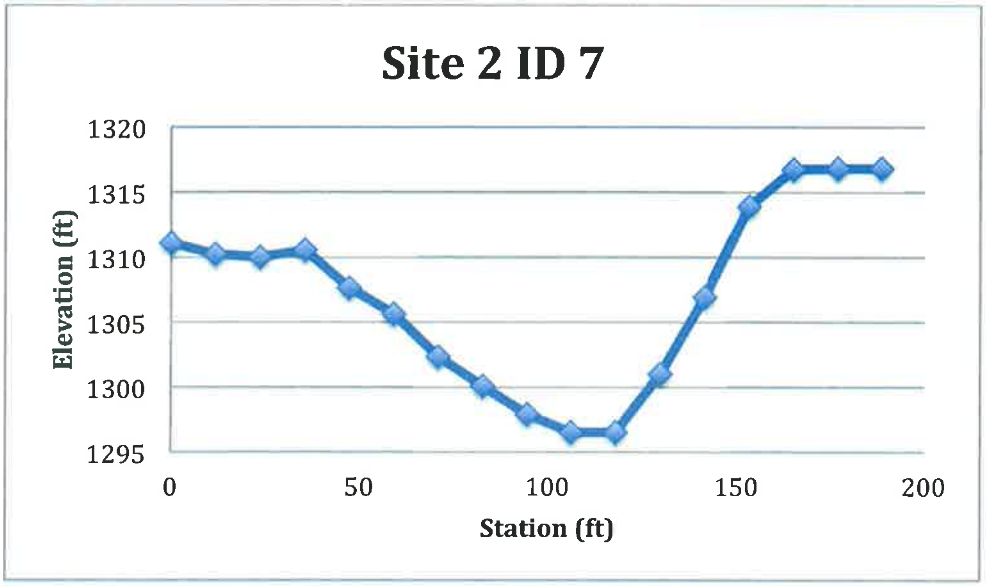


Figure 16. Site location 2, cross section ID 7.

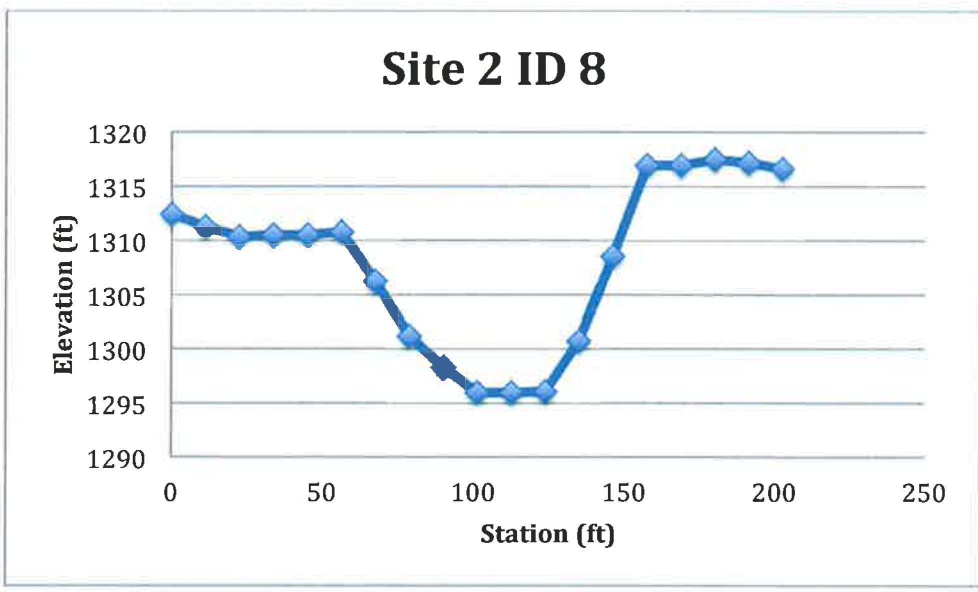


Figure 17. Site location 2, cross section ID 8.

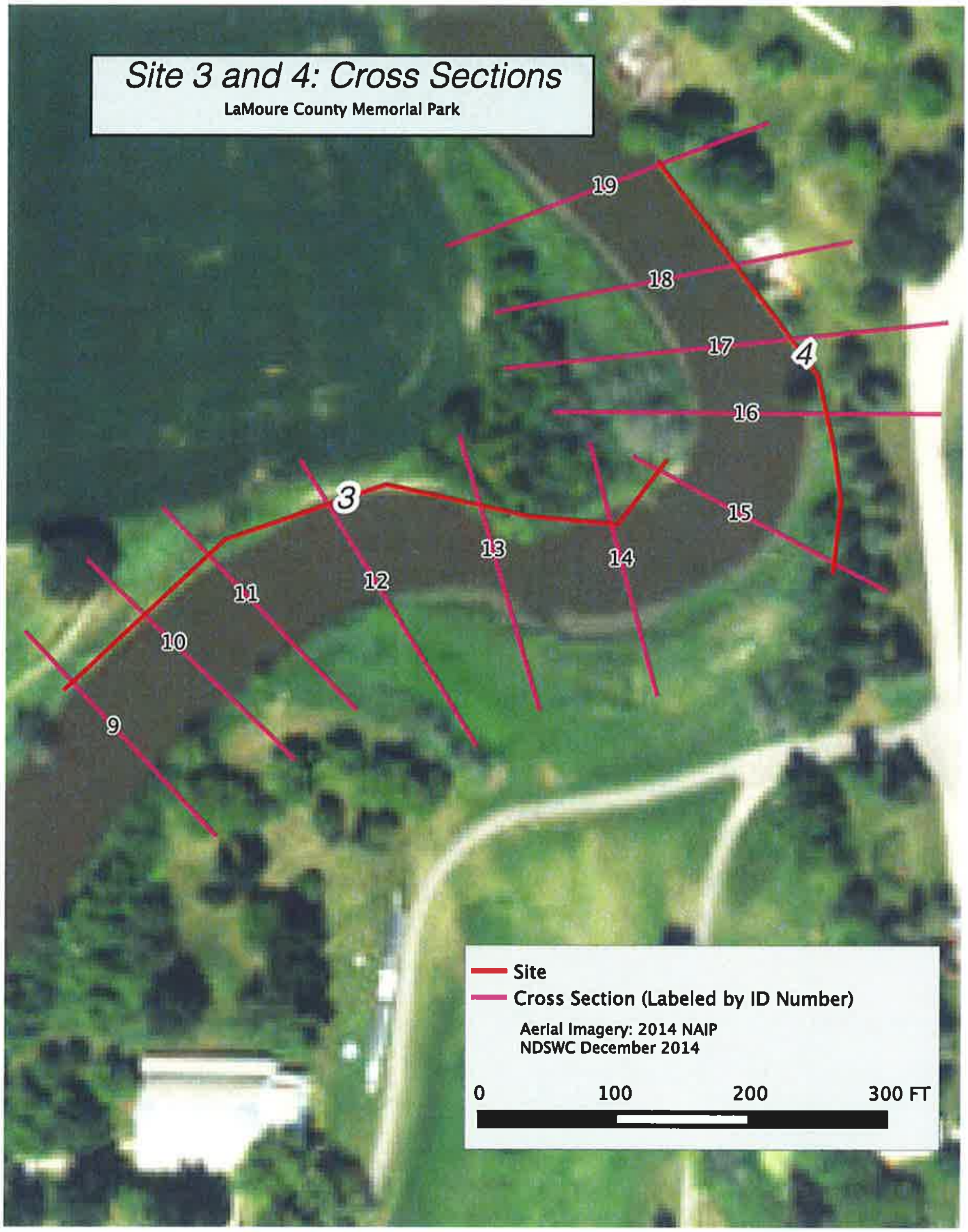


Figure 18. Site location 3 and 4.

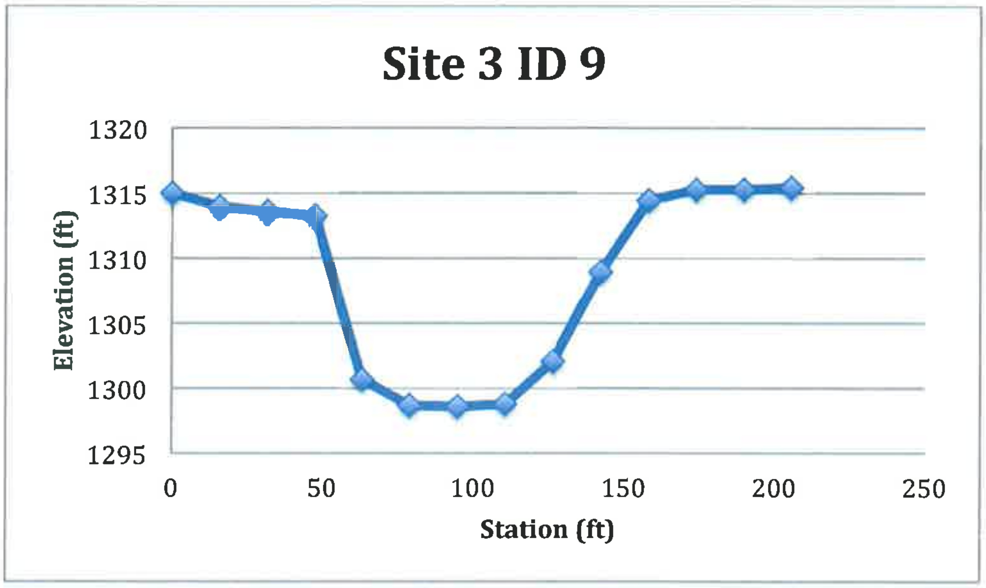


Figure 19. Site location 3, cross section ID 9.

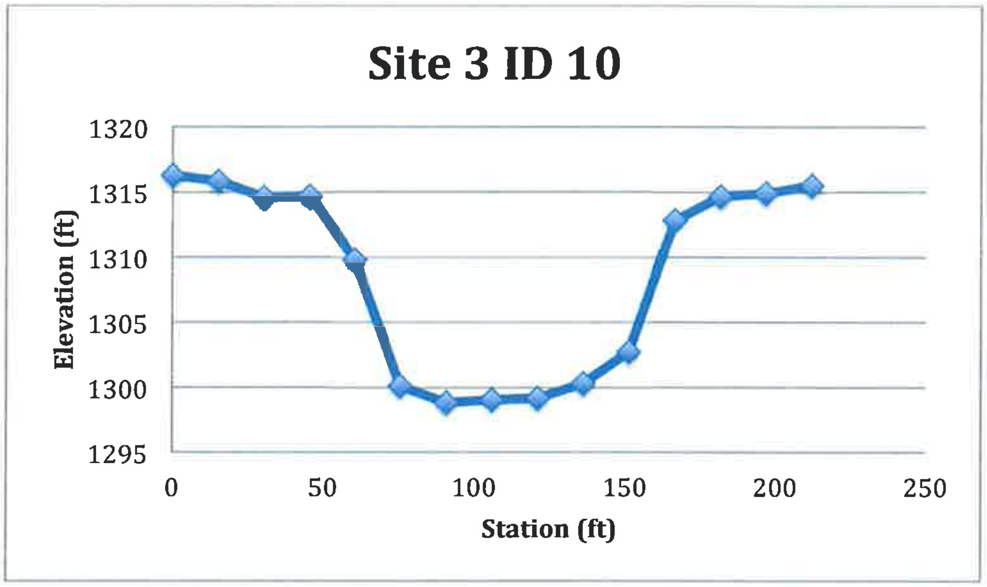


Figure 20. Site location 3, cross section ID 10.

Figure 21. Site location 3, cross section ID 11.

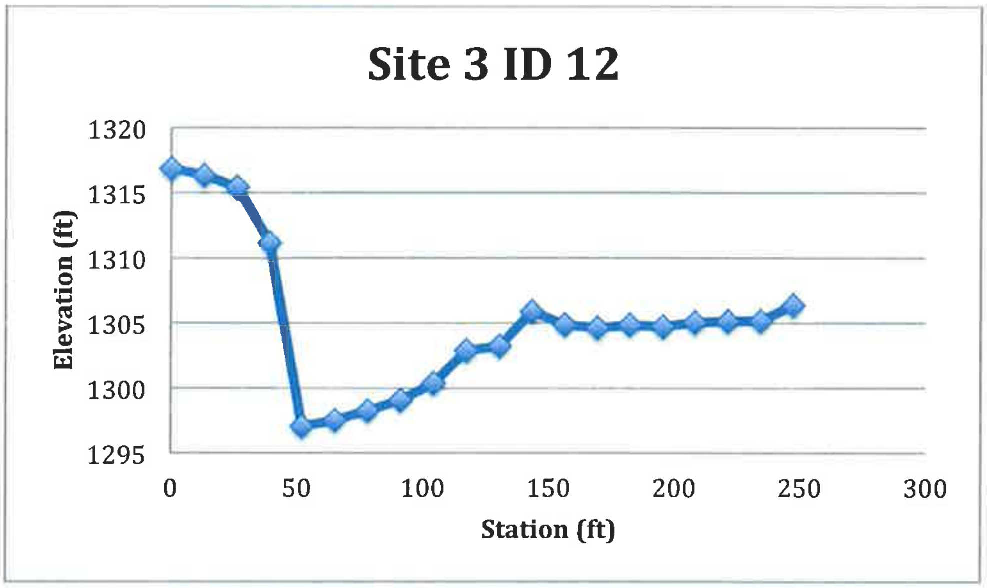


Figure 22. Site location 3, cross section ID 12.

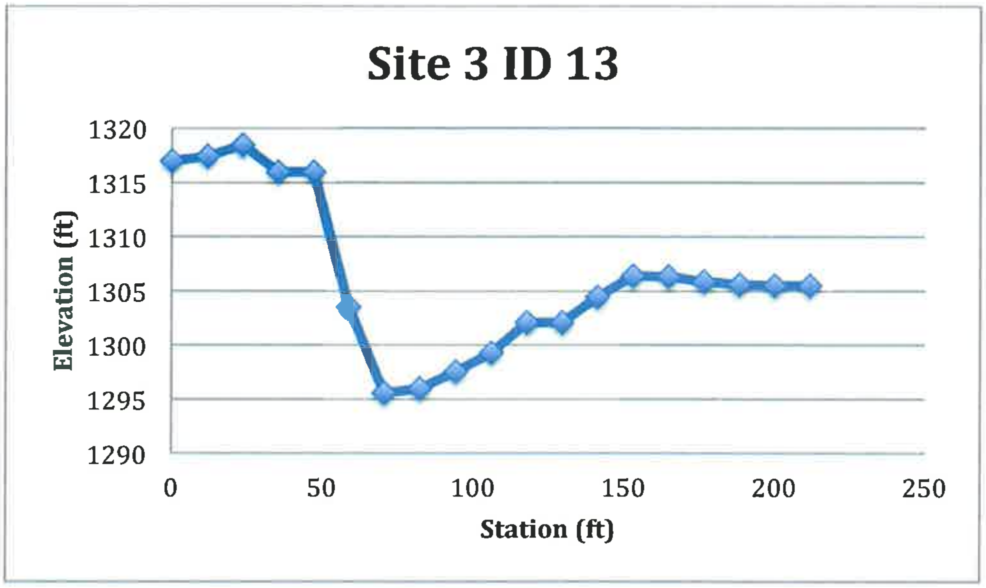


Figure 23. Site location 3, cross section ID 13.

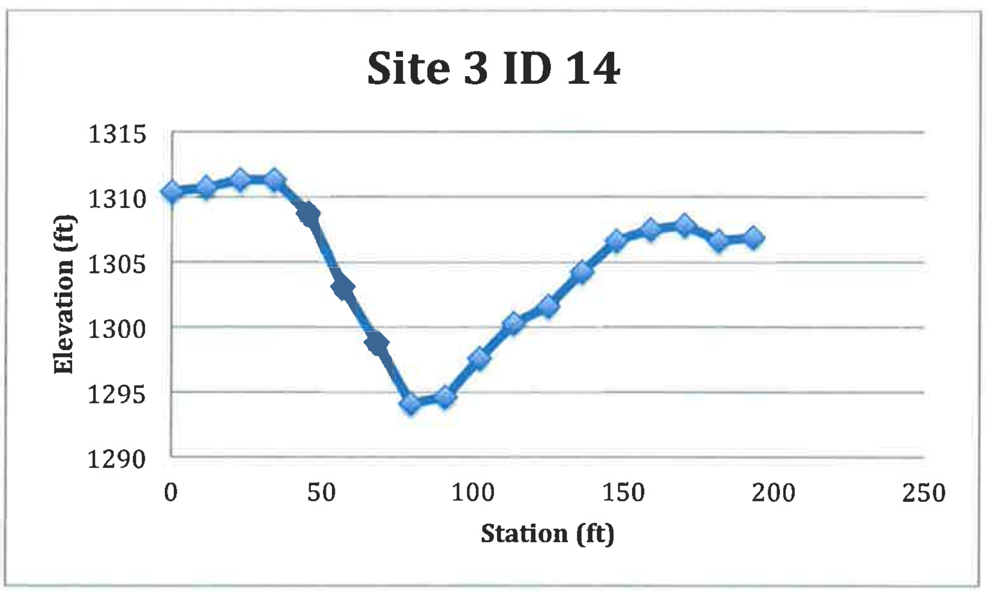


Figure 24. Site location 3, cross section ID 14.

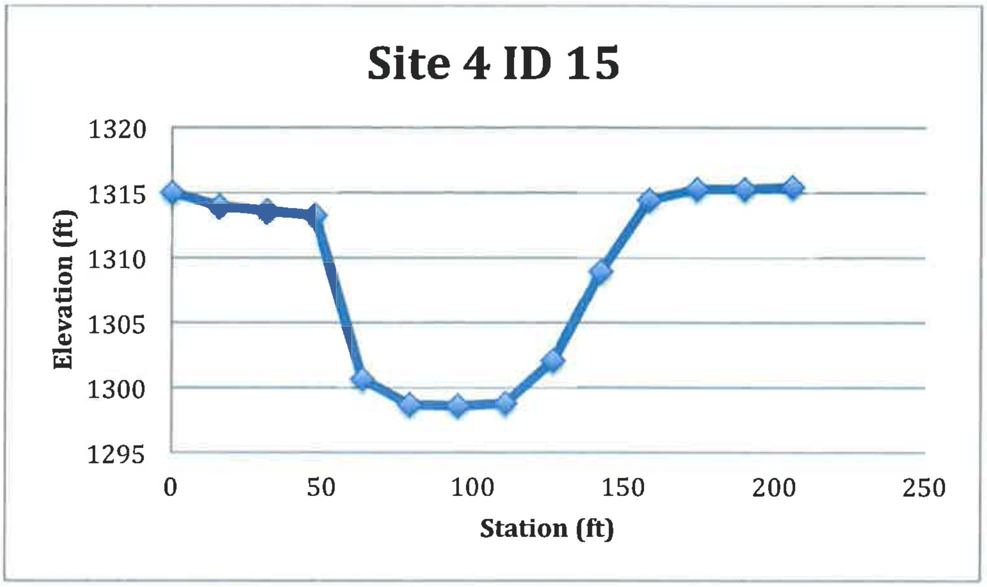
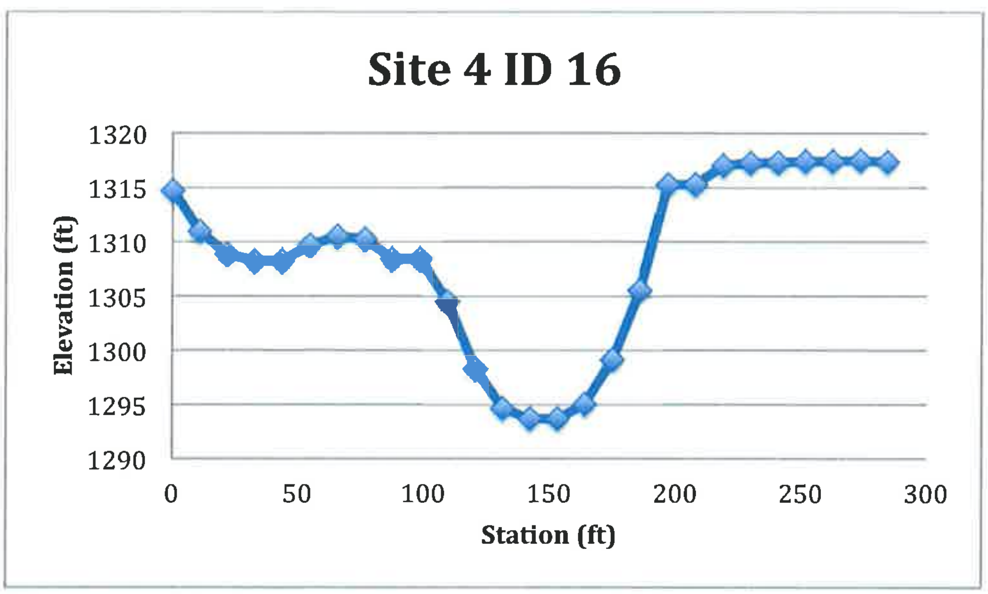


Figure 25. Site location 4, cross section ID 15.



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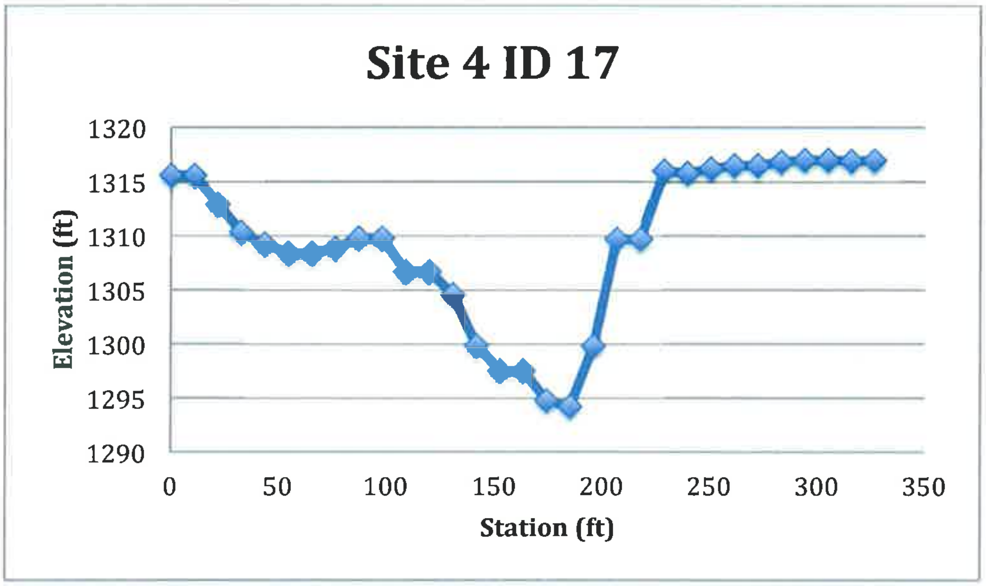


Figure 27. Site location 4, cross section ID 17.

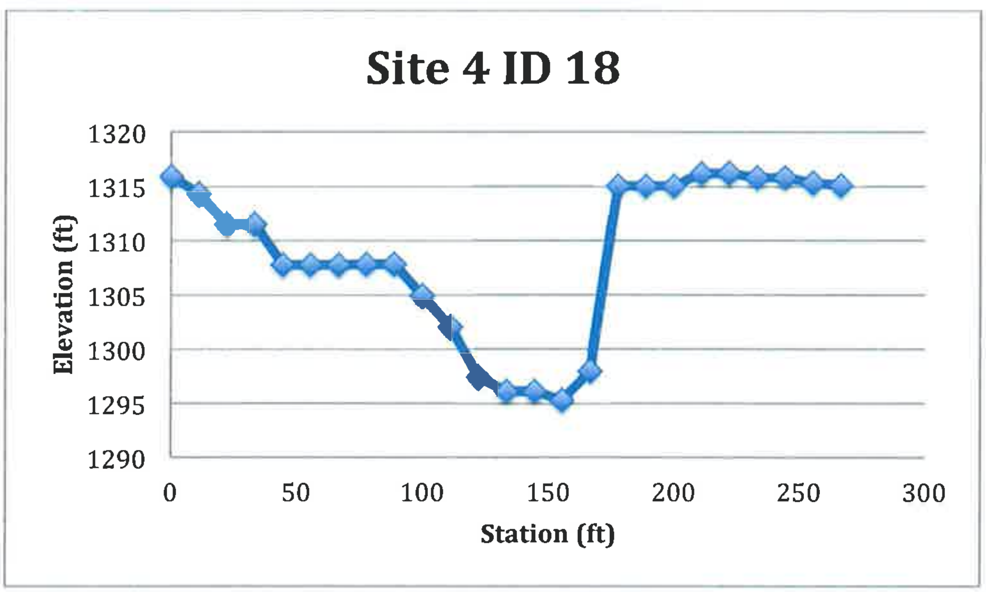


Figure 28. Site location 4, cross section ID 18.

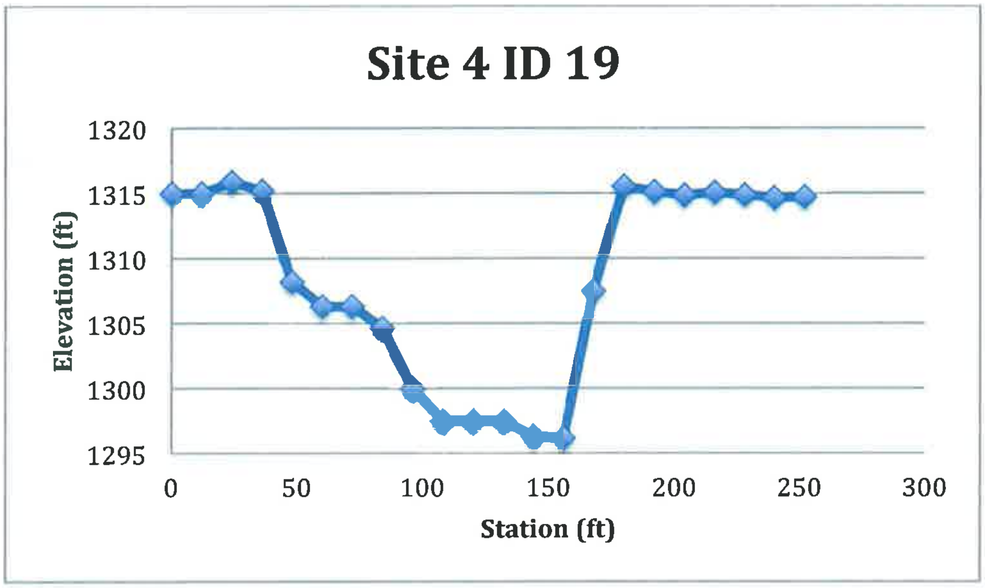


Figure 29. Site location 4, cross section ID 19.

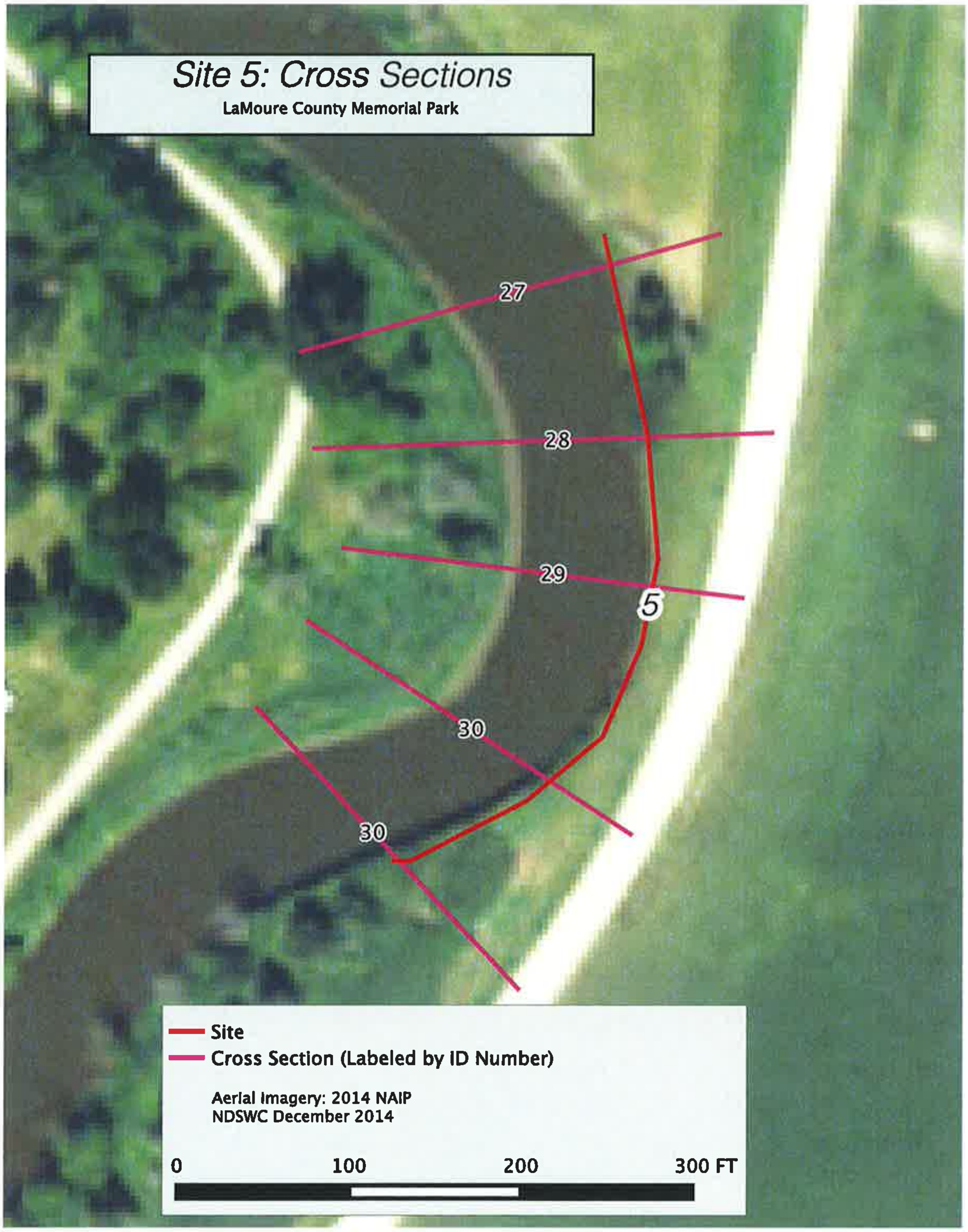
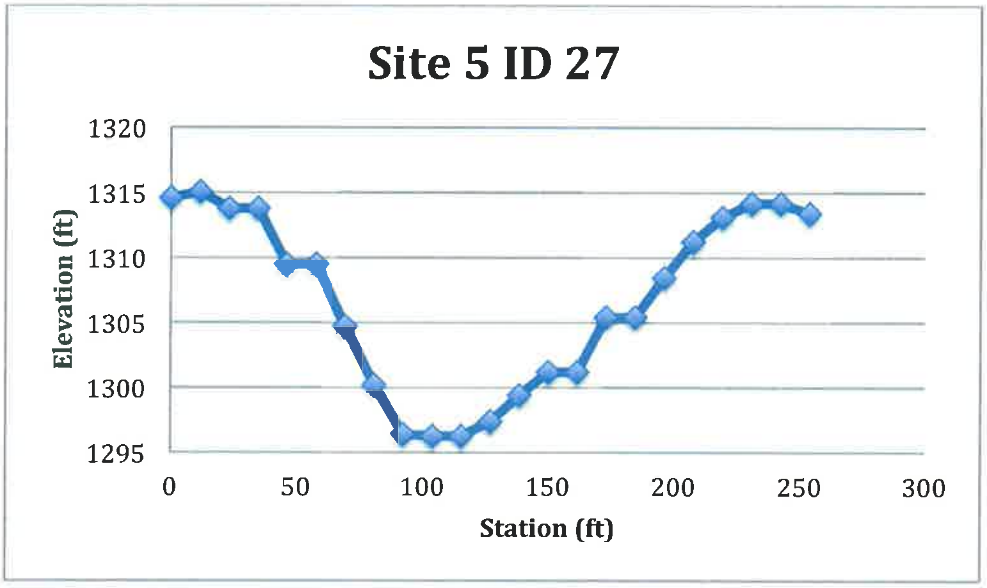


Figure 30. Site location 5.



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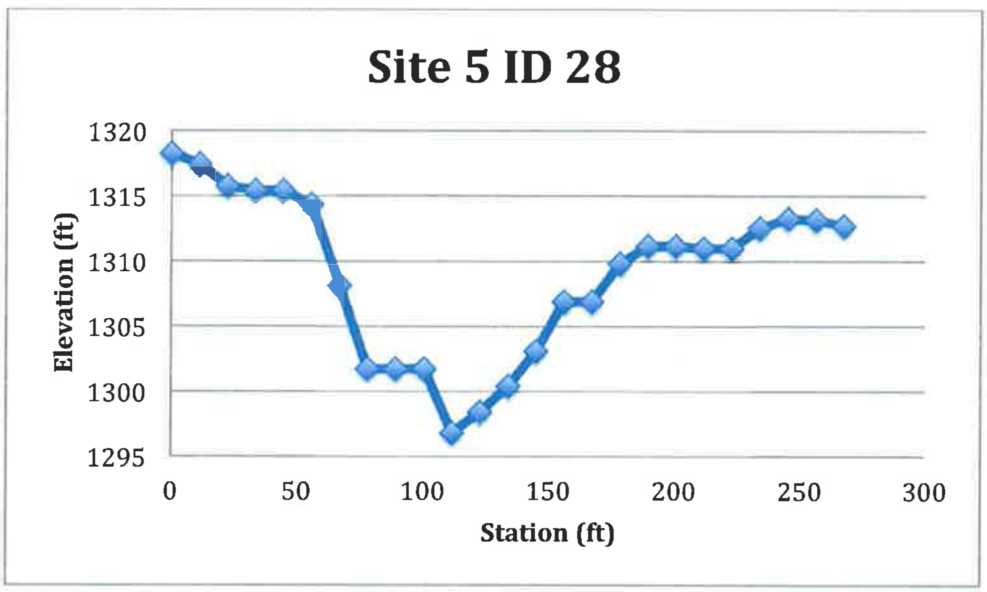

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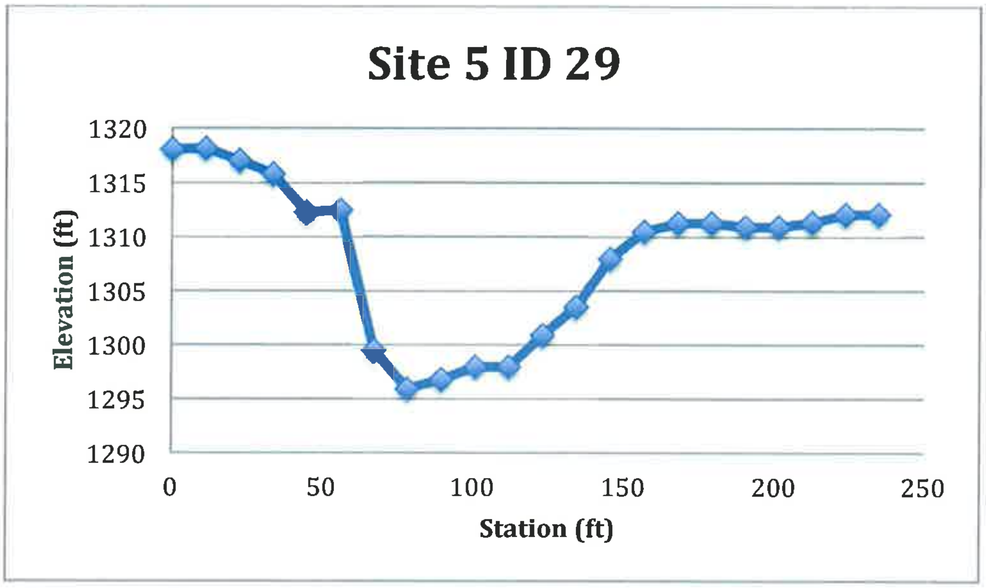

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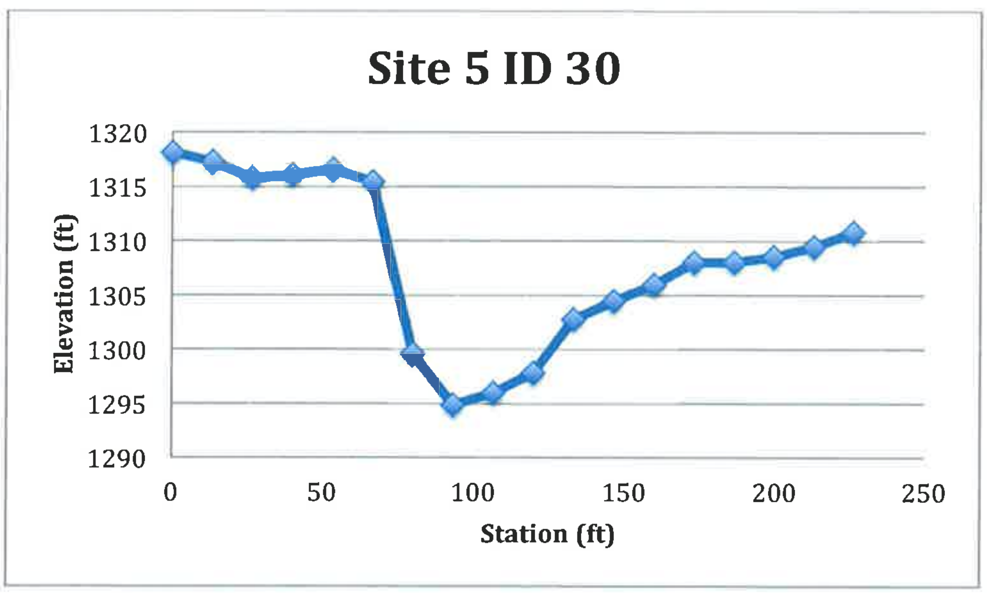

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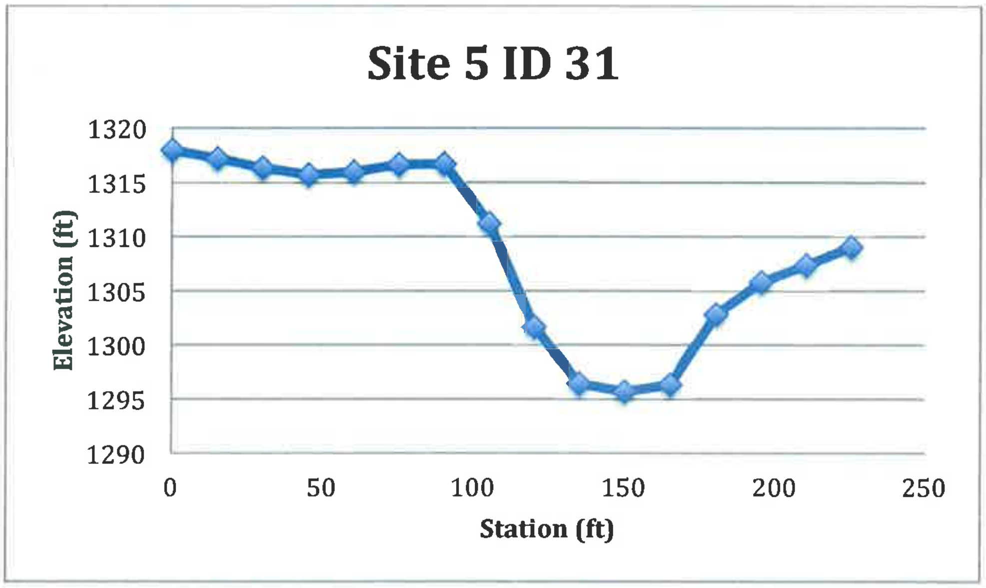


Figure 35. Site location 5, cross section ID 31.

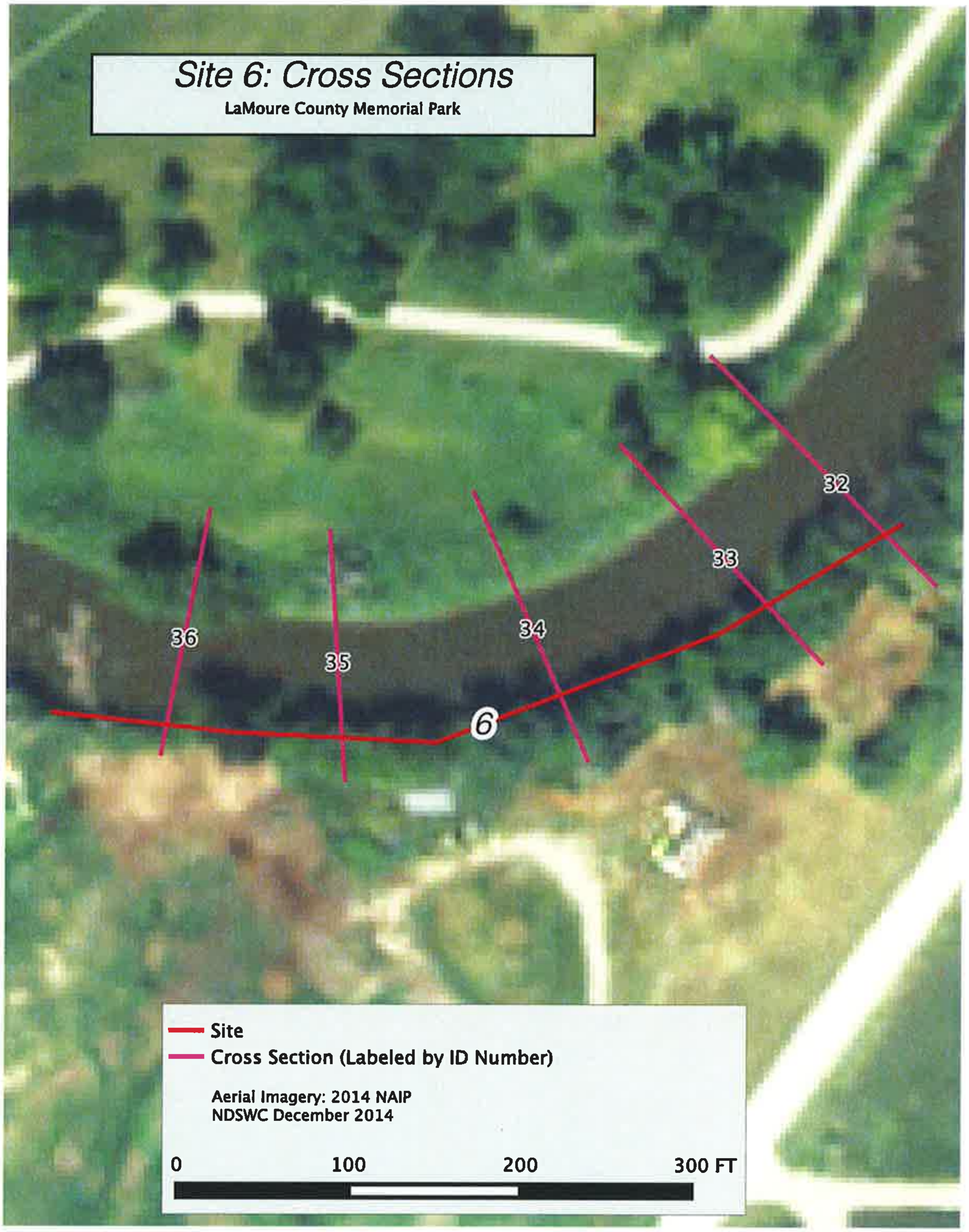


Figure 36. Site location 6.

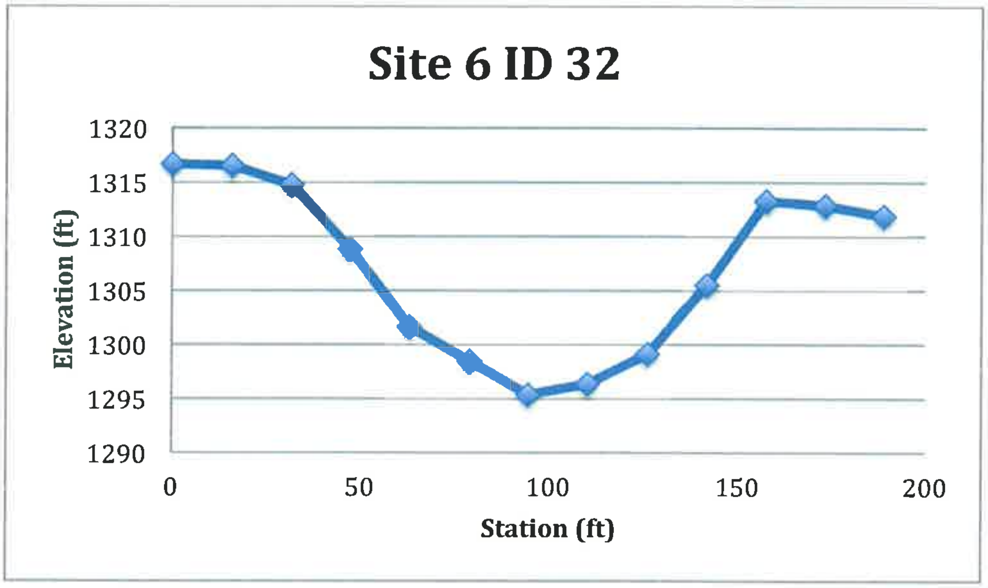
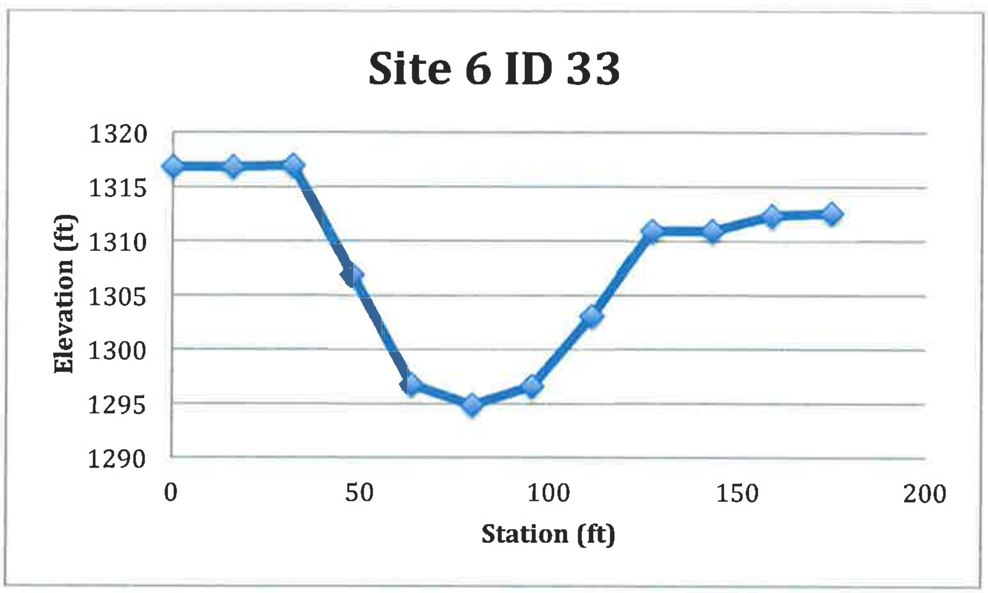


Figure 37. Site location 6, cross section ID 32.



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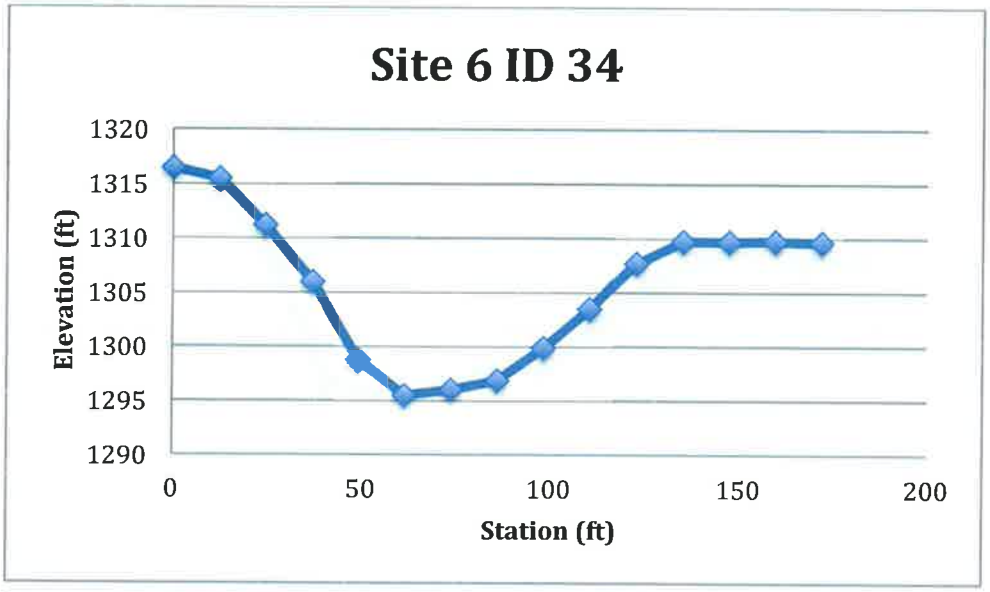

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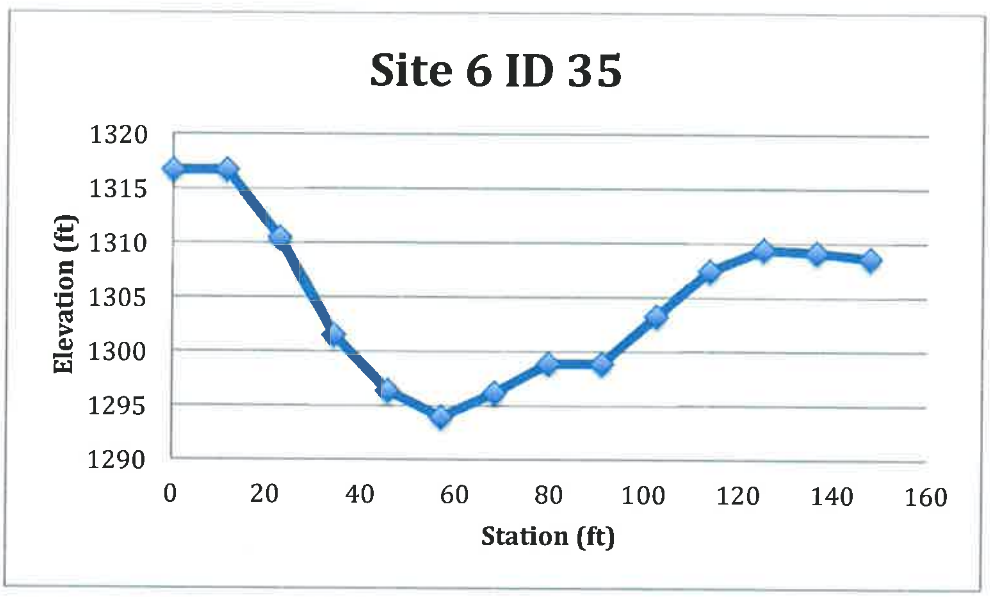

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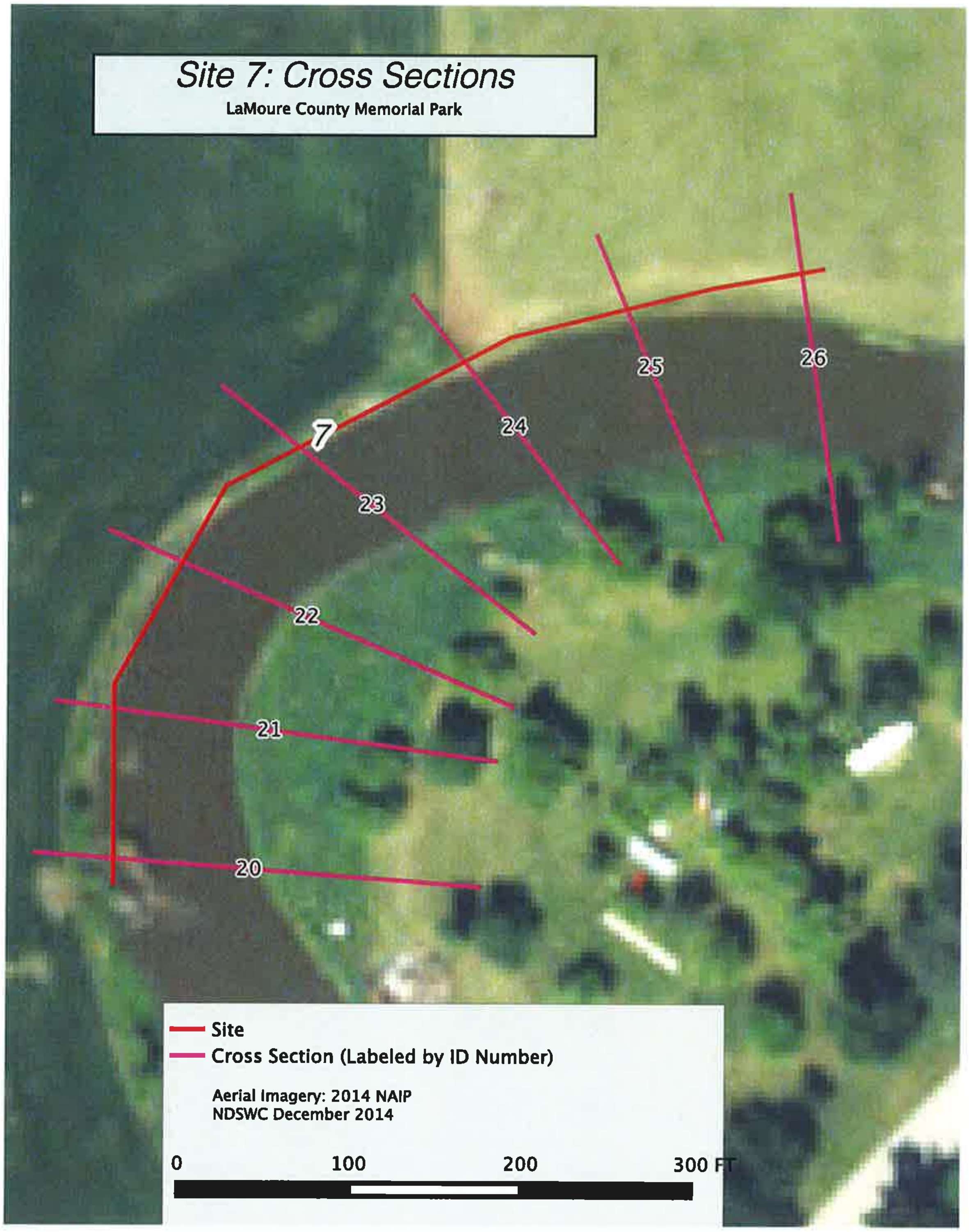
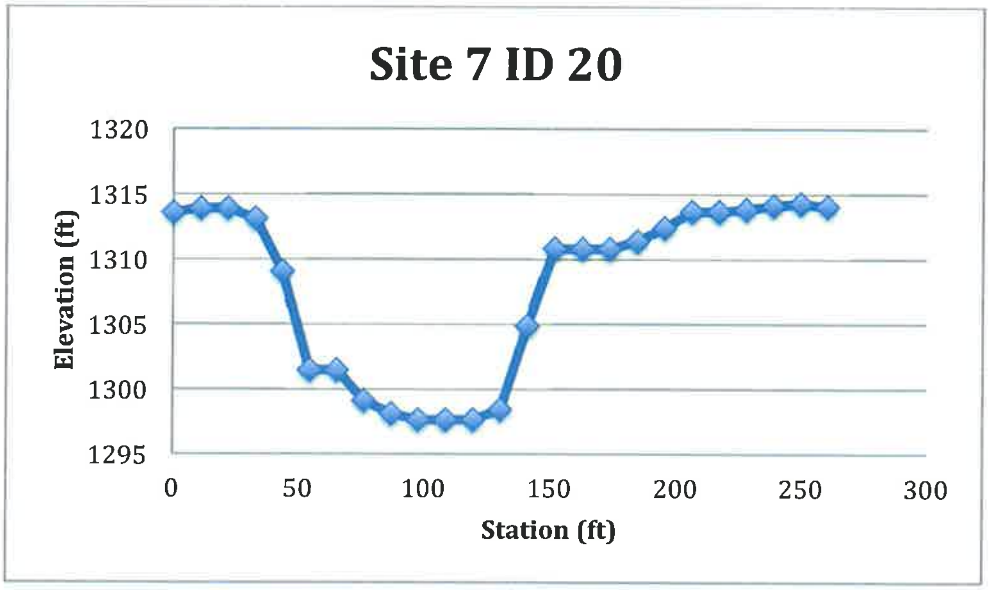


Figure 42. Site location 7.



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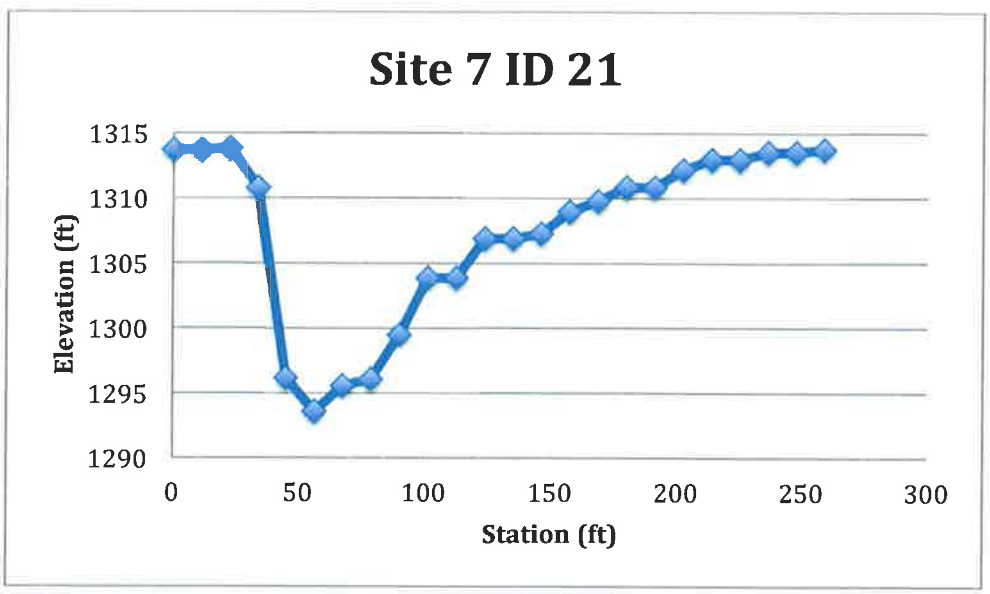

Figure 44. Site location 7, cross section ID 21.

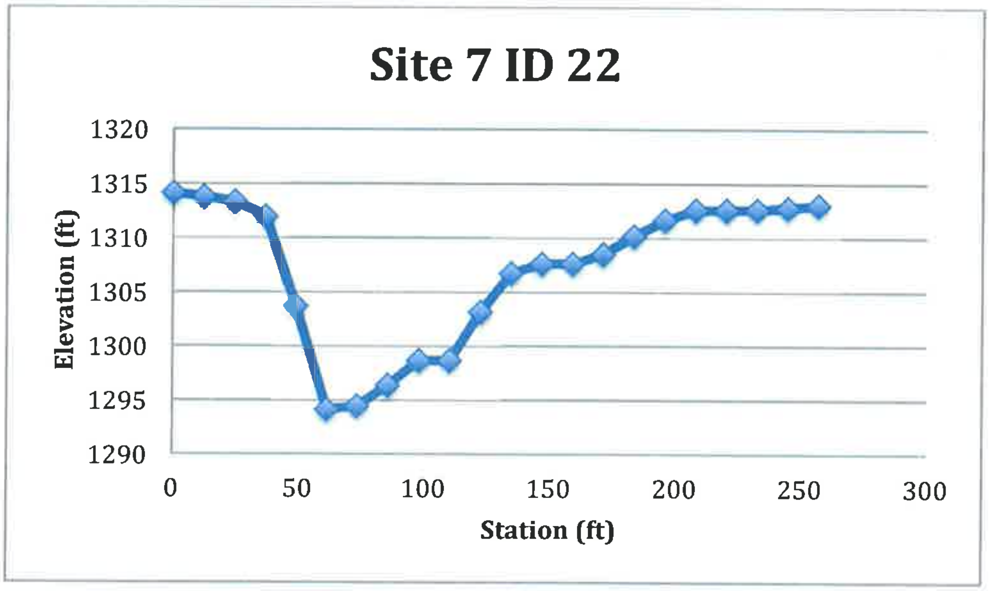

Figure 45. Site location 7, cross section ID 22.

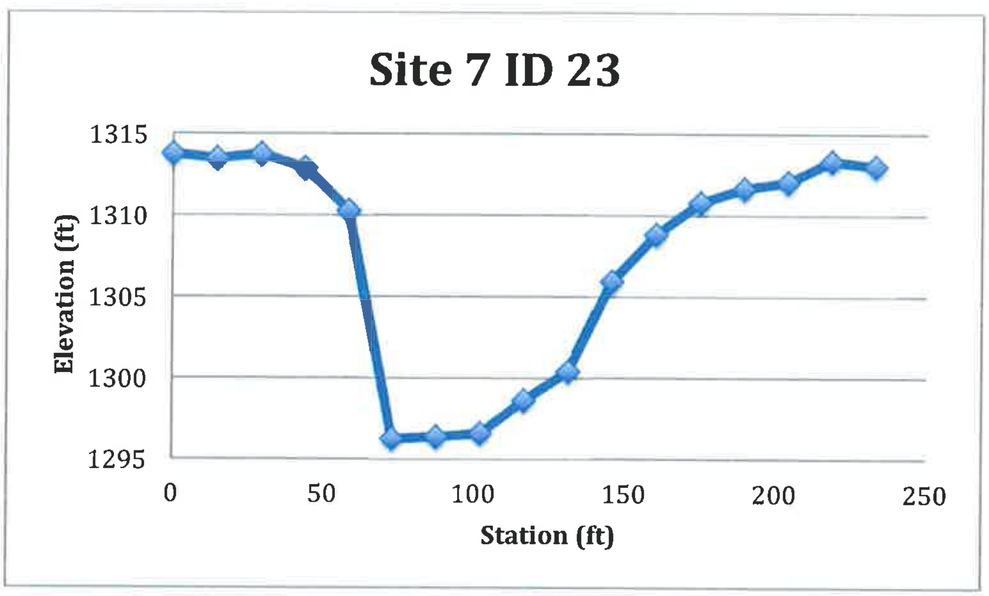

Figure 46. Site location 7, cross section ID 23.

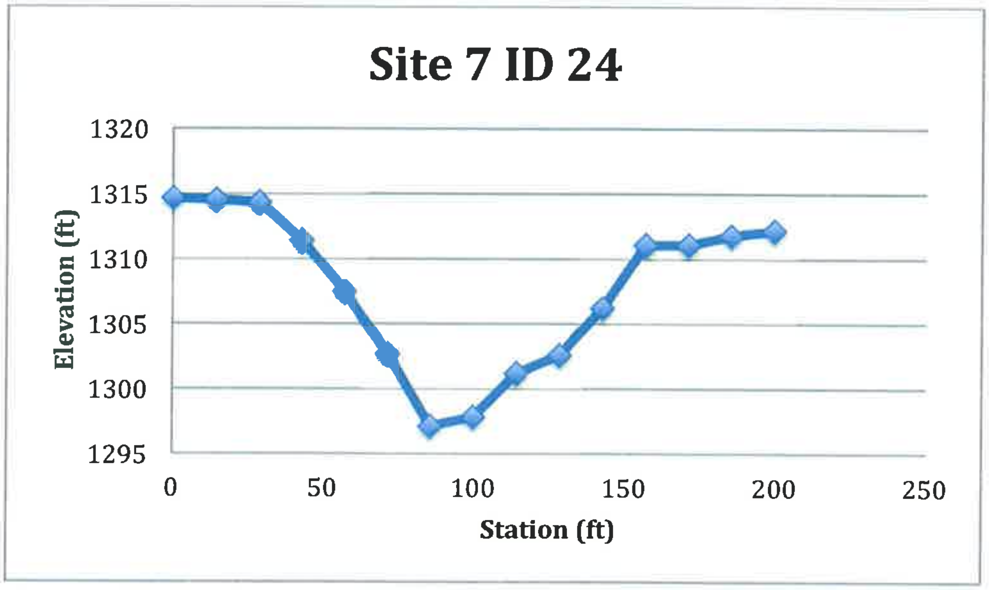

Figure 47. Site location 7, cross section ID 24.

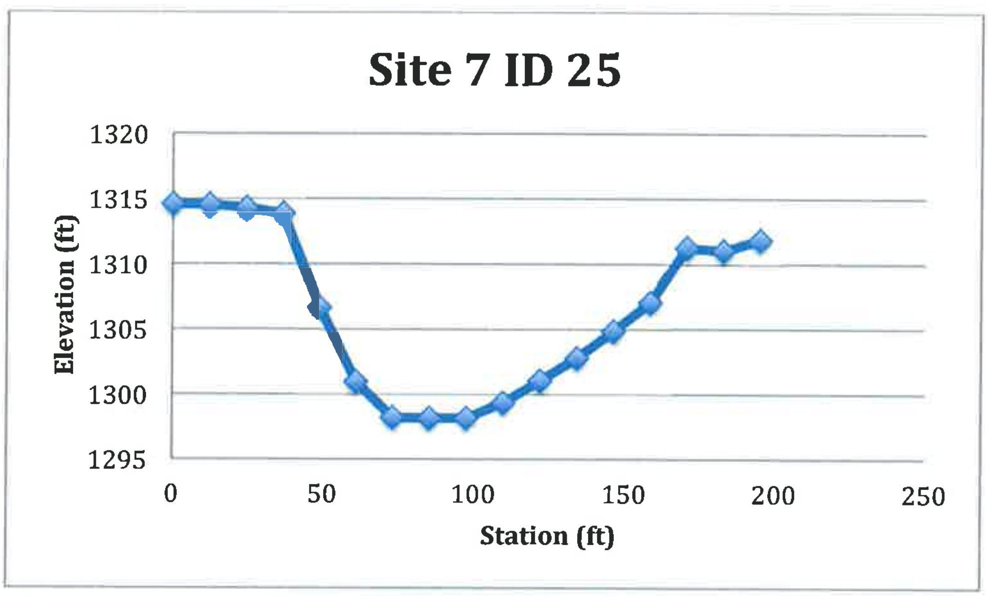

Figure 48. Site location 7, cross section ID 25.

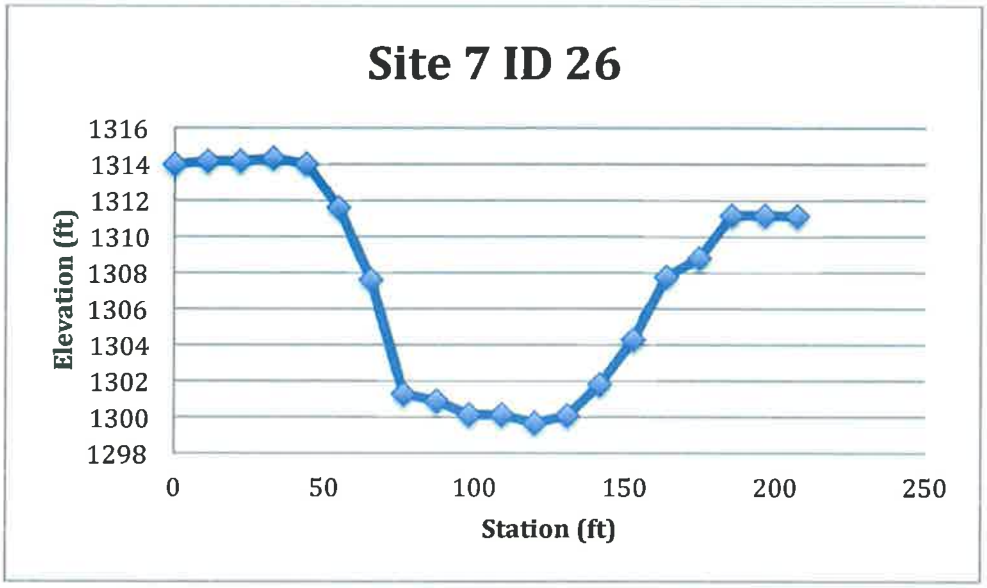

Figure 49. Site location 7, cross section ID 26.