Linton – Beaver Creek Hydraulic Model Report

Emmons County, North Dakota

SWC Project #558
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North Dakota
State Water Commission

Beaver Creek Hydraulic Model Report

Linton, North Dakota, Emmons County

SWC Project #558
North Dakota State Water Commission
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1. Introduction

This report documents the creation and calibration of a hydraulic model for Beaver Creek at Linton, ND. The model was created as part of a Section 22 Planning Assistance to States study between the U.S. Army Corps of Engineers (Omaha District) and the Emmons County Water Resource Board (Board), and pursuant to an investigation agreement between the Board and the North Dakota State Water Commission (NDSWC). The purpose of the Section 22 study is to investigate the flood risk management alternatives for the communities along Beaver Creek. This report summarizes the creation of the hydraulic model for Beaver Creek at Linton, ND.

2. Site Location

The hydraulic model was constructed with the tributaries surrounding Linton, ND. The major tributaries that contribute to flooding within the city are Beaver Creek, Spring Creek, and the Baumgartner Lake Drainage (**Figure 1**). Minor tributaries that flow through the city are Horner's Ravine and an unnamed coulee that parallels Spring Creek before they eventually merge. The hydraulic model's focus is on Beaver Creek, Spring Creek, and Baumgartner Lake Drainage. These streams are the primary drainages that produce the greatest potential flood risks. Portions of the unnamed coulee and Horner's Ravine are included within the hydraulic model, but were not evaluated.

2.1 Unique Features Within the Site

There are several unique features within the region that require special attention (listed below). Each of the unique features was incorporated in the hydraulic model.

- Several bridges are located within the hydraulic systems. **Figure 2** illustrates the location of the bridges that were incorporated into the hydraulic model. Most of the bridges contain significant openings for conveyance; however, the Golf Course Bridge lies within the channel of Beaver Creek and only contains two culverts to convey flow.

- A bifurcation exists through two of the downstream bridges on 6th Avenue Southeast (**Figure 3**). A home lies between the bifurcation. The north branch is an overbank channel, filled with heavy brush and trees, while the south channel is mostly un-vegetated. The United States Geological Survey (USGS) has an active stream gage, gage number 06354580, along the south branch of the bifurcation.

- An earthen embankment (**Figure 4**) extending north-south on Beaver Creek's right overbank exists within the city district commonly referred to as "Old Town".

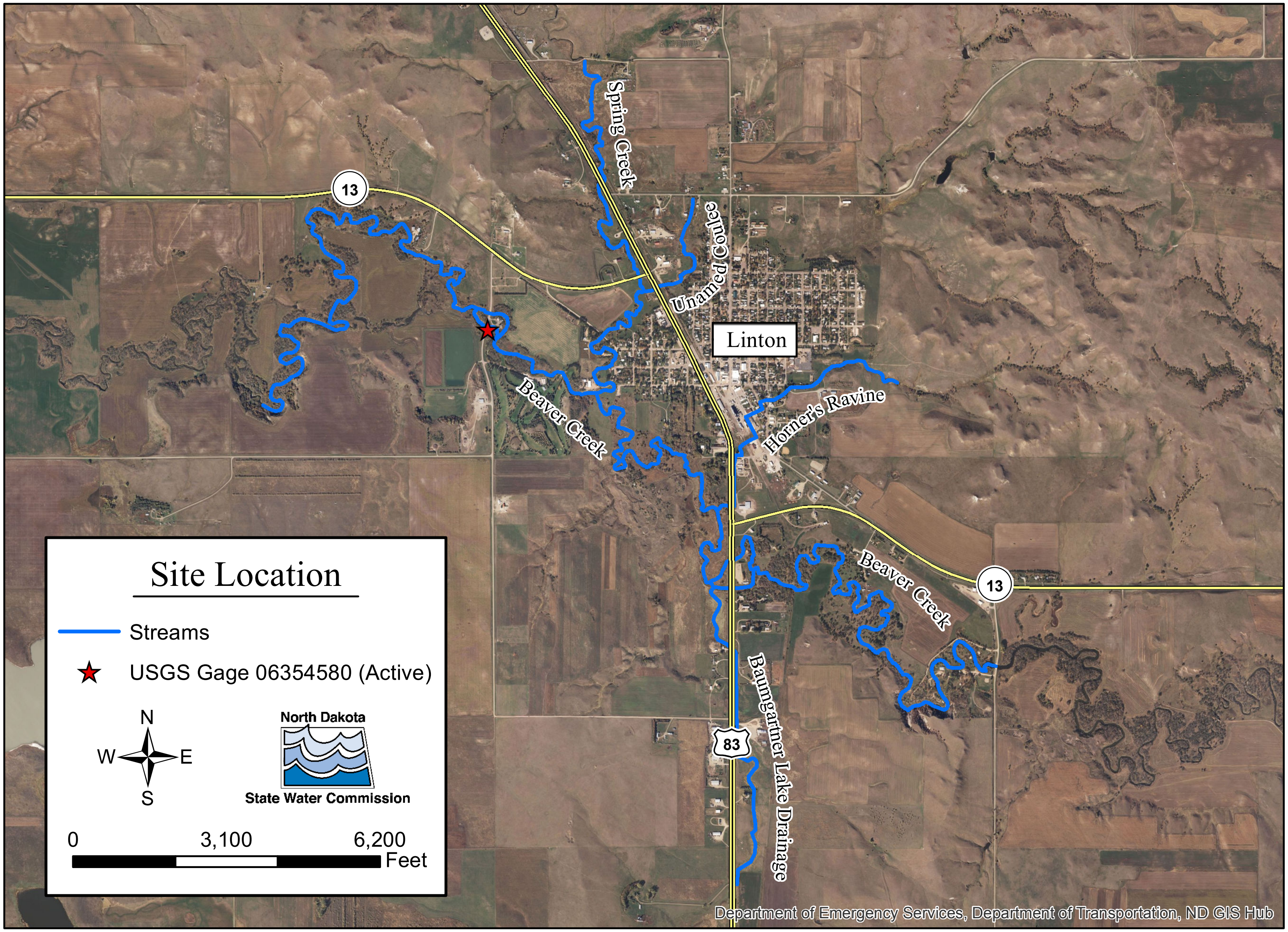

***Figure 1**. Site Location.*

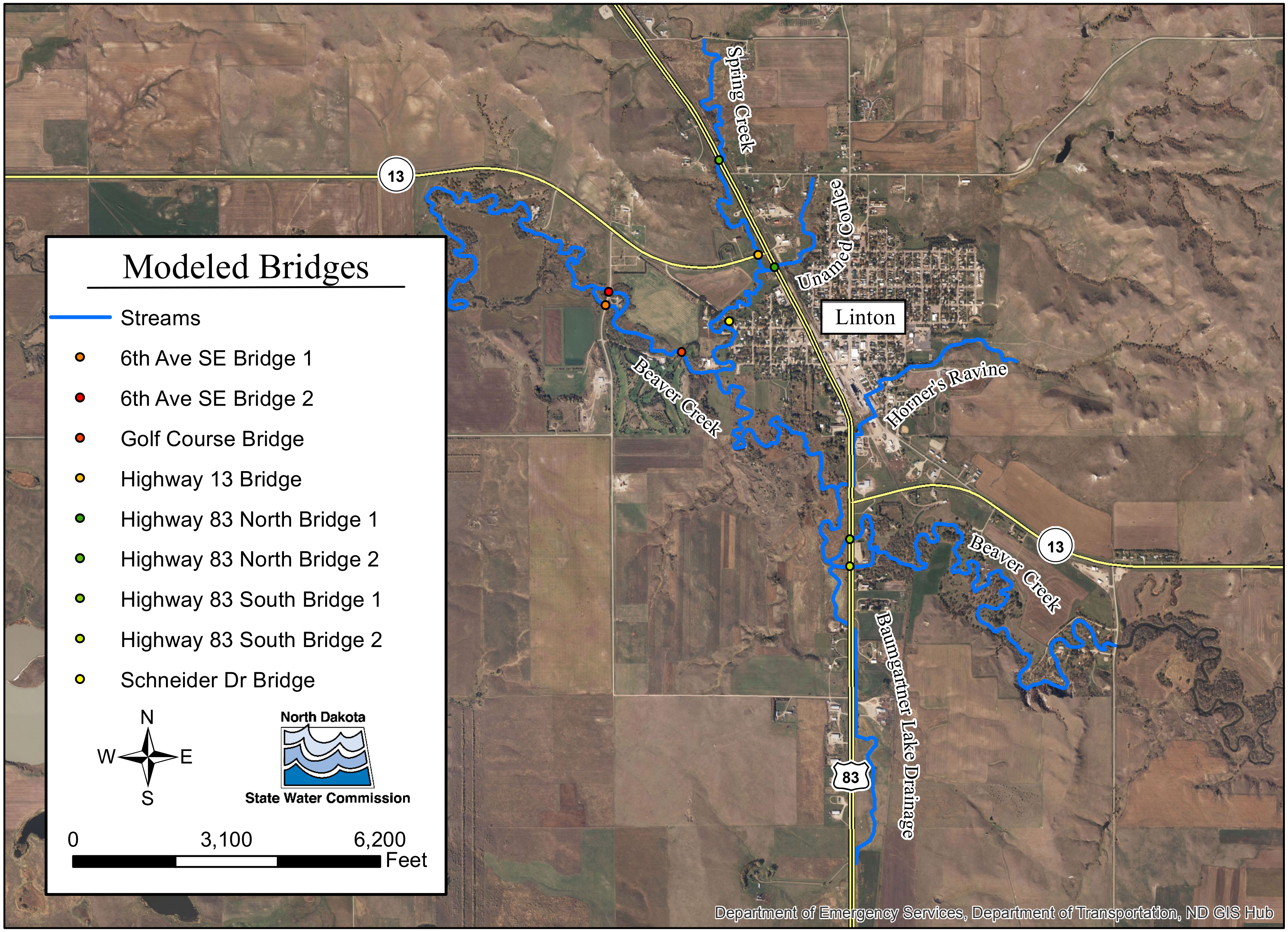

Figure 2. *Modeled Bridges.*

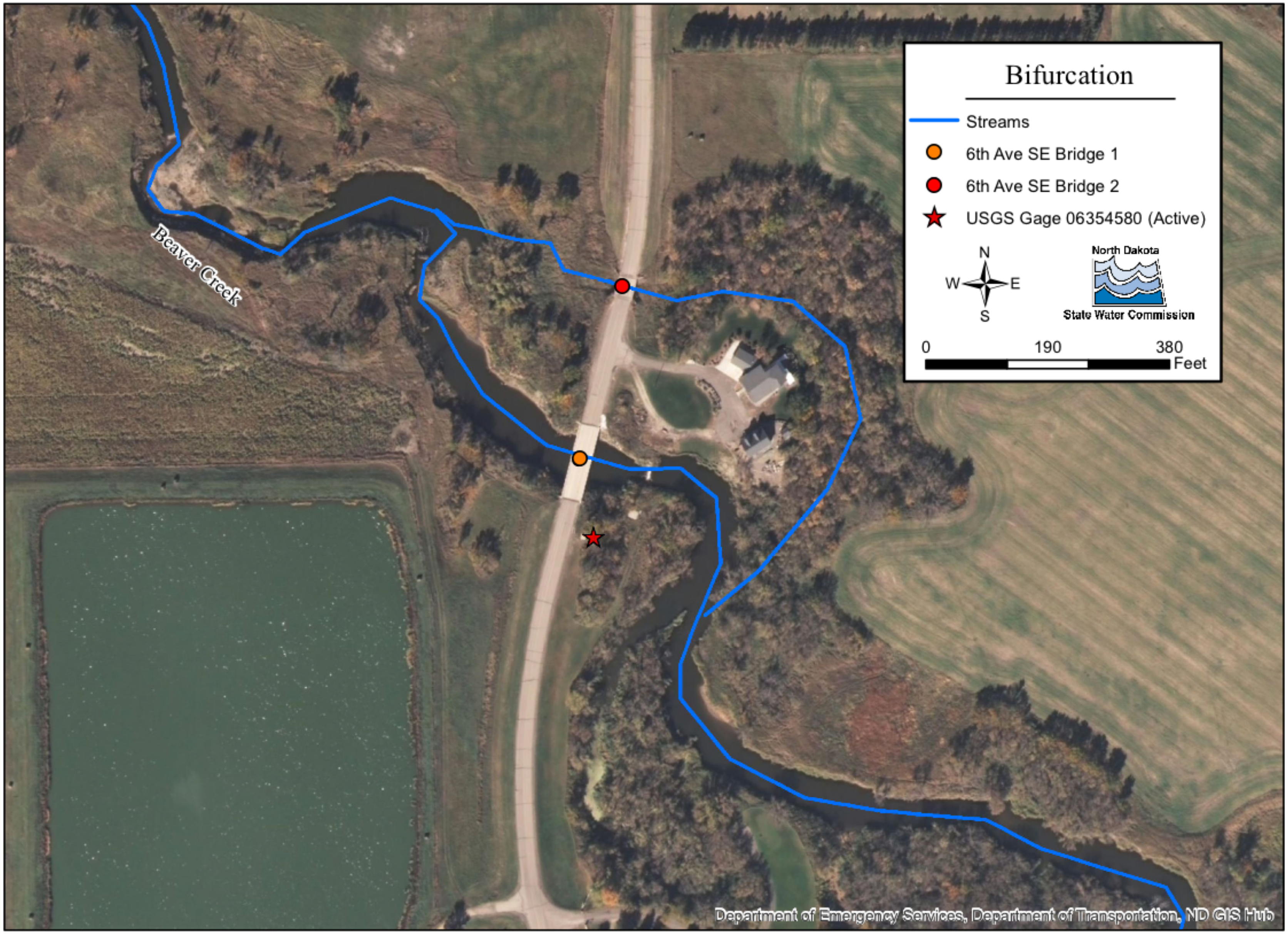

Figure 3. *Bifurcation.*

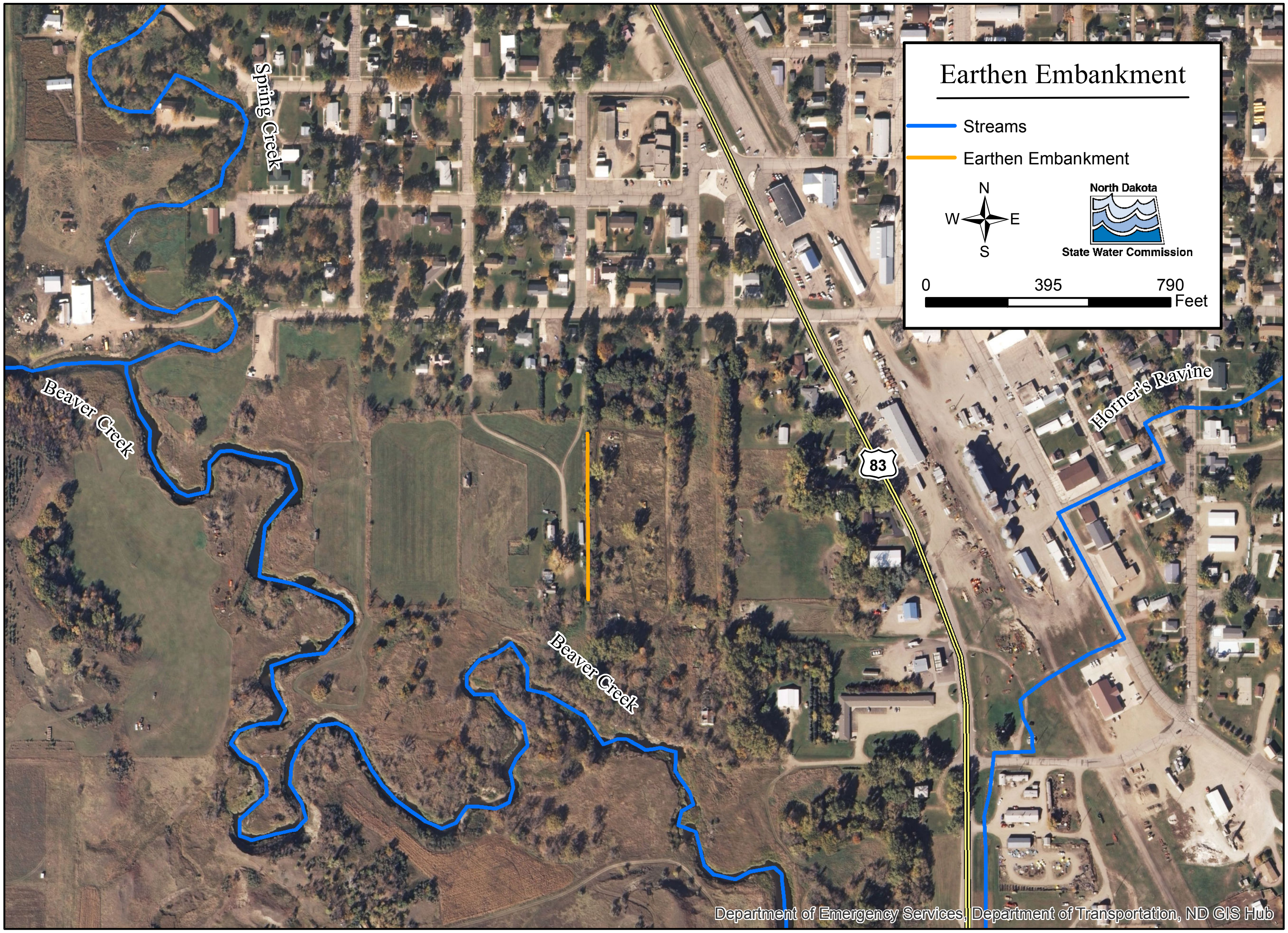

Figure 4. *Earthen Embankment.*

3. Hydraulic Model Development

The hydraulic model was developed using the United States Army Corps of Engineers' (USACE) Hydrologic Engineering Center's River Analysis System (HEC-RAS) version 5.0.3. The model was developed using 2-dimensional equations to increase the model's accuracy due to some of the unique features described earlier. The model requires detailed topographic, hydrologic, and surface roughness data.

3.1 Topographic Data

2-Dimensional models require a Digital Elevation Model (DEM), referred to in the program as a "terrain," to be developed. A grid is created over the high-resolution terrain to model distinct features in the landscape that 1-dimensional models are not capable of capturing. The terrain and solver also capture the effects of 2-dimensional fluid movement along the terrain that can affect water surface elevation, velocity, and flow. The terrain was created by mixing Light Detection and Ranging Data (LiDAR) and surveyed points. The terrain for the overbanks created using primarily LiDAR, while the channels were created by interpolating a surface from existing surveyed cross sections.

The LiDAR data utilized for this study consisted of a bare earth 1-meter DEM. The LiDAR was collected using North American Vertical Datum of 1988 (NAVD88) and horizontal datum Universal Transverse Mercator Zone 14 North in meters. The LiDAR was flown in the fall of 2015. The LiDAR elevations in the model are based on the NAVD88 (GEOID03) with the horizontal coordinate system being the North Dakota State Plane System (NDSPCS), South Zone, units in international feet, based on the NAD83 (1986). Individual LiDAR tiles were obtained from the NDSWC's LiDAR web service and merged using Quantum GIS. The DEM used for this study is included electronically with this report (**Appendix A**).

Survey data collected to construct the terrain consisted of topographic, bathymetric, and structure data. High water marks were also collected as part of the survey and later used for calibration and verification of the hydraulic model. The data were collected on the NAVD88 (GEOID03) using the NDSPCS, South Zone, international feet, NAD83 for the horizontal coordinate system. A text file of the completed survey is provided electronically with this report (**Appendix A**).

3.2 Model Setup

A polygon shapefile was created over the terrain to setup a 2-dimensional grid, incorporating the entire floodplain of Beaver Creek, Spring Creek, and Baumgartner Lake Drainage. The polygon was also expanded to include low lying regions within the community. The shapefile was then used to create a 2-dimensional hydraulic zone within HEC-RAS (**Figure 5**). The 2-dimensional grid was interpolated within the polygon with a minimum X and Y spacing of 50-feet for each cell. Break lines were created in HEC-RAS to force the grid to capture terrain features of interest; including roads, streams, depressions, embankments, ridges, and rail roads.

Four boundary conditions were used to create the model. Boundary conditions for the hydraulic inflows at Beaver Creek, Spring Creek, and Baumgartner Lake Drainage were created using hydrographs from the hydrologic model created as part of this study. Normal depth (slope of 0.0009) was utilized as the downstream boundary condition.

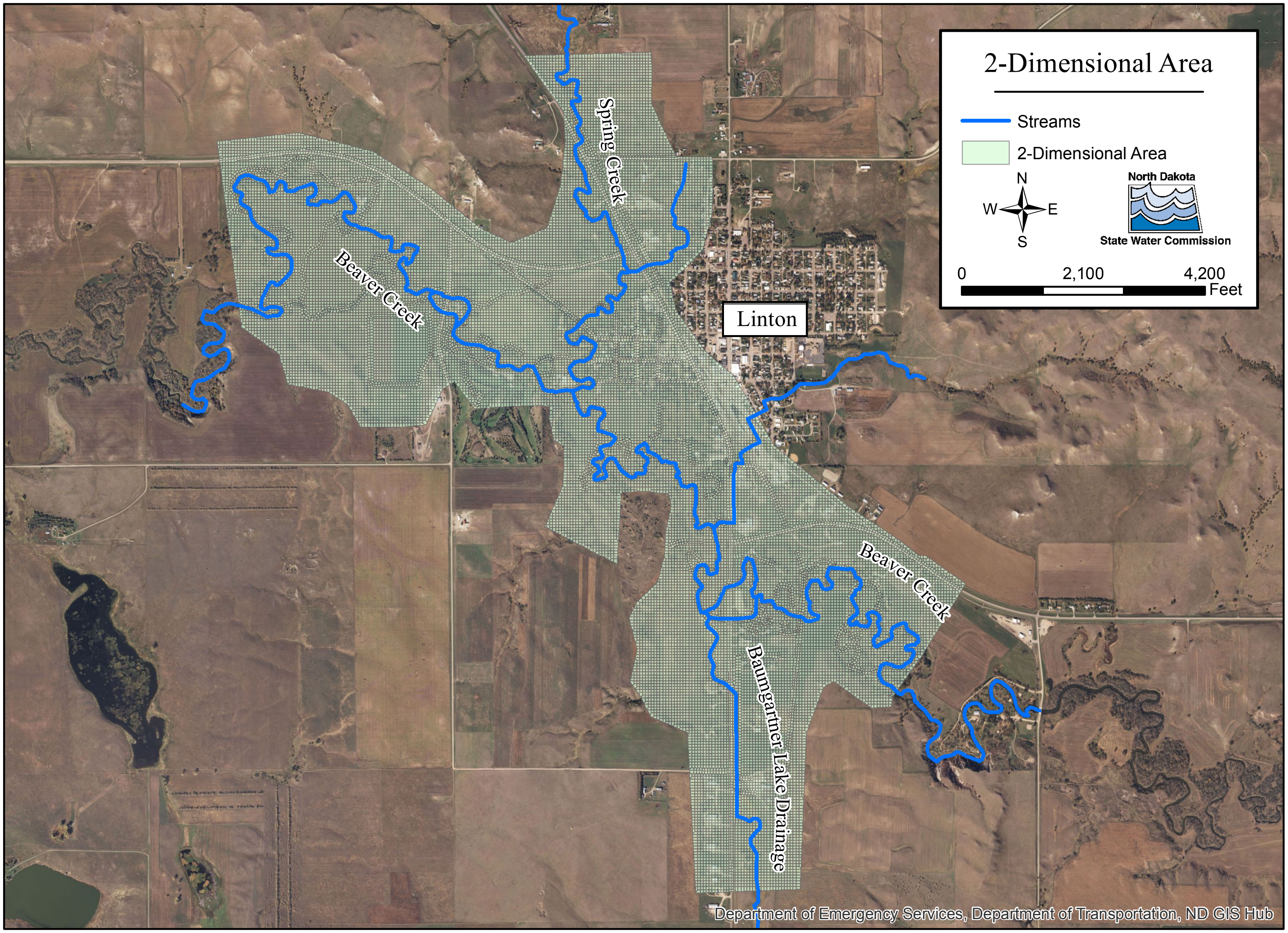

Figure 5. *2-Dimensional Area.*

The roughness coefficients for this model were based on field reconnaissance, photos of the area, the National Land Cover Dataset, and existing studies. **Table 1** shows the Manning's "n" values used prior to model calibration.

Table 1. *Manning's Roughness Coefficients.*

Land Type	Manning's Coefficient
Channel	0.055
Commercial Building	0.12
Light Residential	0.1
Medium Residential	0.14
Trees	0.07
Base Land Cover	0.055

2-Dimensional modeling in HEC-RAS does not support bridge flow. Consequently, any bridge crossing was input into the model as a series of culverts with the opening size equivalent to the bridge opening.

4. Calibration Events

Several events were used to calibrate and verify the hydraulic model. Spring snowmelt events most commonly bring Beaver Creek to flood stage. Local interests are extremely concerned about spring flooding such as the 2009 snowmelt event that caused large amounts of damage to an area of Linton commonly referred to as "Old Town". Calibration of the 2009 snowmelt event provides a large-scale event to calibrate to because it is the flood of record, with a peak flow of approximately 14,000 cfs.

The record at the Beaver Creek stream gage did not appear to contain any large events driven by rainfall. Two events, one in June 2013 and the other in June 2014, were the largest events to occur recently. The June 2013 model had a peak streamflow of approximately 1,600 cfs, and the June 2014 rainfall had a peak streamflow of nearly 1,100 cfs. The stream gage did not appear to capture the entire 2014, event and only one point on the hydrograph was recorded. For this reason, only the 2013 event was used to calibrate the model.

4.1 2009 Snowmelt Event

In late March, a series of extremely wet snowfalls along with a large temperature spike caused flooding along Beaver Creek. Overland flow from Beaver Creek and Spring Creek moved through Linton causing a large amount of damage to area homes and businesses. After the flood, several properties were purchased using federal disaster funds and some homes are still vacant today.

The USGS stream gage on the downstream end of town along with high-water marks surveyed after the flood provided a detailed account of what happened during the flood. This large event was the first event used to calibrate the hydraulic model.

Inflows for the 2009 snowmelt event were obtained from the hydrologic model developed as part of this study for Beaver Creek, Spring Creek, and Baumgartner Lake Drainage. **Figure 6** shows the inflow hydrographs for the 2009 snowmelt event. The normal depth downstream boundary condition was set to 0.0009 ft/ft, the slope of the bottom channel.

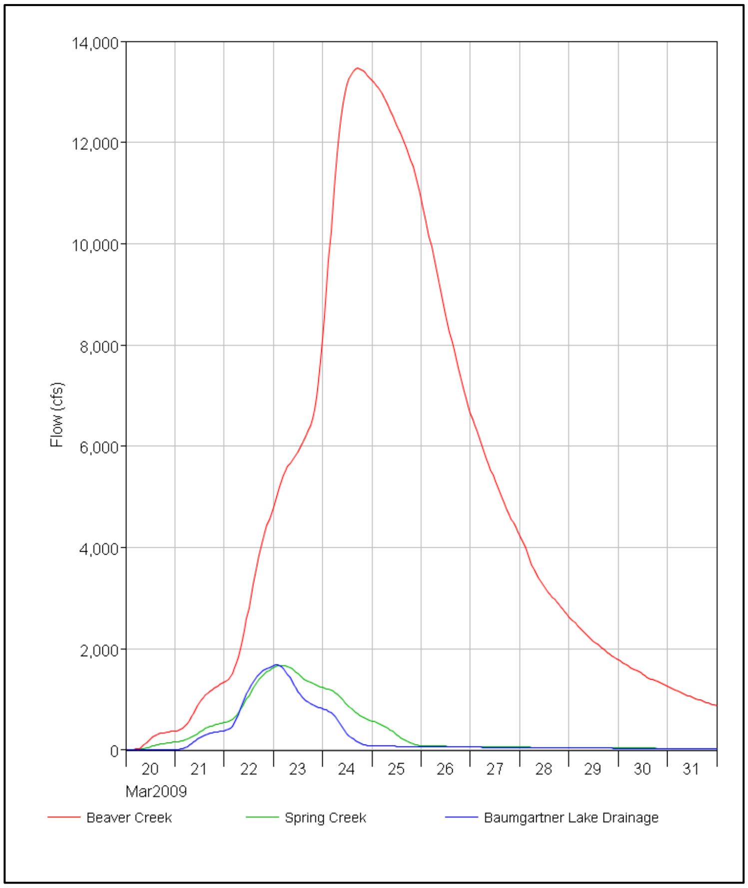

Figure 6. *2009 Snowmelt - Inflow Hydrographs.*

The model was then calibrated to the USGS stream gage and the surveyed high-water marks (**Figure 7**) by changing the Manning's roughness values. In order to properly meet the high-water marks and the gage, the channel roughness value was raised from 0.055 to 0.09. This value represents an ice-affected channel, as the creeks were during the event.

Ideally, high-water marks are considered to be calibrated if the modeled water surface fall within +/- one foot of the observed water surface, but during the calibration process it was clear that some high-water marks did not have that level of accuracy. The majority of high-water marks within Old Town were calibrated within one foot, except one outlier. High-water marks near the USGS stream gage were calibrated within +/- six inches. **Figure 7** and **Table 2** show the difference between modeled and observed water surface elevations at the high-water marks.

Water surface profiles were then plotted along the creeks from the modeled upstream end of Beaver Creek to the Spring Creek confluence (**Figure 8**), from the Spring Creek Confluence to the end of the model on Beaver Creek (**Figure 9**), and from the modeled upstream end of Spring Creek to its confluence with Beaver Creek (**Figure 10**). The terrain in each of the profiles does not follow the thalweg due to the lack of accuracy in digitizing tools, but it provides an estimate of the channel profile along each reach.

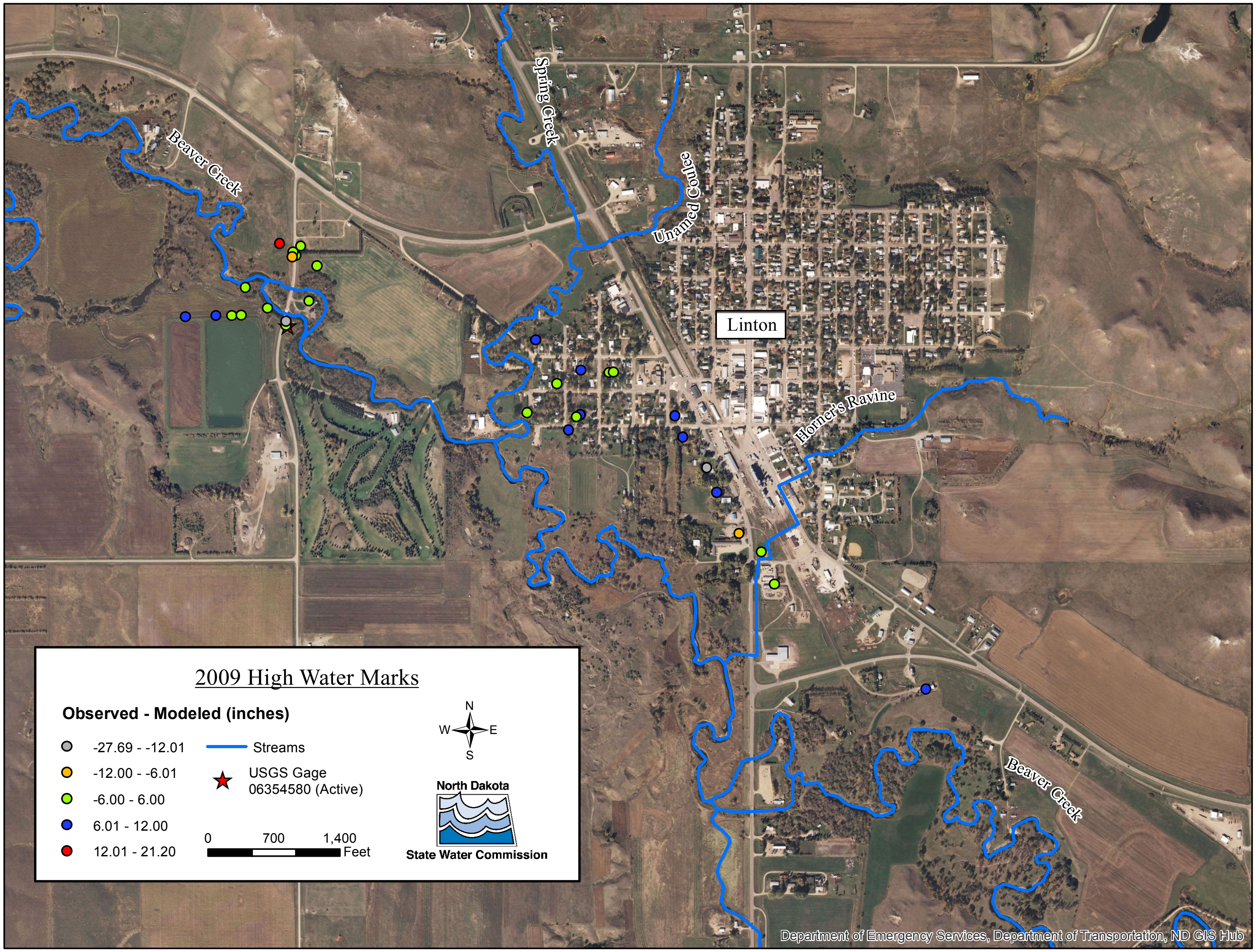

Figure 7. *2009 High Water Marks.*

Table 2. *2009 High Water Marks.*

Survey Note	Surveyed Water Surface Elevation (ft)	Modeled Water Surface Elevation (ft)	Difference (inches)
HWM LAWLER SHED GOOD	1,706.19	1,706.14	0.55
HWM 100 7TH HOUSE GOOD	1,706.65	1,706.20	5.45
HWM ABEL SHED	1,707.17	1,706.38	9.51
HWM ABEL TRAILERHOUSE GOOD	1,706.69	1,706.38	3.78
HWM GAGE HOUSE	1,703.17	1,702.93	2.83
HWM DEBRI LINE	1,701.38	1,702.57	-14.30
HWM PIN FLAG	1,702.77	1,702.67	1.15
HWM PIN FLAG	1,702.80	1,702.73	0.84
HWM PIN FLAG	1,702.86	1,702.64	2.64
HWM PIN FLAG	1,702.89	1,702.68	2.52
HWM PIN FLAG	1,702.83	1,701.06	21.20
HWM HOUSE	1,703.05	1,702.90	1.79
HWM NELSON HOUSE FAIR	1,707.93	1,707.43	6.02
HWM STOPPLER SHED FAIR	1,708.14	1,707.46	8.16
HWM HOUSE 621 GOOD	1,706.96	1,706.35	7.30
HWM SHED 724SCHLEY GOOD	1,706.82	1,705.90	11.02
HWM SHED 611 SCHLEY GOOD	1,706.83	1,706.28	6.62
HWM SHED 517 SCHLEY FAIR	1,706.06	1,706.35	-3.43
HWM SHED 513 SCHLEY POOR	1,706.83	1,706.35	5.80
HWM TRUCK FAIR	1,709.28	1,709.31	-0.37
HWM SHED POOR	1,709.87	1,710.08	-2.49
HWM GAS STATION POOR	1,708.23	1,708.97	-8.89
HWM DEBRIS LINE POOR	1,700.15	1,700.32	-2.03
HWM DEBRIS LINE POOR	1,699.63	1,699.94	-3.69
HWM DEBRIS LINE GOOD	1,699.12	1,698.34	9.41
HWM DEBRIS LINE GOOD	1,700.36	1,699.67	8.28
HWM DEBRIS LINE GOOD	1,699.89	1,700.08	-2.30
HWM DEBRIS LINE POOR	1,701.52	1,701.27	2.97
HWM DEBRIS LINE POOR	1,700.43	1,701.03	-7.20
HWM SHED 244 ST PAUL GOOD	1,708.52	1,707.74	9.35
HWM SHED 234 ST PAUL FAIR	1,705.26	1,707.57	-27.69
HWM HOUSE 742 HWY 13 ANECDOTAL	1,714.92	1,713.92	12.00

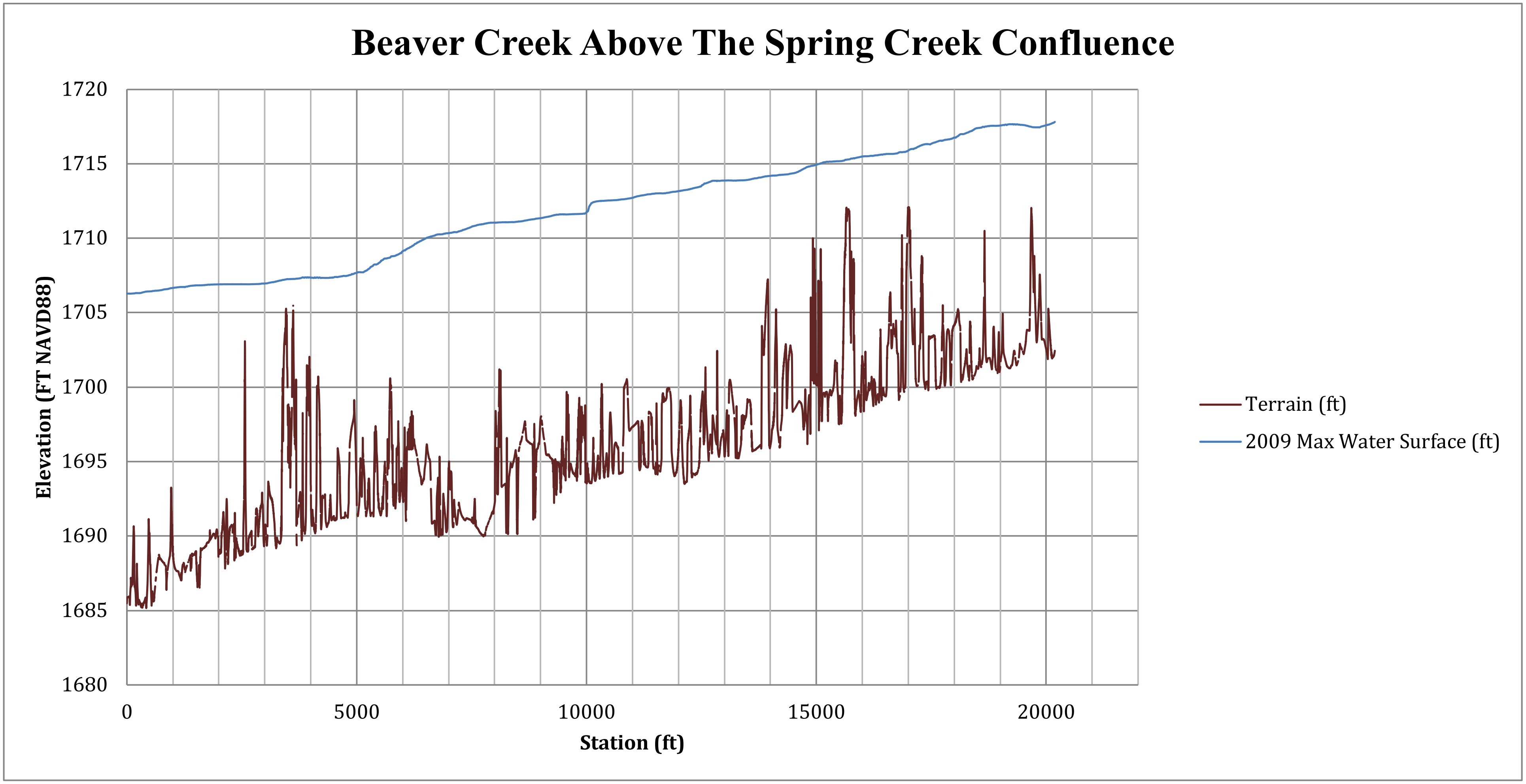

Figure 8. *2009 Max Water Surface Profile - Beaver Creek Above the Spring Creek Confluence.*

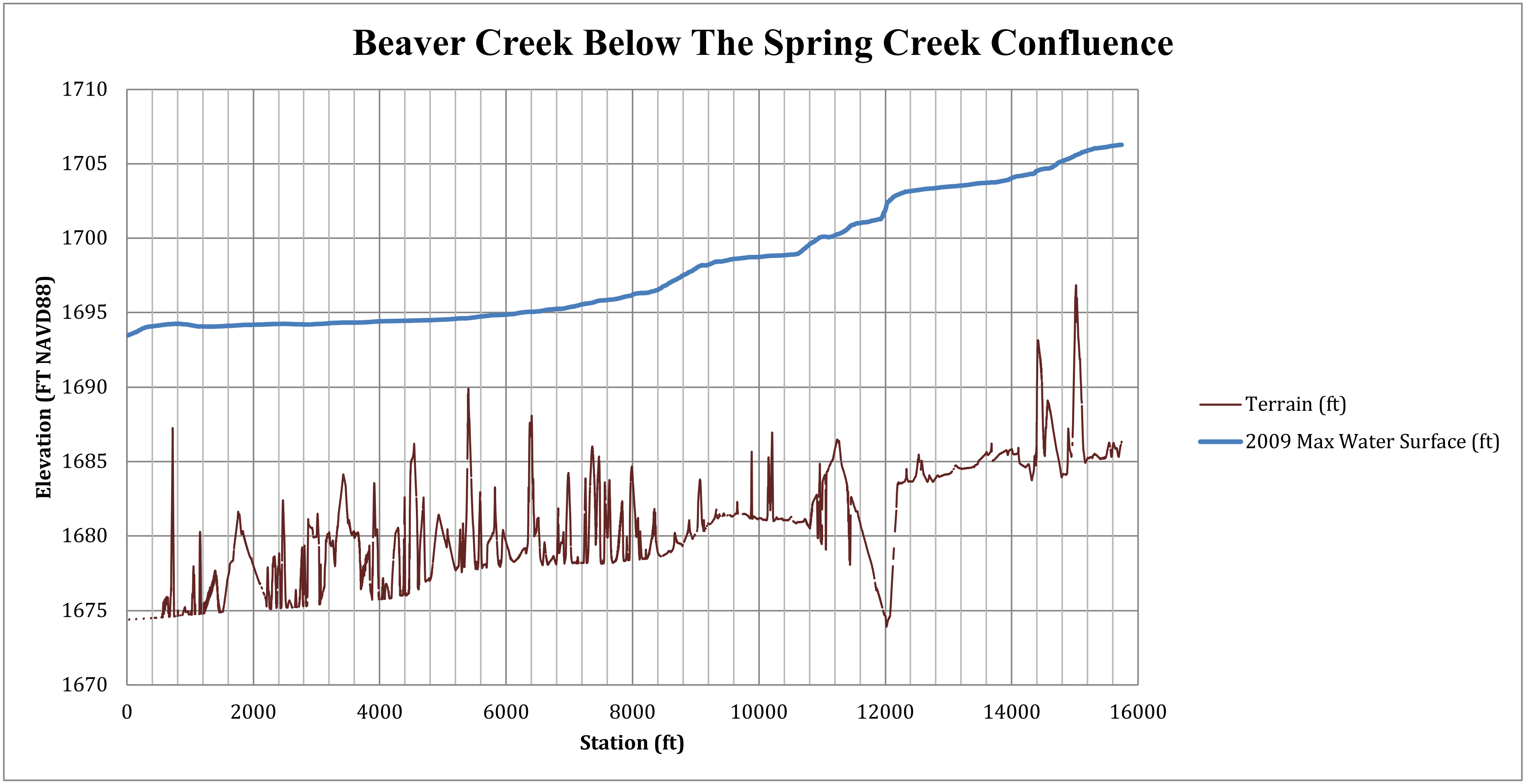

Figure 9. *2009 Max Water Surface Profile - Beaver Creek Below the Spring Creek Confluence.*

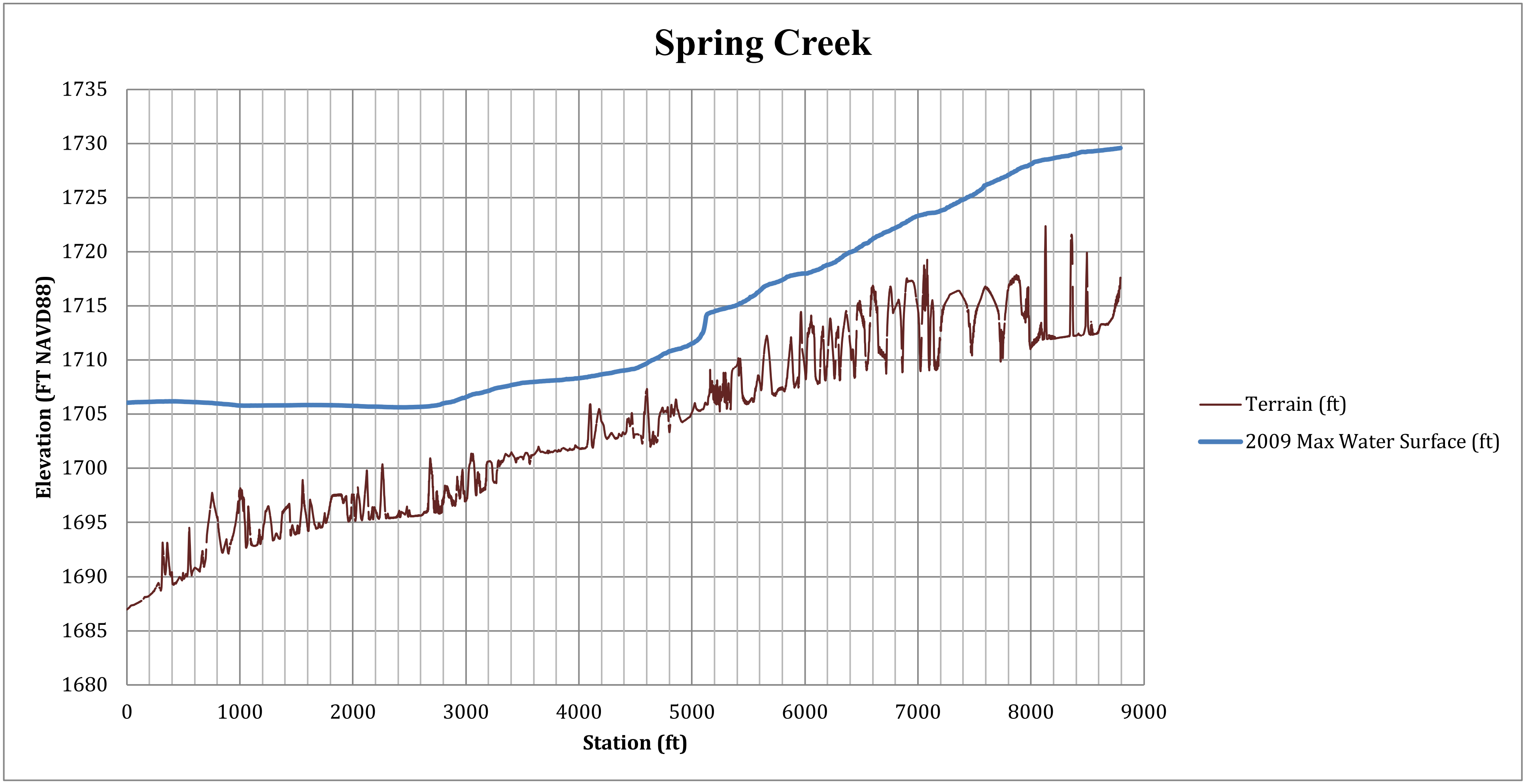

Figure 10. *2009 Max Water Surface Profile - Spring Creek.*

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The recorded average daily flow hydrograph at the USGS stream gage was then compared to the modeled gage location (**Figure 11**). The USGS estimated the peak flow for the 2009 event at 14,000 cfs on March 24th. **Figure 12** shows the modeled inundation of the 2009 event. **Figure 12** shows a small amount of inundation within the city's lagoon system, which did not occur in 2009. The inundation is likely caused by a small leak in the 2-dimensional mesh, which would not account for enough volume to significantly impact modeled results.

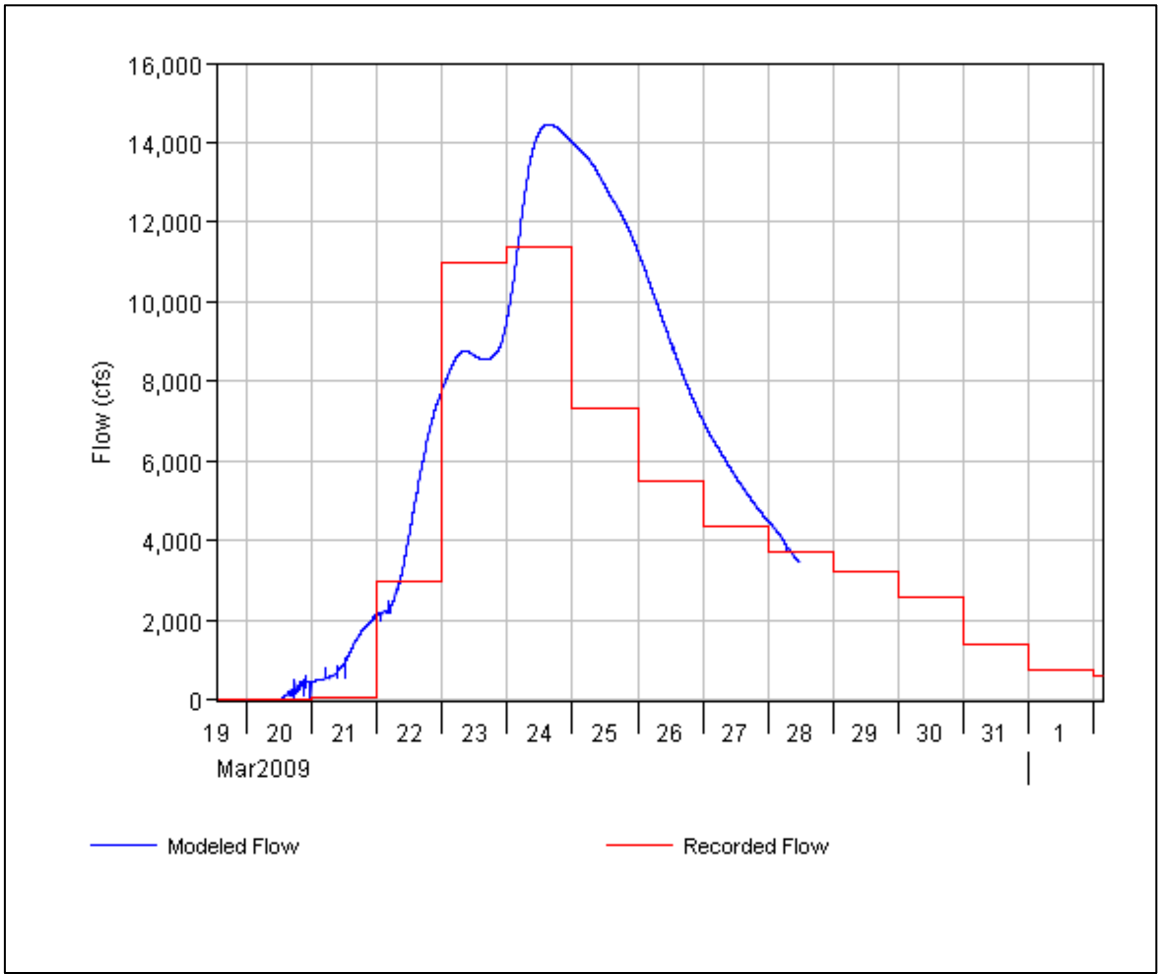

Figure 11. *2009 Hydrograph Comparison.*

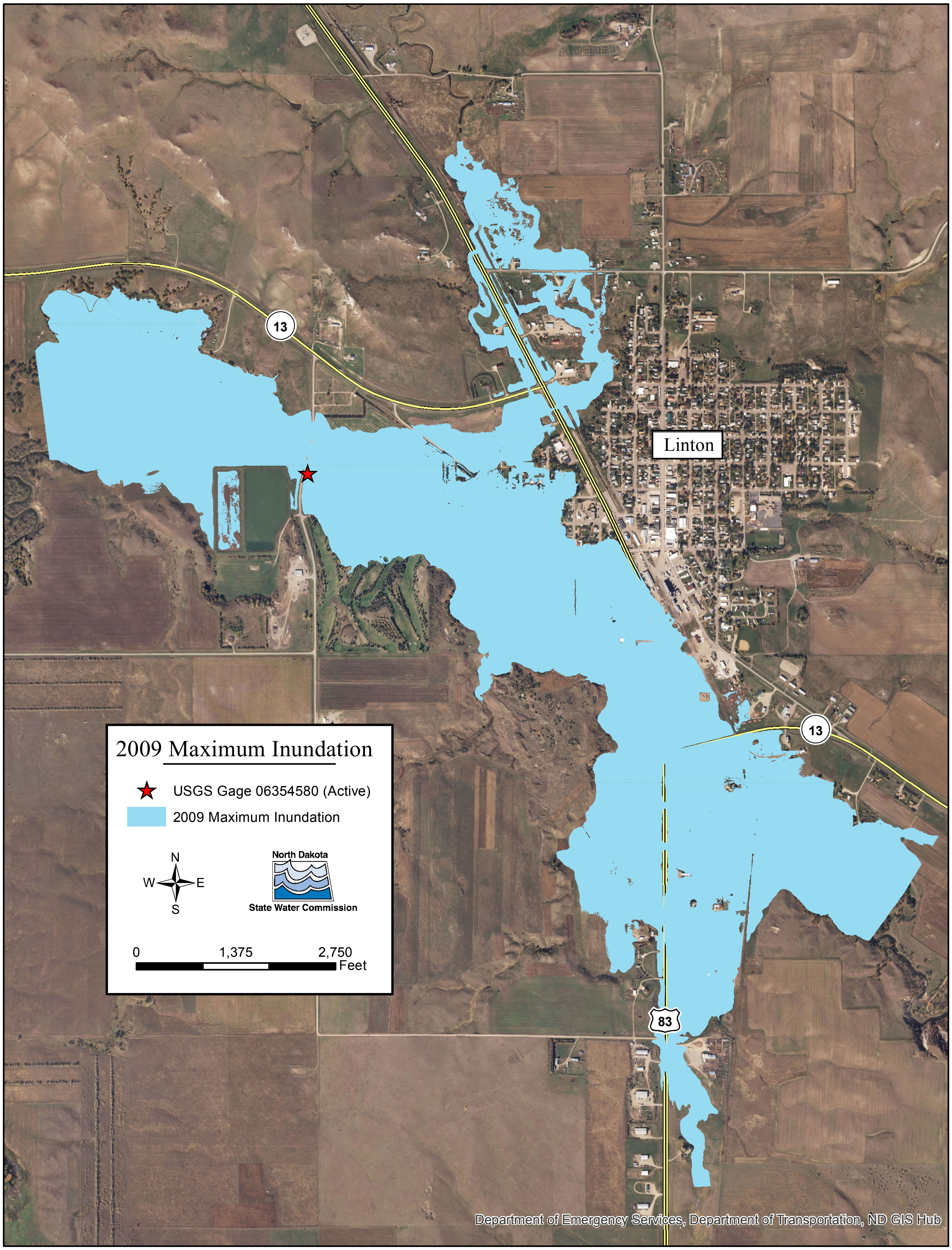

***Figure 12.** 2009 Inundation.*

4.2 2013 Rainfall Event

The 2013 event was a widespread rainfall event that covered most of the Beaver Creek Basin, with more falling on the Clear Creek Basin (see hydrologic report). Inflows for the 2013 rainfall event were obtained from the hydrologic model developed as part of this study for Beaver Creek, Spring Creek, and Baumgartner Lake Drainage. **Figure 13** shows the inflow hydrographs for the 2013 rainfall event. The normal depth downstream boundary condition was set to 0.0009 ft/ft, the slope of the bottom channel. **Figure 14** is a comparison of the modeled water surface elevation at the USGS gage compared to the observed event. No high-water marks were obtained after the 2013 rainfall event, so only the USGS gage was used in calibration. The channel Manning's roughness coefficient was decreased to 0.02 to calibrate the 2013 event. Calibration of this event was not as accurate due to a variety of model limitations. The current version of HEC-RAS does not readily allow the modeling of bridges within a 2-dimensional area. The bridges can be represented by box culverts with 2-dimensional connections. The calibration of the channel may be impacted due to the box culvert bridges being too effective in limiting channel flow. Since the USGS gage is located upstream of the bridge, this backwater effect is shown at the gage. **Figure 15** shows the modeled inundation of the 2013 event.

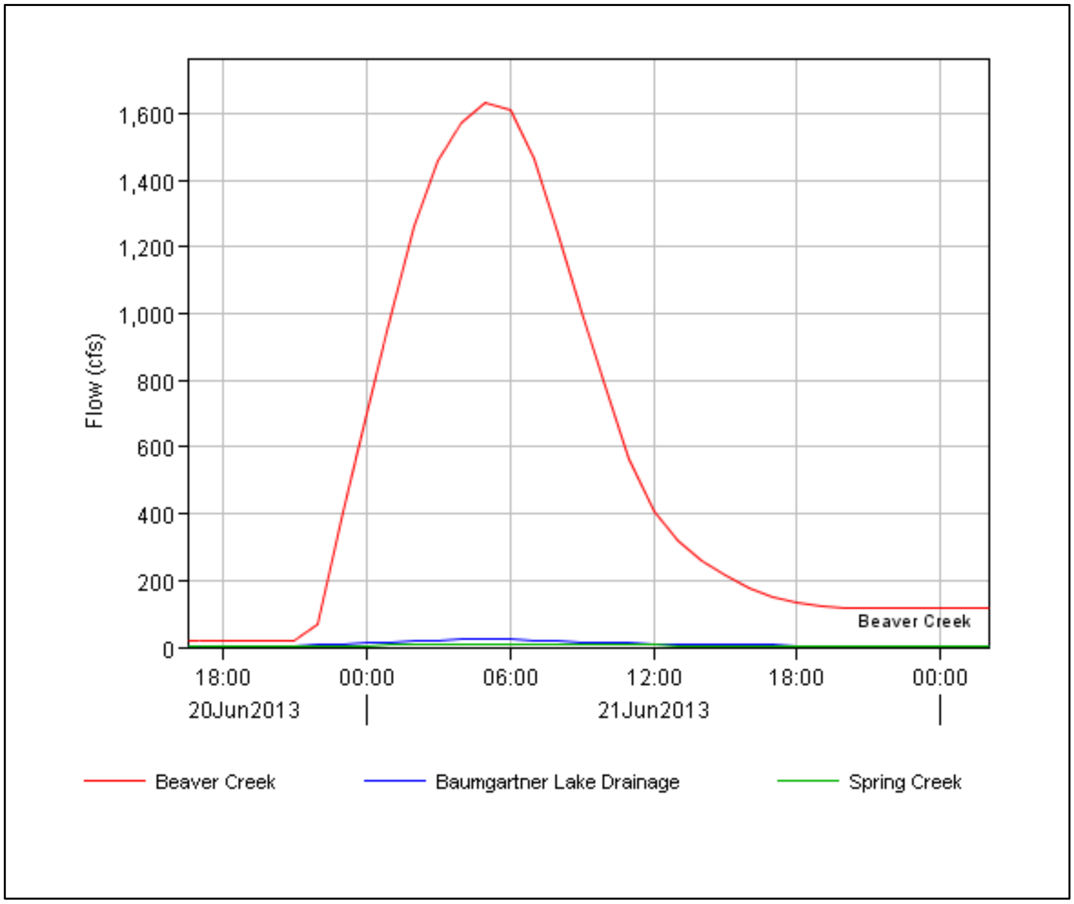

Figure 13. *2013 Rainfall - Inflow Hydrographs.*

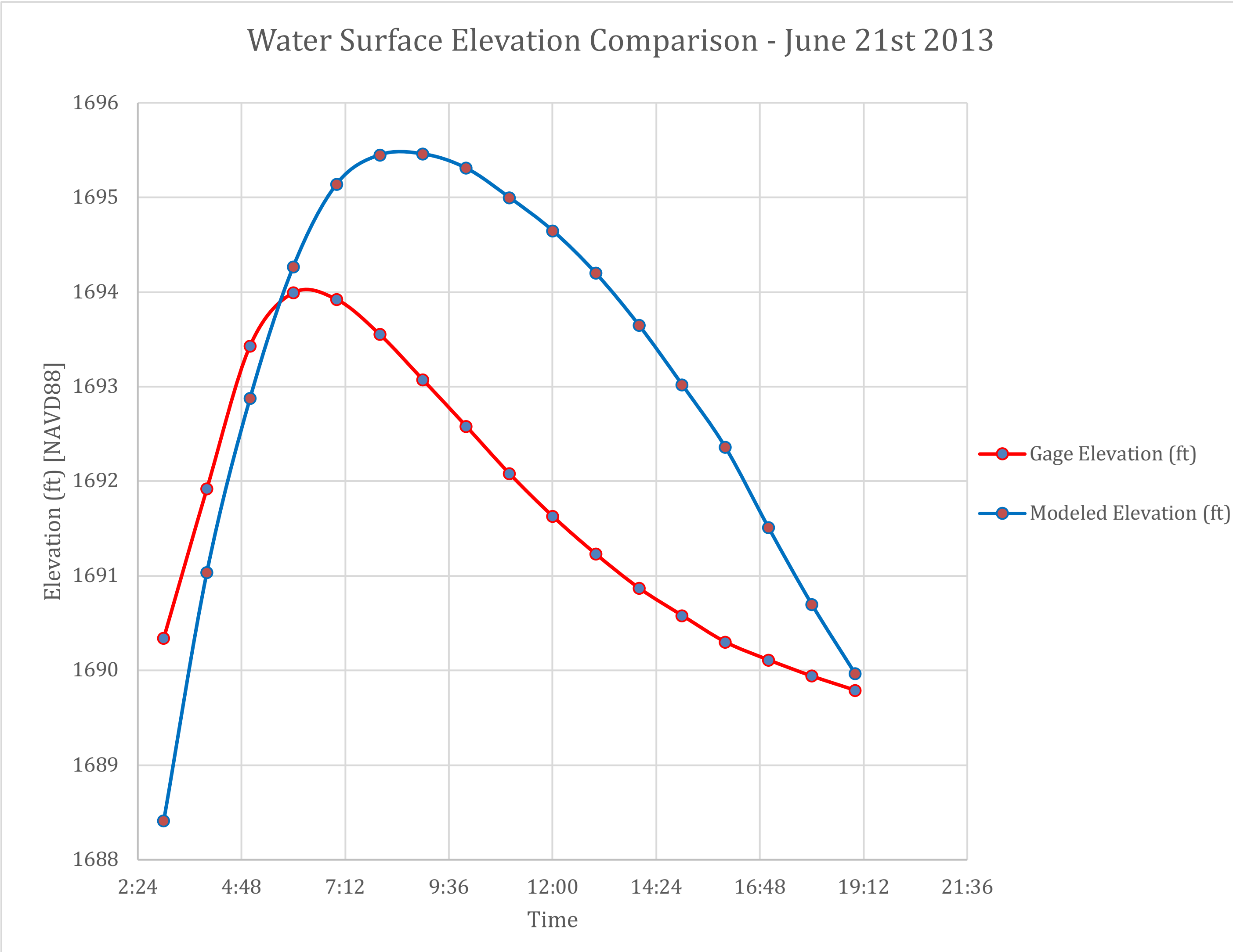

Figure 14. *2013 Hydrograph Comparison.*

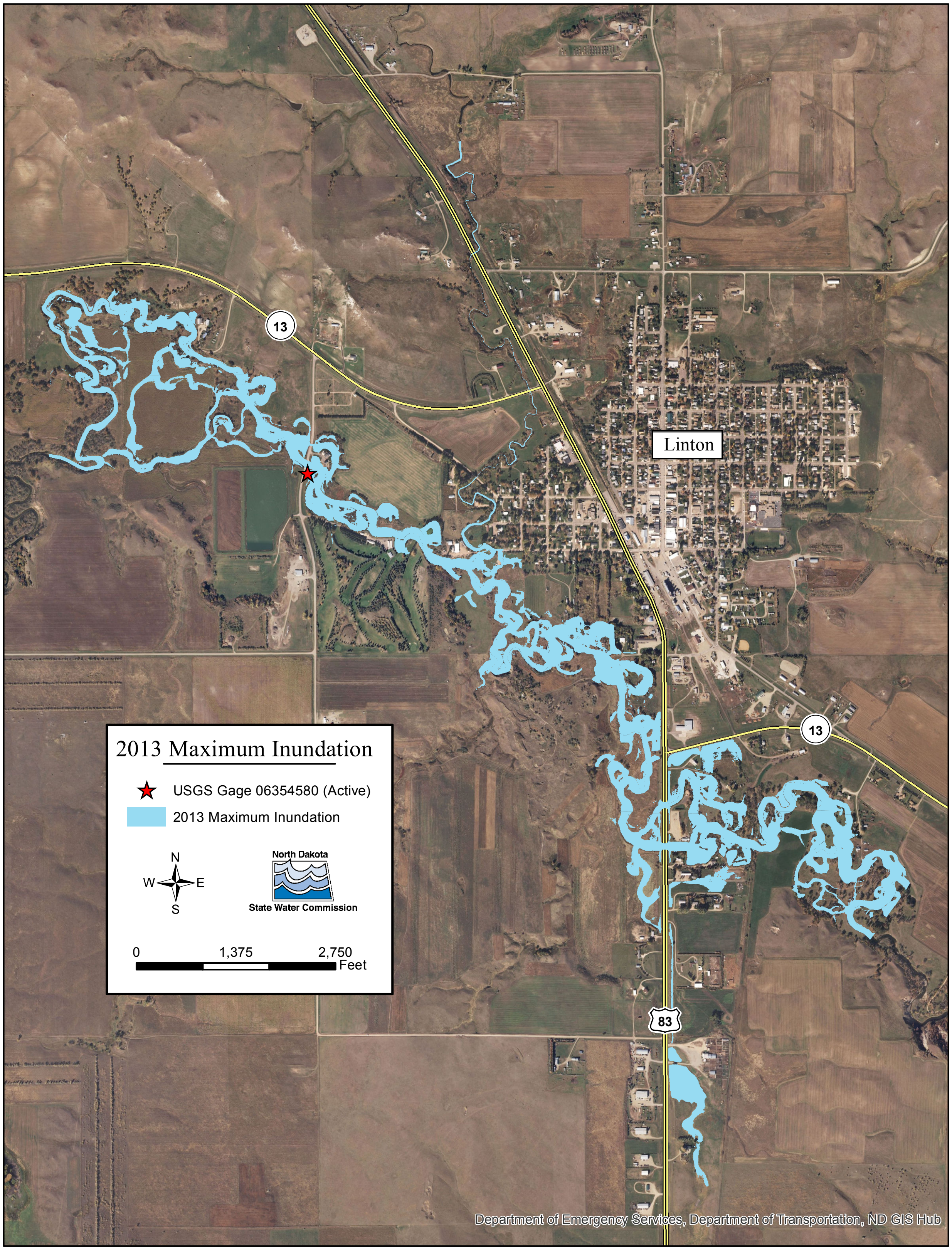

Figure 15. *2013 Inundation.*

4.3 Model Limitations

The model predicts higher water surface elevations during low flow events. Any in-bank event may not produce representative water surface elevations due to conveyance issues that could be caused by the bridges being modeled as culverts. The model does however accurately reproduce the 2009 event which is the largest event on record and the reason for this study.

The model also appears to have random velocity hot spots for solitary time steps and cells throughout the various model runs. These velocity hot spots all appear to occur during initial wetting of the cells and do not last longer than one-time step. This is a small limitation, as the hot spots do not appear to have any effect on the surrounding water surface.

5. Frequency Events

Frequency events for the Beaver Creek Hydraulic Model at Linton were simulated using flows from the Beaver Creek Hydrologic Model that were developed as part of the study. Inflows for the frequency event were assumed to be equal to the event being analyzed. For instance, to analyze a 100-year event, 100-year inflow hydrographs for Beaver Creek, Spring Creek, and Baumgartner Lake were utilized from the hydrologic model. This approach may produce higher flows at the USGS stream gage, but is a conservative estimate when designing flood mitigation works. **Table 3** and **Figure 16** provides a comparison between frequency event peak flows computed by the hydrologic model, hydraulic model, and regression analysis at the location of the USGS stream gage. The frequency flows utilized from the hydrologic model varied at the USGS stream gage location in the hydraulic model due to the routing in the hydraulic model having greater detail of the region’s physical characteristics.

Table 3. *Frequency Events Peak Flow Comparison at USGS Stream Gage.*

Frequency Event	Regression Peak Flow (cfs)	Hydrologic Model Peak Flow (cfs)	Hydraulic Model Peak Flow (cfs)	Percent Difference Between Regression and Hydraulic Model	Percent Difference Between Models
500-YR	32,531	30,446	31,422	-3.41%	3.21%
200-YR	23,265	24,403	26,571	14.21%	8.88%
100-YR	17,534	20,224	22,277	27.05%	10.15%
50-YR	12,792	16,305	18,361	43.54%	12.61%
25-YR	8,938	8,445	9,666	8.14%	14.46%
10-YR	5,047	5,190	5,211	3.25%	0.40%
5-YR	2,898	2,383	2,328	-19.67%	-2.31%
2-YR	953	898	773	-18.89%	-13.92%

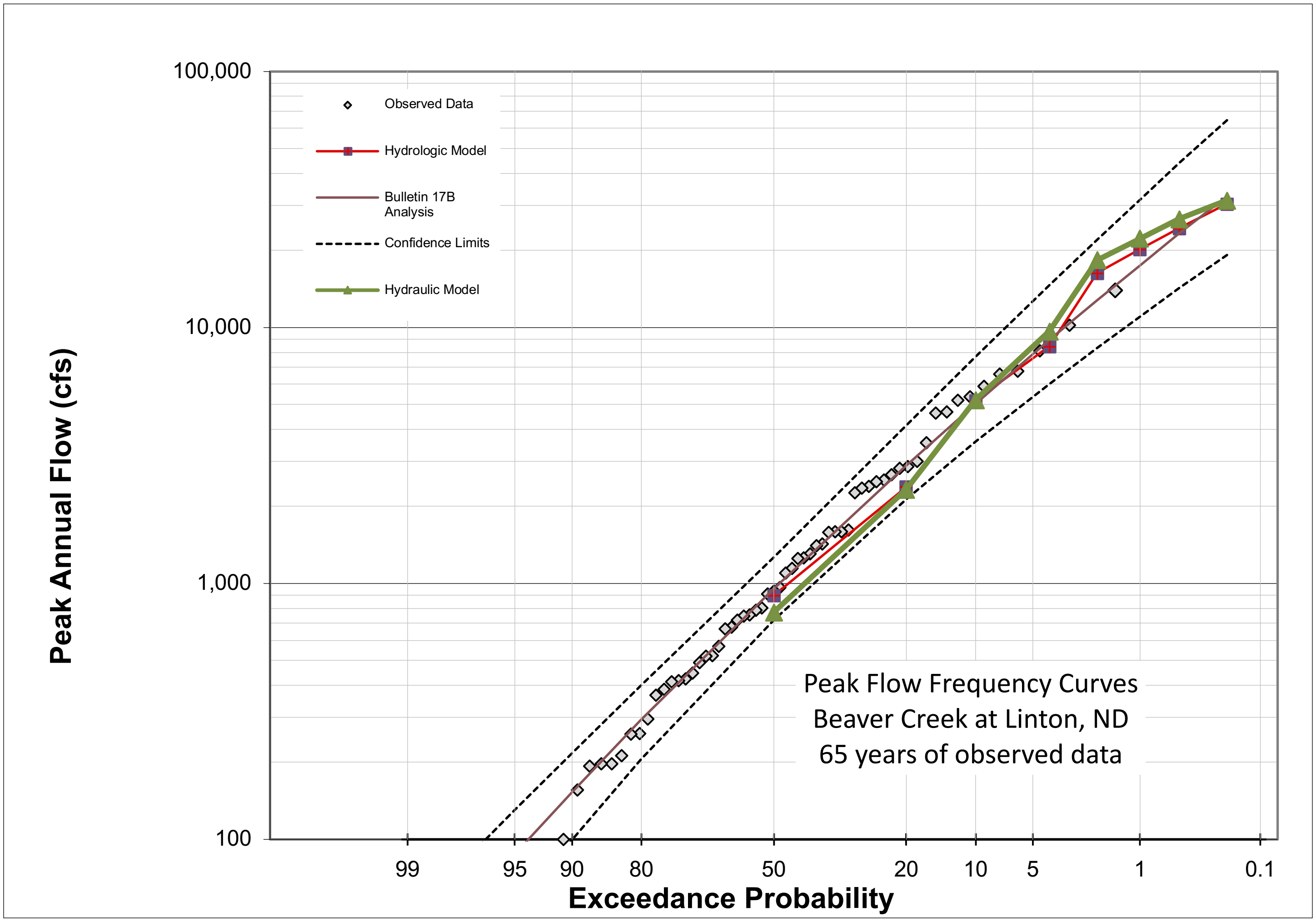

Figure 16. *Frequency Event Peak Flow Comparison at USGS Stream Gage.*

The analyzed frequency events in the hydraulic model can be utilized to determine flood mitigation alternatives as well as cost benefit ratios for alternatives. The calibration and verification of the hydraulic model help verify the model's ability to predict stage caused by certain events and provide confidence in modeled frequency events. **Figure 17** illustrates the maximum water surface elevation for each frequency event computed in the hydraulic model at the location of the USGS stream gage. The lower level frequency events were run using the channel Manning's coefficients from calibration of the 2013 event (0.02 – referred to as "Low Manning's" in figures) and 2009 event (0.09). **Figure 18** provides an inundation comparison of several of the modeled frequency events.

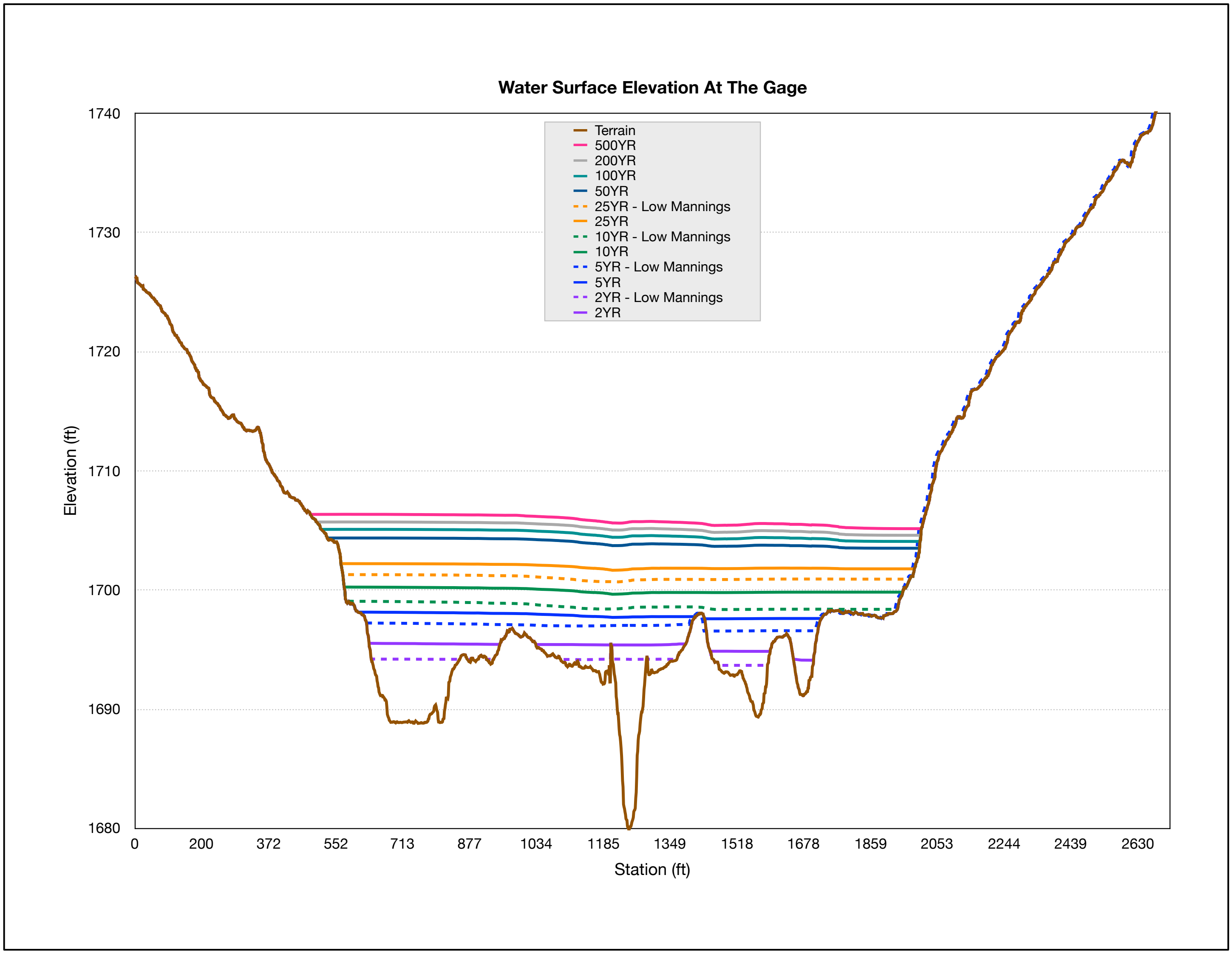

Figure 17. *Frequency Events Maximum Water Surface Elevation at The USGS Stream Gage.*

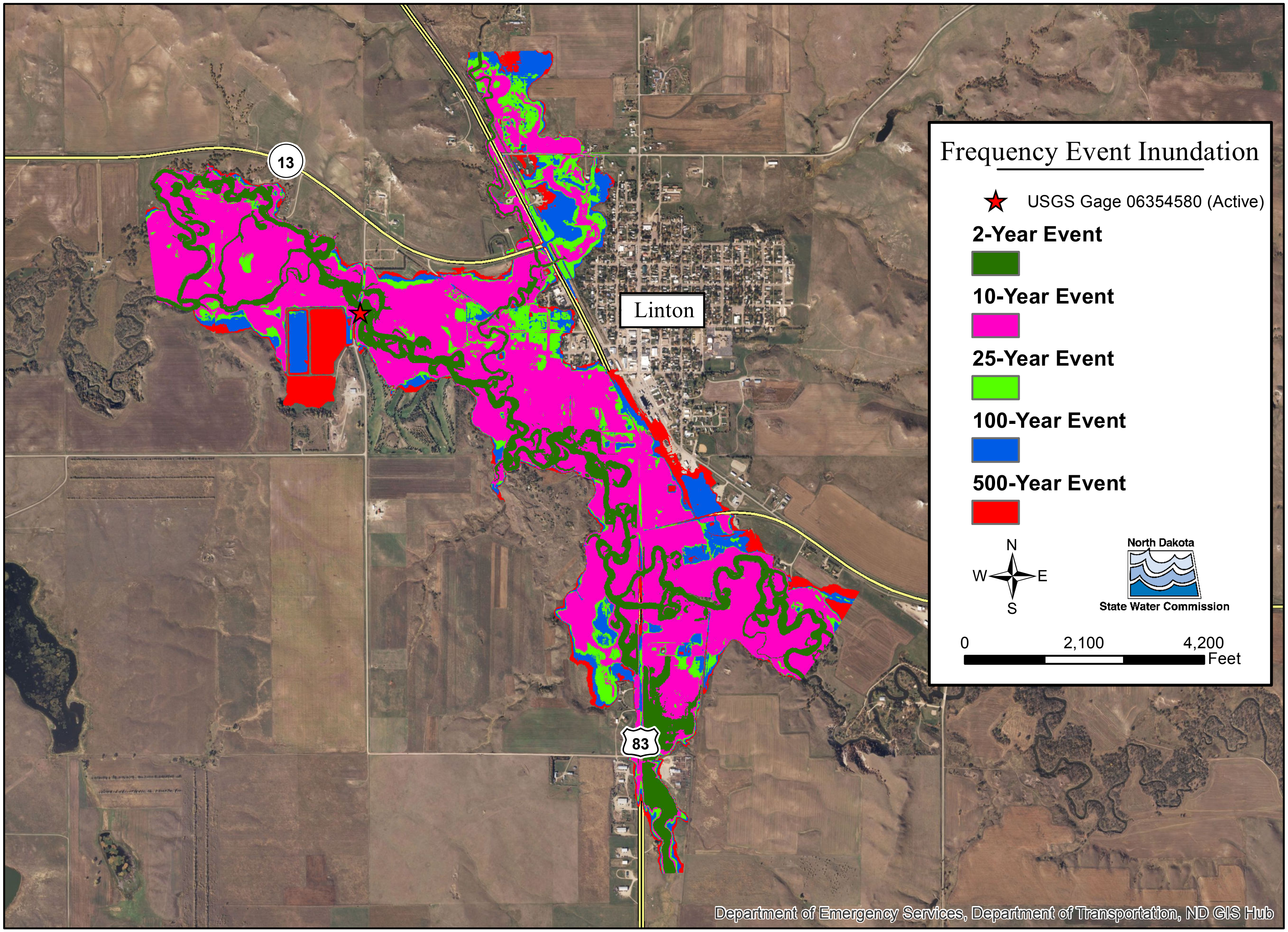

Figure 18. *Frequency Event Inundation*

6. Summary

This report documents the creation and calibration of a hydraulic model for Beaver Creek at Linton, ND. The model was created as part of a Section 22 Planning Assistance to States study between the Omaha District and the Board, and pursuant to an investigation agreement between the Board and the NDSWC. The model predicts higher water surface elevations during low flow events. Any in-bank event may not produce representative water surface elevations due to conveyance issues that could be caused by the bridges being modeled as culverts, which is a limitation of the model used to complete the study. The model does however accurately reproduce the 2009 event, which is the largest event on record and the reason for this study. The model provides a platform to investigate flood risk management alternatives for the City of Linton, ND.

7. References

Hydrologic Engineering Center, 2013. River Analysis System HEC-RAS, User's Manual, Version 5.0.3, U.S. Army Corps of Engineers, Davis CA.

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