Section 4
Hydraulic Model Development

4.1 Introduction
The Hydraulic Investigation presents a description of the methodology used to create and calibrate the hydraulic model for the Little Salt Creek watershed. The streams located within the Little Salt Creek watershed range from highly incised channels having moderate degrees of meandering, mild slopes (approximately five feet per mile) and wide floodplains in the lower reaches; to large swales with moderately steep slopes (about 36 feet per mile) and overgrown in the upper stream reaches.

This section provides a brief description of the data and methodology used in creating the stream network and cross sectional geometries; the establishment of the hydraulic parameters assigned to the cross sections; the incorporation of field survey for roadway crossings; the special hydraulic situations encountered during the modeling process; the boundary conditions utilized; the calibration of the hydraulic model to gauge information; and the Floodway development.

The hydraulic modeling was performed using the USACE Hydrologic Engineering Center's River Analysis System (HEC-RAS) version 4.0. The following appendix sections provide detailed information on the hydraulic model data input and results:

- Appendix D – Hydraulic Model Input Data and Results
- Appendix M – Stream Profiles
- Appendix N – Hydraulic Structure Performance Data

4.2 HEC-RAS Model Development
The HEC-RAS data requirements are categorized into data sets as shown in Table 4-1. The model parameters were developed using a combination of manual procedures and automation tools within ArcGIS 9.2 and HEC-GeoRAS 4.2.92. All GIS datasets and files were created in Nebraska State Plane NAD83 projection.

Table 4.1 HEC-RAS Model Data Sets

HEC-RAS Model Parameter	Development Method	Data Requirements
Stream Network	ArcGIS and HEC-GeoRAS	Stream centerline shapefiles with unique stream reach names
Cross sections (river station and geometry data)	ArcGIS, HEC-GeoRAS, and field survey data	Digital elevation model (DEM), cross section cut line coverage
Channel bank stations	Manually input using engineering judgment	Cross section geometries
Manning's n values	Field visits and calibration	Field visit photos and aerial imagery
Downstream reach lengths (channel and overbanks)	ArcGIS and HEC-GeoRAS	Stream centerline and overbank flow path shapefiles
Roadway crossings	Manually input using field survey data	Roadway profile along with the structure opening
Ineffective flow areas	Manually input using standard procedures and engineering judgment	Cross section shapefiles and roadway crossing data
Expansion and contraction coefficients	Manually input using standard values	Cross section shapefiles
Normal depth boundary conditions	ArcGIS	Stream centerline and cross section shapefiles, contours
Known water surface boundary conditions	Referenced from the FIS Report for Salt Creek	Salt Creek FIS Report

4.2.1 Stream Network, Cross Sections, and Reach Lengths

The first step in developing the HEC-RAS model was to create a geometry file describing the stream network, junctions, cross section station and geometries, as well as the downstream reach lengths of the channel and overbanks for each cross section. The stream network defines the extent of the Little Salt Creek and all tributaries that collect runoff from contributing areas that are at least 150 acres. Junctions were used to note the locations where two or more streams come together or split apart. Each cross section station defines the location of the cross section along the respective stream as the distance in feet measured from its confluence. The cross section geometries are described by station and elevation points that portray the layout of the stream channel and floodplain. The downstream reach lengths of the channel define the distance to the next downstream cross section measured along the stream. The downstream reach lengths of the overbanks define the distance to the next downstream cross section measured along the path of the center of mass for the overbank flow.

The stream network, cross sections, and cross sectional characteristics were created using an automated process. This process was performed through the use of ArcGIS 9.2, as well as HEC-GeoRAS 4.2.92. These tools were used to create the physical layout of the modeled area that was imported directly into the HEC-RAS model. The data used to create the stream network, cross sections, and cross sectional characteristics of the modeled area are described in the following sections.

4.2.1.1 Digital Elevation Model (DEM)

As previously discussed in Section 2, multiple DEMs were used to create the three-dimensional surfaces of the Little Salt Creek watershed. Areas located south of Rock Creek Road were described using Light Detection and Ranging (LiDAR) made available by the City of Lincoln and Nebraska Department of Natural Resources (NDNR). These areas were described using a DEM with a grid cell size of two feet. A DEM containing a grid cell size of 10 meters was used to describe areas north of Rock Creek Road. The 10 meter DEM was also provided by the NDNR. The vertical datum referenced for the multiple DEMs was NAVD88. These DEMs were used in conjunction with a cross section cut line coverage to develop a series of station and elevation points for each cross section.

4.2.1.2 Stream Centerline Coverage

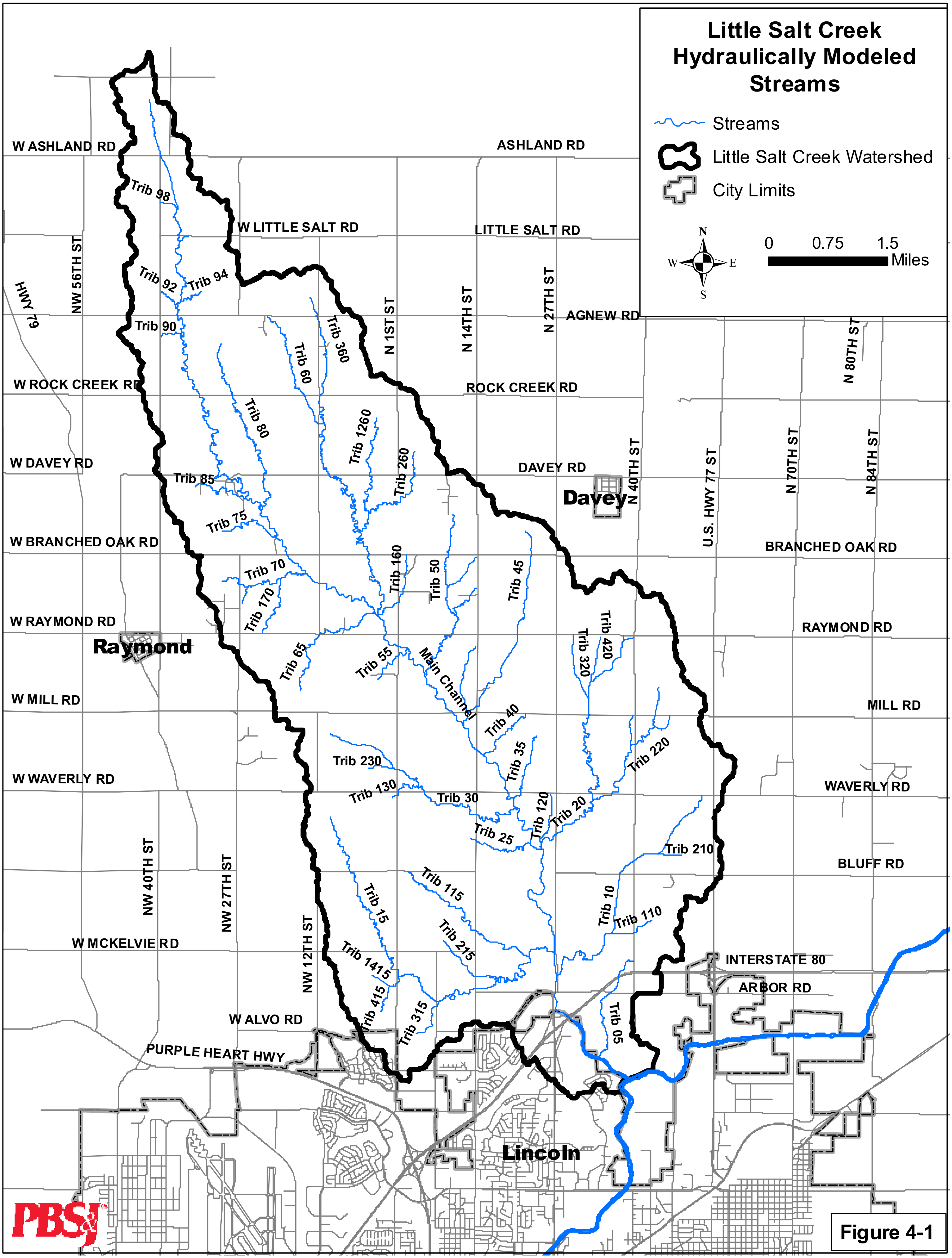
The stream centerline coverage was created in ArcGIS 9.2 using a series of aerial photographs as well as quad maps. The stream centerline coverage defines the Little Salt Creek stream network which includes the Little Salt Creek and all tributaries that collect runoff from drainage areas that are at least 150 acres. Overall a total of 86 miles encompass the 47 modeled streams that are modeled within the Little Salt Creek watershed. Figure 4-1 displays the modeled stream network.

4.2.1.3 Stream Junction Data

In order to simulate the entire Little Salt Creek watershed stream network in one model, the use of multiple stream junctions was needed. A stream junction is required at any location where two or more streams come together or where flow from a single stream splits apart. The only required junction data entered into the HEC-RAS model is the stream length across the junction between the two bounding cross sections. This length was automatically calculated within HEC Geo-RAS and confirmed manually.

4.2.1.4 Cross Section Coverage

The cross section coverage identifies the location and extent of each cross section. The cross section coverage was generated in ArcGIS along with the aforementioned HEC-GeoRAS extension. Cross section locations were placed along each stream at control points and locations that represent the average geometry of the stream. The control points of the stream are locations where there are abrupt changes in channel or floodplain geometry, slope, and discharge. Available aerial photography and contour information were utilized in the layout of the cross sections. An effort was made to limit the distance between cross sections to a maximum of 500 feet. However, cross sections that were located at structures and control points were placed with less distance between each other to capture the more rapidly changing flow characteristics. Each cross section is labeled with a river station, stream name, and reach name. The river station for each cross section is the cumulative distance in feet measured from the respective stream's confluence.



Little Salt Creek Hydraulically Modeled Streams
Streams
Little Salt Creek Watershed
City Limits
N
S
E
W
0
0.75
1.5
Miles
W ASHLAND RD
ASHLAND RD
W LITTLE SALT RD
LITTLE SALT RD
AGNEW RD
W ROCK CREEK RD
ROCK CREEK RD
W DAVEY RD
DAVEY RD
Davey
W BRANCHED OAK RD
BRANCHED OAK RD
W RAYMOND RD
RAYMOND RD
Raymond
W MILL RD
MILL RD
W WAVERLY RD
WAVERLY RD
BLUFF RD
W MCKELVIE RD
INTERSTATE 80
ARBOR RD
W ALVO RD
PURPLE HEART HWY
Lincoln
HWY 79
NW 56TH ST
N 1ST ST
N 14TH ST
N 27TH ST
N 40TH ST
U.S. HWY 77 ST
N 70TH ST
N 80TH ST
N 84TH ST
NW 40TH ST
NW 27TH ST
NW 12TH ST
Trib 98
Trib 92
Trib 94
Trib 90
Trib 360
Trib 60
Trib 80
Trib 1260
Trib 260
Trib 85
Trib 75
Trib 70
Trib 170
Trib 160
Trib 50
Trib 45
Trib 65
Trib 55
Main Channel
Trib 420
Trib 320
Trib 40
Trib 35
Trib 220
Trib 230
Trib 130
Trib 30
Trib 120
Trib 20
Trib 25
Trib 210
Trib 115
Trib 15
Trib 10
Trib 110
Trib 215
Trib 1415
Trib 415
Trib 315
Trib 05
PBSJ

Figure 4-1

4.2.1.5 Overbank Flow Path Coverage

The overbank flow path coverage was created in GIS and represents the distance to the next downstream cross section measured along the path of the center of mass for the overbank flow. The flow path coverage was used to determine the downstream reach lengths for the left and right overbanks. When creating the flow path coverage, the location of each flow path was approximated based upon the estimated width of the local floodplain.

4.2.2 Manning's n-Values

The Manning's n-value was used to help calculate the energy losses between cross sections due to friction. The Manning's n-value depends on a number of factors which include: surface roughness; vegetation; channel irregularities; degree of meander; obstructions; size and shape of the channel. For the present study, each reach was assigned Manning's n-values for the channel and overbank flow areas. The Manning's n-values were estimated using field and aerial photography. The range of Manning's n-values used with the Little Salt Creek hydraulic analysis along with the description of land surface can be found in Table 4-2. The assigned Manning's n-values were validated through the calibration of the model. The calibration process is further described in Section 4.5 of this report.

Table 4.2 Range of Manning's n-values utilized

Channel Description	Range of Manning's n-Values
Relatively clean, slight meanders, incised	0.025 - 0.033
Relatively clean, appreciable meanders, deep	0.033 - 0.045
Heavier vegetation, irregular, shallow	0.050 - 0.080
Floodplain Description	
Light brush and some trees	0.040 - 0.080
Medium to dense brush and trees	0.045 - 0.110

4.2.3 Roadway Crossings

Bridge and culvert openings along with roadway profiles were developed using data collected during field surveys. A total of 81 hydraulic structures were surveyed using a combination of a Global Positioning System (GPS) and total station technology to obtain the required elevations. All survey information references NAVD88 and can be found in Appendix F and the data CD previously mentioned in Section 2. Field survey data for bridges included measurements such as span widths, pier count and dimensions, bridge deck profile and width, as well as station and elevation points used to describe the channel. The survey data used to describe culverts included culvert type and geometry, upstream and downstream inverts, as well as roadway profile and width. All of the surveyed information was manually entered into the HEC-RAS model. For instances where the surveyed channel geometry or roadway profile did not extend far enough horizontally to capture the extents of the overbank flow, LiDAR information was imported to supply the remainder of the required geometries.

4.2.4 Expansion and Contraction Coefficients

The contraction and expansion of flow due to changes in the cross sectional geometry is a typical cause for the loss of energy between two cross sections. To assist in computing this loss, HEC-RAS requires the user to define an expansion and contraction coefficient at each cross section. The expansion and contraction coefficients were estimated based on the ratio of the expansion and contraction of the effective flow area between two cross sections and are typical of values used in similar studies. The coefficients used in the present study are listed in Table 4-3.

Table 4.3 Contraction and expansion coefficients utilized

Transition Type	Contraction Coefficient	Expansion Coefficient
Gradual Transitions	0.1	0.3
Typical Conveyance Sections	0.3	0.5
Abrupt	0.6	0.8

4.2.5 Ineffective Flow Areas

Ineffective flow areas can be defined as areas of a cross section that provide little or no conveyance of flow in the downstream direction. In the present study, ineffective flow areas were utilized where the following instances occurred:

- Ineffective areas were initially placed within the bounding cross sections of all roadway crossings. Using expansion and contraction ratios of 2:1 and 1:1 (reach length: width) respectively, ineffective areas were calculated from the edges of the culvert or bridge opening. This process was carried through to the next upstream or downstream cross section until the flow was completely expanded. However, in the case of a roadway overtop, the downstream ineffective areas were established at the edge of the road overtop.
- Reaches experiencing drastic changes in floodplain width. The locations of these areas were set using the expansion and contraction ratios of 2:1 and 1:1, as well as engineering judgment.
- Floodplain areas located within cross sections that were not hydraulically connected to the upstream or downstream cross sections. The locations of such areas were determined using the cross sectional geometries as well as the available DEMs and contour data.

4.2.6 Boundary Conditions

When determining the downstream boundary condition for the Little Salt Creek hydraulic model, the affect that the Salt Creek has on the Little Salt Creek was considered. In the previous study performed in 2002 (*Lower Little Salt Creek Watershed – Interim Stormwater Hydrology and Hydraulic Report*) the downstream boundary condition correlating to the 1% frequency stage of the Salt Creek was utilized for the 1% frequency event of the Little Salt Creek. However, the two events involved are possibly not coincident with each other. The probability of the simultaneous occurrence that both the Salt Creek and the Little Salt Creek are experiencing a 1% stage at the confluence of these two creeks may be far less than the 1%. To provide a more reasonable estimate of coincident Salt Creek stage with a respective Little Salt Creek peak discharge-frequency, a Texas Department of Transportation (TXDOT) criterion for coincident occurrence at the confluence of two streams (shown in Table 4-4) was utilized (TXDOT, 2004). TXDOT obtained this criterion from the U.S. Army Corps of Engineers. The criterion assigns the coincident main stem or tributary frequency based on the ratio of the drainage areas of the streams. For this study, the ratio of the Salt Creek watershed area to Little Salt Creek watershed area is slightly greater than 15 to 1. Therefore, the Area Ratio of 10 to 1 was deemed the appropriate relationship to incorporate. Table 4-5 displays the coincident Salt Creek stage-frequency for the respective Little Salt Creek design storm. The 500-year Little Salt Creek coincident frequency was assumed (see Hydrologic Model Development Section 3 of this report). Note: The 100-yr backwater for Salt Creek was used for floodplain mapping per FEMA requirements.

Table 4.4 Frequencies for coincidental occurrence based upon the ratio of watershed sizes

Frequencies for Coincidental Occurrence						
Area Ratio	10 Year Design		50 Year Design		100 Year Design	
	Main Stream	Tributary	Main Stream	Tributary	Main Stream	Tributary
10,000 to 1	1	10	2	50	2	100
	10	1	50	2	100	2
1,000 to 1	2	10	5	50	10	100
	10	2	50	5	100	10
100 to 1	5	10	10	50	25	100
	10	5	50	10	100	25
10 to 1	10	10	25	50	50	100
	10	10	50	25	100	50
1 to 1	10	10	50	50	100	100
	10	10	50	50	100	100

Table 4.5 Assigned boundary condition stages for the Little Salt Creek

Little Salt Creek Design Storm	Salt Creek Design Storm	Salt Creek Stage (ft NAVD)
2-yr	2-yr	1131.5
10-yr	10-yr	1133.7
50-yr	25-yr	1136.5
100-yr	50-yr	1138.0
500-yr	100-yr	1140.4

4.3 Special Modeling Cases

During the development of the hydraulic model, a few locations required further analysis. These unique situations are described below.

4.3.1 Split Flow Locations

At three road crossing locations within the watershed, the road overtopping flow will cause a flow split downstream of the structure. These structures are shown in Table 4-6 and in Figures 4-2, 4-3, 4-4 and 4-5. For frequent flow events at all three of these road structures, the respective main conveyance structure will allow the flood flows to pass through before road overtop. During rare-event flooding, the flood flows exceed the capacity of the conveyance structure and overtop the road. Some of the road overtopping flow will be directed above the next, downstream road structure. The remaining of the road overtopping flow will be directed below the next, downstream road structure.

For the structure on Trib 65 at W. Raymond Road, this is due to the overtopping road section paralleling the downstream stream for a long distance, with the a portion of the overflow of the road overtop introduced several reaches downstream of the road culvert structure (see Figure 4-3).

For the structures on Trib 45 at N. 14th Street and Trib 220 at N. 40th Street, this is due to the downstream road "teeing" into the upstream road (see Figures 4-4 and 4-5). Overtopping flows to one side of the "Tee" will be on the upstream side whereas flows on the other side of the "Tee" will be on the downstream side of the downstream structure. The flow that is directed below the downstream structure will provide additional submergence and reduced capacity of that respective downstream structure. In order to model this condition, a bifurcation was established allowing the overtopping flows to split. This was accomplished by creating a separate channel and using an iterative process in which flow was subtracted from the primary channel and added to the split channel. The process was performed until the water surface elevations of two conjoined cross sections located immediately above the toe of the upstream structure embankment were identical. The locations and events of these split flow occurrences are shown in Figure 4-2 and Table 4-6.

Table 4.6 Locations and frequencies of the split flows

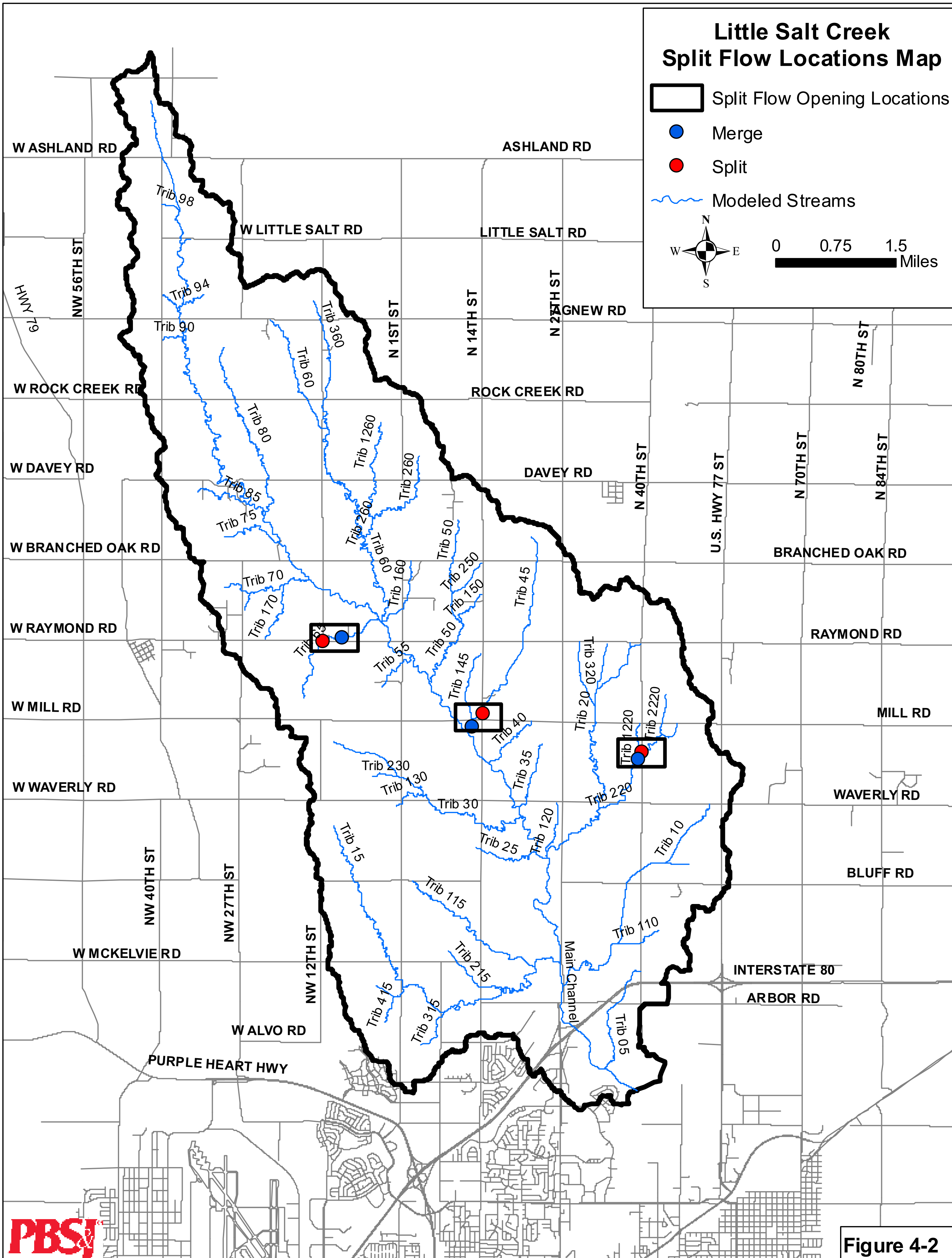
	Split Flow Occurrences				
Location	**2-yr**	**10-yr**	**50-yr**	**100-yr**	**500-yr**
Trib 65 at W Raymond Rd	--	--	X	X	X
Trib 45 at N 14th Street	--	--	X	X	X
Trib 220 at N 40th Street	--	X	X	X	X

4.3.2 Multiple Structure Analysis

Within the Little Salt Creek watershed, many roadway crossings contain multiple structures that convey flow from separate streams. However, during rare-events, the two separate streams act as one due to ponding that exceeds the drainage boundary divide elevation. To simulate this, the junction was moved from the streams confluence located on the downstream side of the roadway, to the upstream side where the streams combined due to the ponding. The cross sections located within the vicinity of the hydraulic structures were also combined to include the two channels in the same cross section. The locations and events that required the relocation of stream junctions are displayed in Figures 4-6, 4-7, 4-8, 4-9, and Table 4-7.

Table 4.7 Locations and frequencies of multiple opening analysis

	Multiple Opening Occurrences				
Location	**2-yr**	**10-yr**	**50-yr**	**100-yr**	**500-yr**
Little Salt Creek and Trib 35 at Waverly Rd	--	X	X	X	X
Trib 15 and Trib 215 at N 14th St	--	--	X	X	X
Trib 15 and Trib 315 at N 7th St	--	--	X	X	X



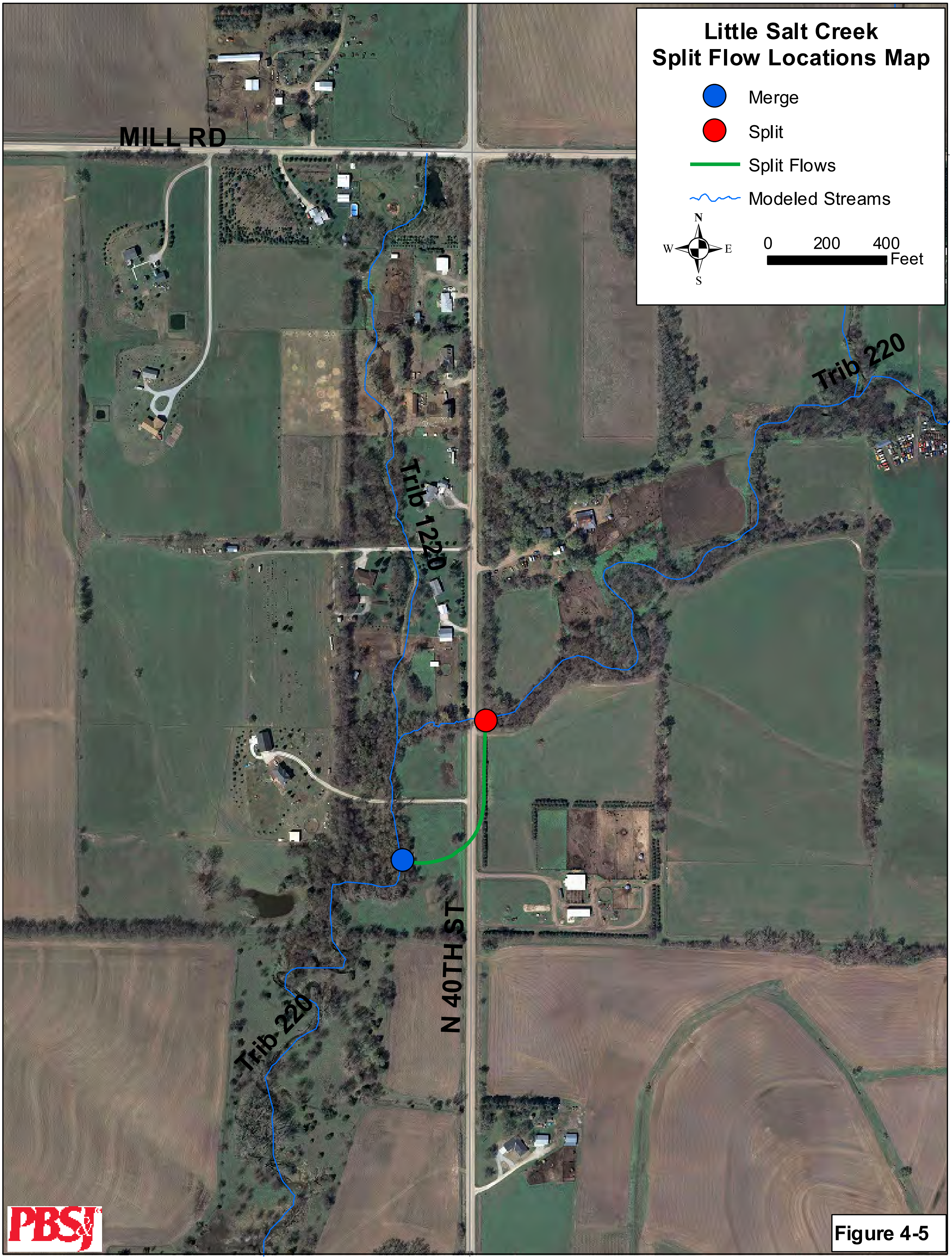
Little Salt Creek
Split Flow Locations Map
Split Flow Opening Locations
Merge
Split
Modeled Streams
N
S
E
W
0
0.75
1.5
Miles
W ASHLAND RD
ASHLAND RD
W LITTLE SALT RD
LITTLE SALT RD
AGNEW RD
W ROCK CREEK RD
ROCK CREEK RD
W DAVEY RD
DAVEY RD
W BRANCHED OAK RD
BRANCHED OAK RD
W RAYMOND RD
RAYMOND RD
W MILL RD
MILL RD
W WAVERLY RD
WAVERLY RD
BLUFF RD
W MCKELVIE RD
INTERSTATE 80
ARBOR RD
W ALVO RD
PURPLE HEART HWY
HWY 79
NW 56TH ST
NW 40TH ST
NW 27TH ST
NW 12TH ST
N 1ST ST
N 14TH ST
N 27TH ST
N 40TH ST
U.S. HWY 77 ST
N 70TH ST
N 80TH ST
N 84TH ST
Trib 98
Trib 94
Trib 90
Trib 360
Trib 60
Trib 80
Trib 1260
Trib 260
Trib 85
Trib 75
Trib 50
Trib 250
Trib 150
Trib 45
Trib 70
Trib 170
Trib 160
Trib 55
Trib 145
Trib 320
Trib 20
Trib 1220
Trib 2220
Trib 40
Trib 35
Trib 230
Trib 130
Trib 30
Trib 220
Trib 25
Trib 120
Trib 10
Trib 15
Trib 115
Trib 110
Trib 215
Trib 415
Trib 315
Main Channel
Trib 05
PBSJ

Figure 4-2


Little Salt Creek
Split Flow Locations Map
Merge
Split
Split Flows
Modeled Streams
N
W
E
S
0
200
400
Feet
NW 12TH ST
W RAYMOND RD
Trib 65
PBSJ
Figure 4-3

Little Salt Creek
Split Flow Locations Map
Merge
Split
Split Flows
Modeled Streams
N
S
E
W
0
200
400
Feet
N 14TH ST
Trib 45
Trib 145
MILL RD
Main Channel
Trib 40
PBSJ

Figure 4-4



Little Salt Creek
Split Flow Locations Map
Merge
Split
Split Flows
Modeled Streams
N
W
E
S
0
200
400
Feet
MILL RD
Trib 1220
Trib 220
Trib 220
N 40TH ST
PBSJ

Figure 4-5

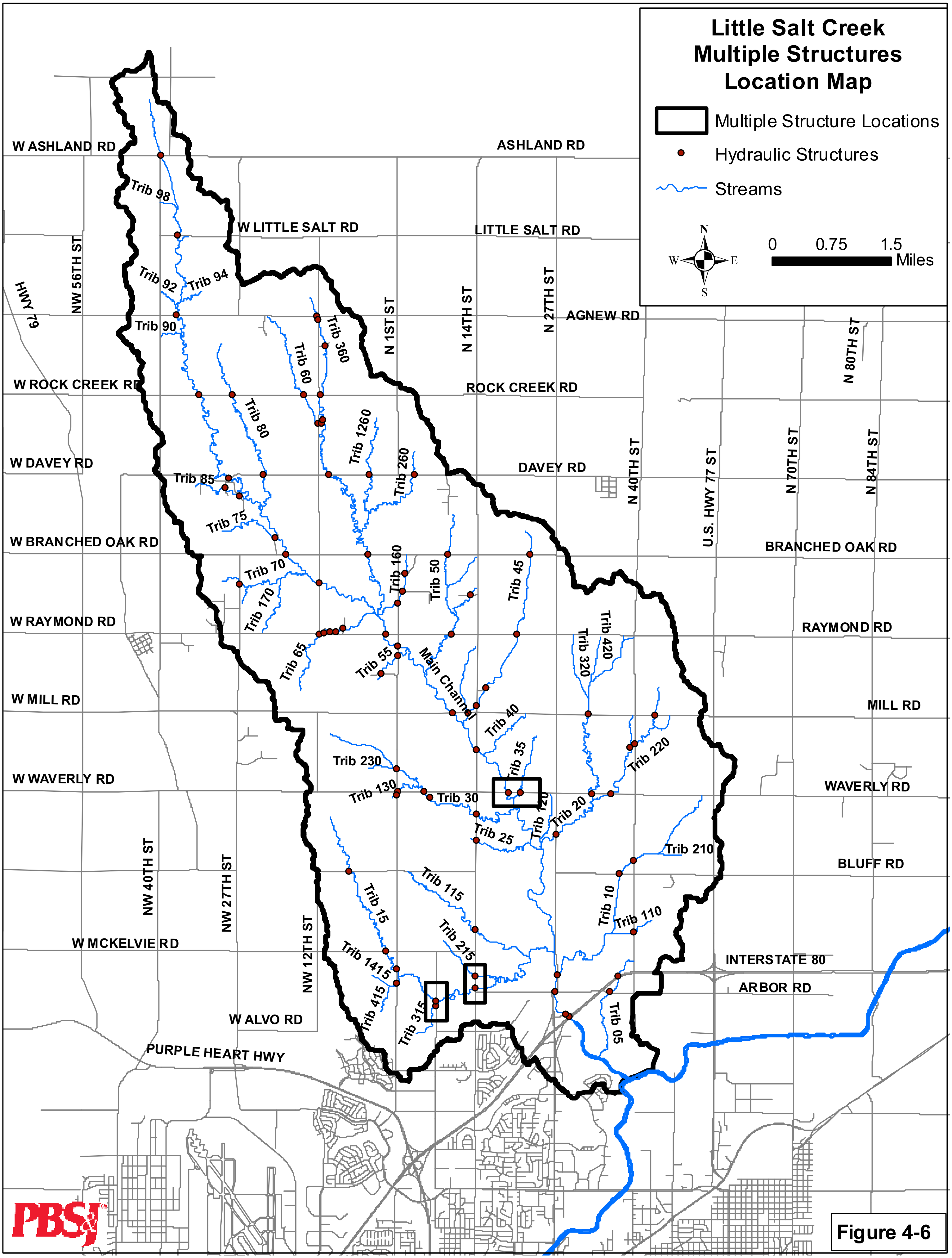
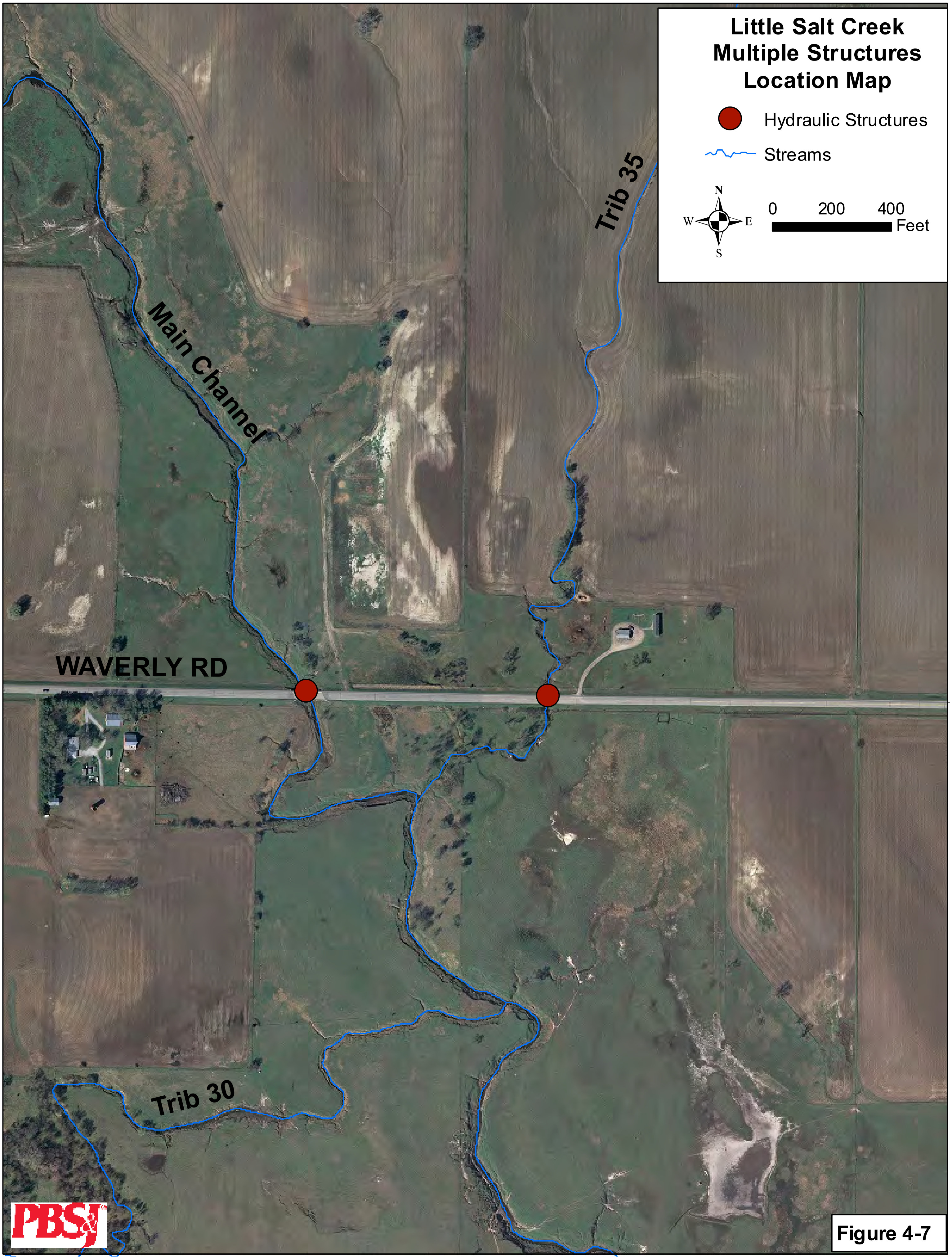

Little Salt Creek
Multiple Structures
Location Map
Multiple Structure Locations
Hydraulic Structures
Streams
N
S
E
W
0
0.75
1.5
Miles
W ASHLAND RD
ASHLAND RD
W LITTLE SALT RD
LITTLE SALT RD
AGNEW RD
W ROCK CREEK RD
ROCK CREEK RD
W DAVEY RD
DAVEY RD
W BRANCHED OAK RD
BRANCHED OAK RD
W RAYMOND RD
RAYMOND RD
W MILL RD
MILL RD
W WAVERLY RD
WAVERLY RD
BLUFF RD
W MCKELVIE RD
INTERSTATE 80
ARBOR RD
W ALVO RD
PURPLE HEART HWY
HWY 79
NW 56TH ST
N 1ST ST
N 14TH ST
N 27TH ST
N 40TH ST
U.S. HWY 77 ST
N 70TH ST
N 80TH ST
N 84TH ST
NW 40TH ST
NW 27TH ST
NW 12TH ST
Trib 98
Trib 92
Trib 94
Trib 90
Trib 360
Trib 60
Trib 80
Trib 1260
Trib 260
Trib 85
Trib 75
Trib 70
Trib 170
Trib 160
Trib 50
Trib 45
Trib 65
Trib 55
Main Channel
Trib 420
Trib 320
Trib 40
Trib 35
Trib 220
Trib 230
Trib 130
Trib 30
Trib 120
Trib 20
Trib 25
Trib 210
Trib 115
Trib 15
Trib 10
Trib 110
Trib 215
Trib 1415
Trib 415
Trib 315
Trib 05
PBSJ

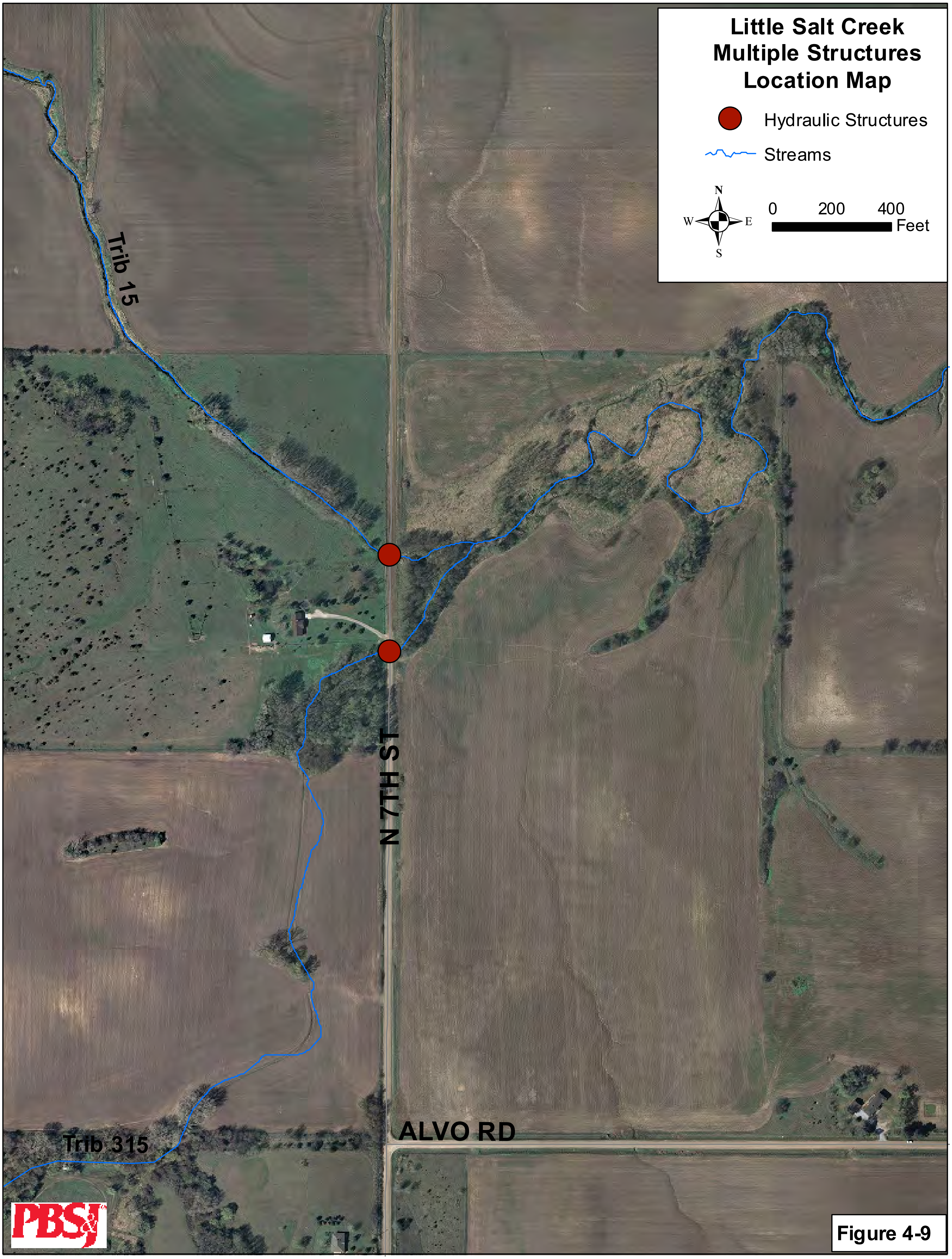
Figure 4-6



Little Salt Creek
Multiple Structures
Location Map
Hydraulic Structures
Streams
N
W
E
S
0
200
400
Feet
Trib 35
Main Channel
WAVERLY RD
Trib 30
Figure 4-7

Little Salt Creek
Multiple Structures
Location Map
Hydraulic Structures
Streams
N
W
E
S
0
200
400
Feet
Trib 215
N 14TH ST
Trib 15
ARBOR RD
PBS&J

Figure 4-8


Little Salt Creek
Multiple Structures
Location Map
Hydraulic Structures
Streams
N
W
E
S
0
200
400
Feet
Trib 15
N 7TH ST
ALVO RD
Trib 315
PBS&J
Figure 4-9

4.3.3 Roadway Skew Analysis

Special consideration was given to roadway crossings where the stream's angle of approach to the hydraulic structure was greater than 20 degrees. To account for this occurrence, HEC-RAS allows the user to define the skew angle. HEC-RAS then adjusts the bounding cross sections and bridge dimensions to reflect the skew angle. This adjustment was made along the Little Salt Creek at the N 14th Street crossing to account for an approach angle of 40 degrees.

The skew correction is not an option within HEC-RAS for culverts. However, at the Tributary 60 crossing of Davey Road, which has a box culvert structure, it appears that the culvert capacity is of a similar magnitude as the channel capacity, i.e., the box culvert acts similar to that of a bridge condition. At this specific location the stream has an approach angle of 21 degrees. In order to account for the reduction in flow efficiency due to the stream's approach angle, hand calculations were made resulting in the box culvert having a 10.15' span being altered to resemble a box culvert with a 9.45' span.

4.4 Model Calibration

The HEC-RAS model was calibrated using gauge information made available by the United States Geological Survey (USGS). As mentioned in Section 3 of this report, a stream gauge (USGS Stream Gauge 06803510) is situated near the downstream end of the Little Salt Creek at the intersection of Arbor Road and 27th Street. The USGS stage-discharge rating curve was obtained to allow comparison of model predicted stage-discharge at the stream gauge location.

Due to the Little Salt Creek at the stream gauge location being deeply incised, the stream record and stage-discharge rating mainly applies to the channel section. This allows for good prediction of the channel roughness values, but does not provide adequate information for overbank calibration. The HEC-RAS model channel roughness value within the lower reaches of Little Salt Creek were modified slightly to provide a good fit to the USGS rating curve. During the calibration process, the model downstream boundary condition was set to normal depth instead of a design tailwater depth. Since the downstream boundary location is several miles below the USGS gauge location, this was of minor consequence.

The model output is shown in Table 4-8 and the model output in relation to the rating curve is provided in Figure 4-10. It is noted that model results beyond 10,000 cfs are beyond the extent of the USGS rating curve. Although the values above the 10,000 cfs rating limit appears to fit on an extrapolated curve, such judgment is suspect given to the possibility of a curve break due to floodplain conveyance becoming more of a factor. Based on the calibration, it is believed that the channel roughness value within the lower reaches of Little Salt Creek is proper for the range of low flows through the rare-event flows.

Table 4.8 HEC-RAS model output at the gauge location

HEC-RAS Model Output		
Event	**Stage (ft NAVD88)**	**Discharge (cfs)**
2-yr	1125.60	957
10-yr	1134.86	7429
50-yr	1138.43	12668
100-yr	1139.68	15043
500-yr	1142.00	20909

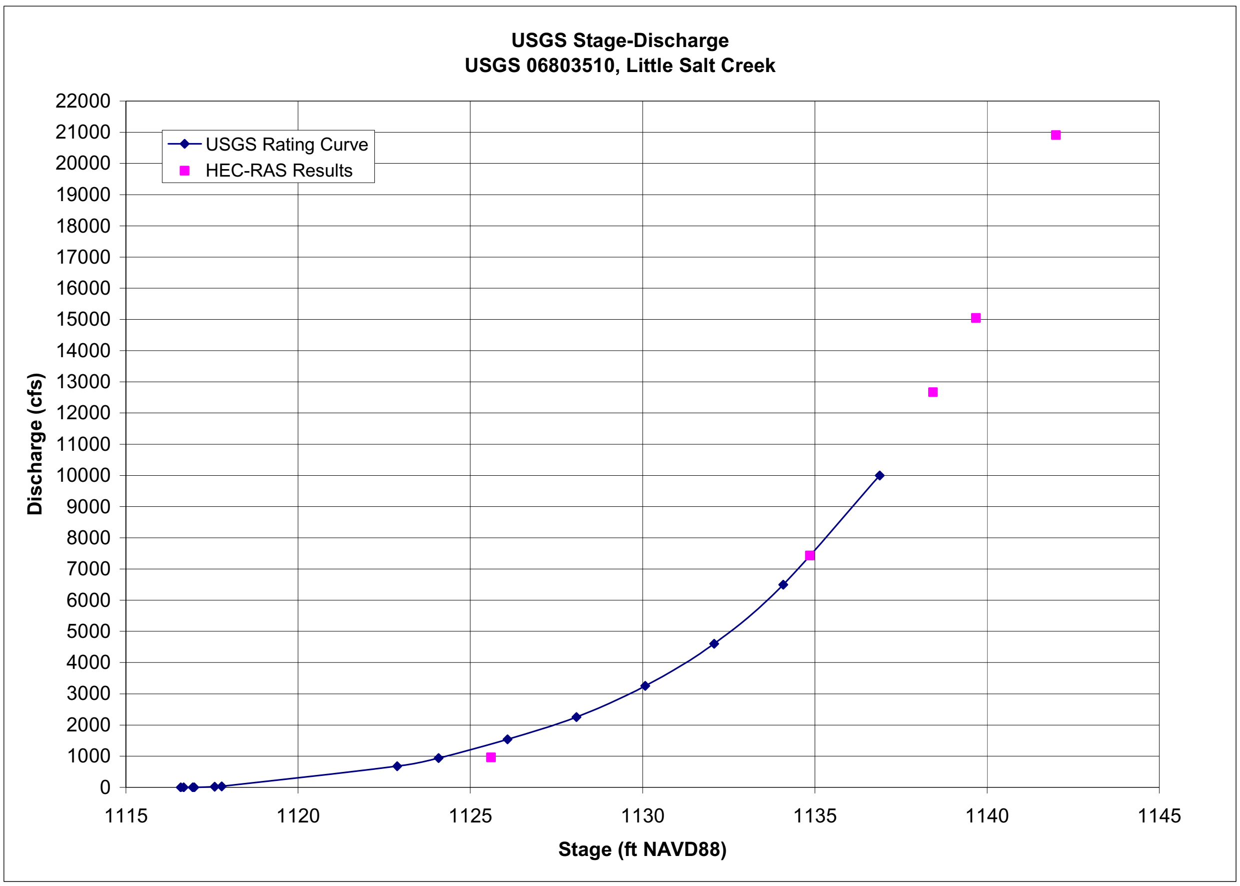


Figure 4-10: Comparison of HEC-RAS Model Output with the Rating Curve Provided by the USGS

4.5 Floodway Determination

A floodway was determined for each of the modeled streams. The floodway is determined from the floodplain model by encroaching upon the left and right overbanks of each cross section to produce a maximum rise of one foot in the water surface elevation. The encroachments simulate fill within the floodplain that reduces conveyance of flood flows.

A one-foot rise criterion was used to determine the encroachment stations at each cross section. Initially, Encroachment Method 4 was used to estimate encroachment stations at each cross section. Encroachment Method 4 automates the floodway modeling process by computing the left and right floodplain encroachment station so that the overall change in conveyance within the encroached system produces a target water level that meets the rise criterion.

Once the initial encroachment stations were determined by HEC-RAS, each cross section was reviewed and adjusted if necessary to meet the target one-foot rise. The downstream boundary condition for the floodway model was set to one foot higher than that of the 100-year floodplain analysis.