Section 3
Hydrologic Model Development

3.1 Introduction

The Hydrologic Investigation presents the methodology used to create and calibrate the hydrologic model for the Little Salt Creek watershed. This section provides a brief description of the basin, the incorporation of a previously generated hydrologic model of Little Salt Creek, the refinement of the previous hydrologic model basin delineations, the design rainfall, the determination of rainfall excess (runoff), and the channel routing methods utilized. This section also presents the model verification, sensitivity analysis, and calibration process that led to the adopted model; followed by the model results.

3.1.1 Basin Description

Little Salt Creek is a left bank tributary to Salt Creek. Its watershed is situated just above the northern city limits of Lincoln, Nebraska. An overall view of the Little Salt Creek watershed is displayed in Figure 3-1. Little Salt Creek has a contributing area of 45.8 square miles that is largely composed of agricultural lands such as farms and natural grasslands. The soil types found throughout the basins are classified as B, C, and D type soils with the vast majority of the watershed comprised of a shallow loess or sandy loam (B type soils). The topography ranges from mild to steep hill slopes in the upper reaches of the watershed to wide and low sloping floodplains in the lower reaches. Little Salt Creek meanders in a southeast direction for a length of 25.8 miles. The channel slopes vary from a rate of 36 feet per mile in the upper reaches to a rate of about 5 feet per mile in the lower reaches.

3.2 Methodology

3.2.1 Incorporation of Previous Little Salt Creek Model

In a previous study done by the City of Lincoln (the City) in 2002, the hydrologic characteristics of the lower reaches of the Little Salt Creek basin were modeled using the U.S. Army Corps of Engineers HEC-1 computer model (HEC-1). The extent of the previously studied area can be seen in Figure 3-2. The HEC-1 model received from the City was imported into U.S. Army Corps of Engineers HEC-HMS, version 3.1.0 (HMS). Once imported, all basin characteristics such as area (mi^2), lag time (hr), and runoff curve number were compared to those values given in the HEC-1 model report. A check was also performed to ensure that all the necessary basins and reservoirs were referencing the proper stage-discharge, elevation-stage, and elevation-area tables. Basic reviews of all reaches were also performed to ensure that the utilized slopes (ft/ft), reach lengths (ft), and Manning's values matched those of the HEC-1 model report.

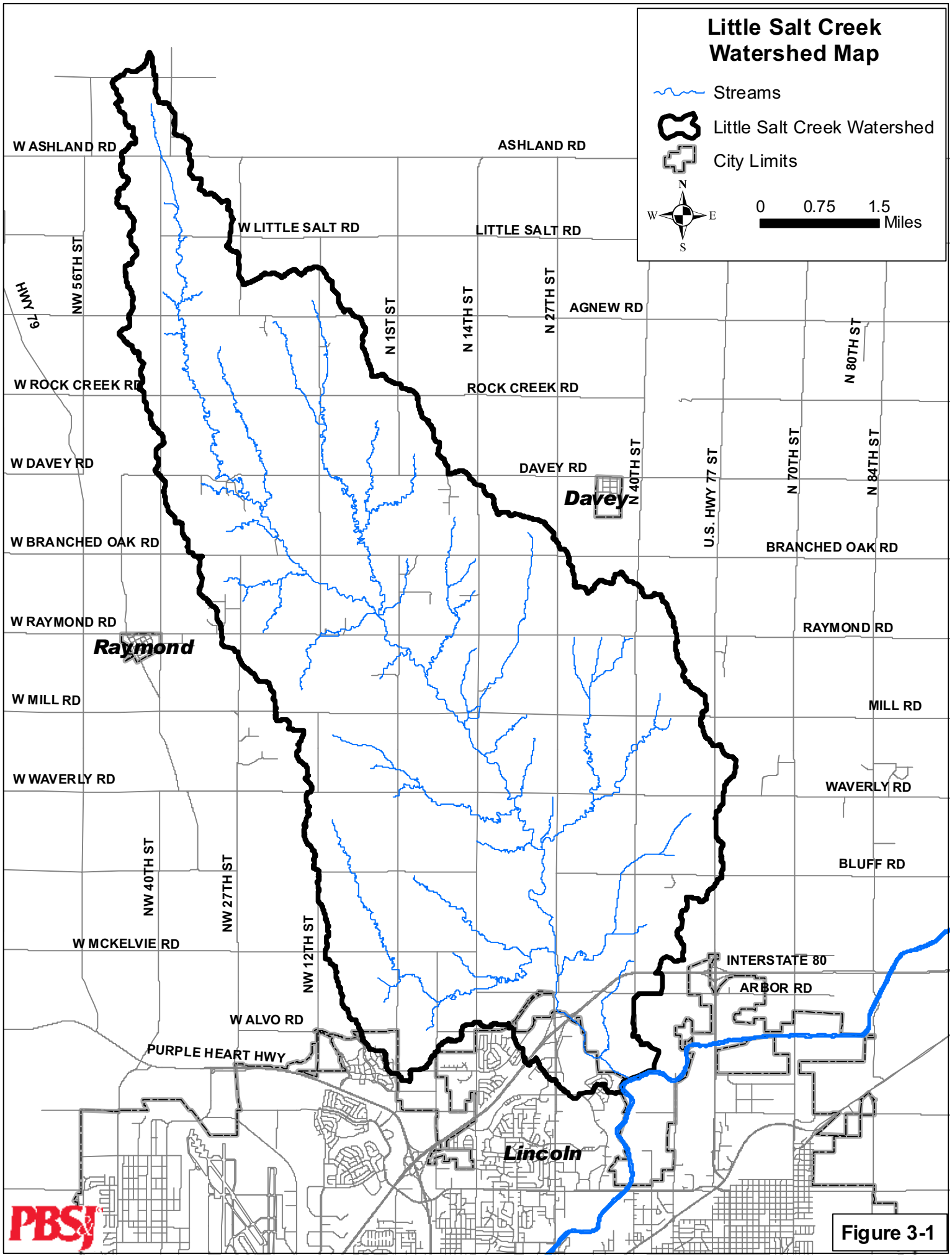
Little Salt Creek Watershed Map
Streams
Little Salt Creek Watershed
City Limits
N
W
E
S
0
0.75
1.5
Miles
W ASHLAND RD
ASHLAND RD
W LITTLE SALT RD
LITTLE SALT RD
HWY 79
NW 56TH ST
N 1ST ST
N 14TH ST
N 27TH ST
AGNEW RD
N 80TH ST
W ROCK CREEK RD
ROCK CREEK RD
W DAVEY RD
DAVEY RD
Davey
N 40TH ST
U.S. HWY 77 ST
N 70TH ST
N 84TH ST
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
NW 40TH ST
NW 27TH ST
NW 12TH ST
W MCKELVIE RD
INTERSTATE 80
ARBOR RD
W ALVO RD
PURPLE HEART HWY
Lincoln
PBSJ

Figure 3-1

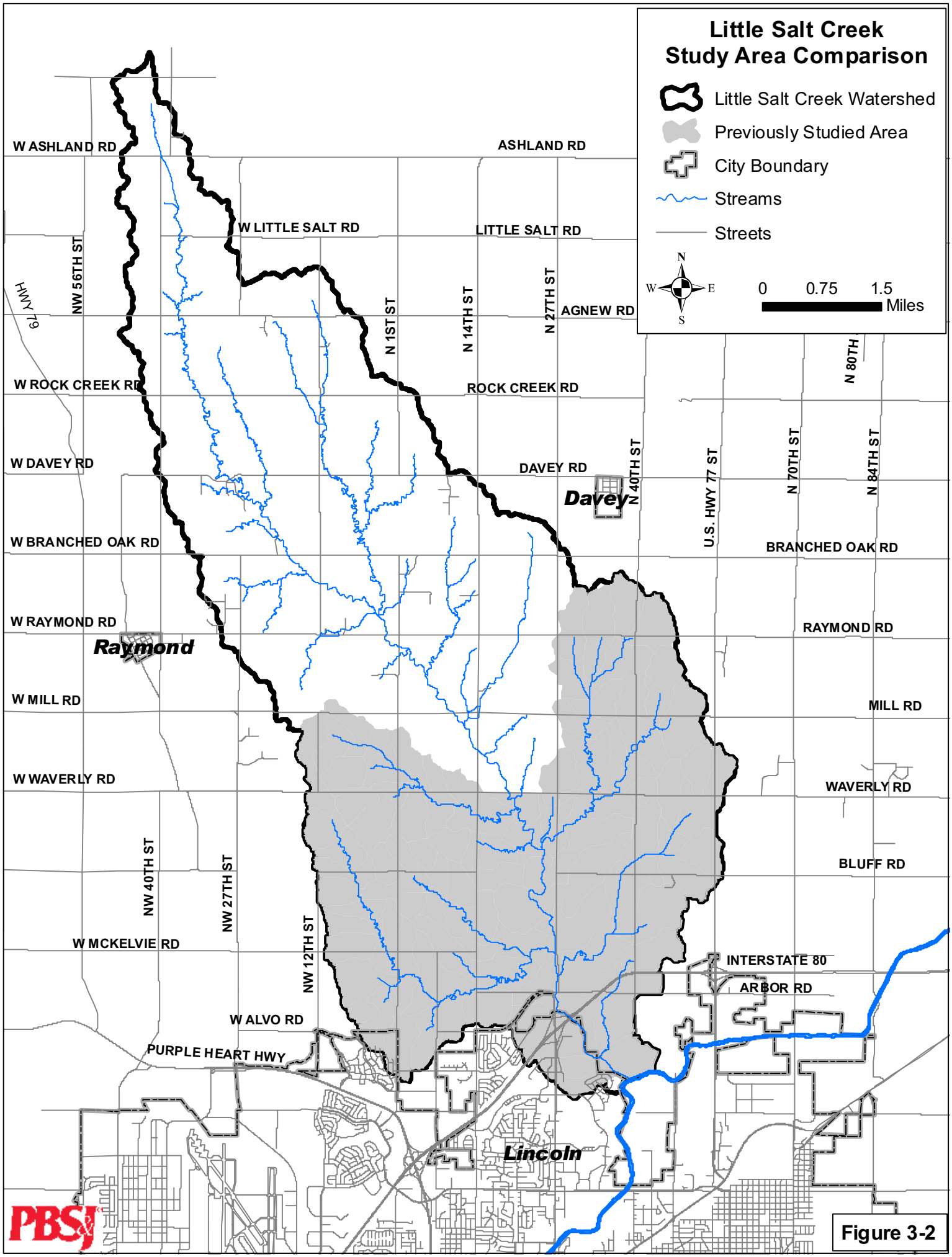
Little Salt Creek
Study Area Comparison
Little Salt Creek Watershed
Previously Studied Area
City Boundary
Streams
Streets
N
W
E
S
0
0.75
1.5
Miles
W ASHLAND RD
ASHLAND RD
W LITTLE SALT RD
LITTLE SALT RD
AGNEW RD
W ROCK CREEK RD
ROCK CREEK RD
W DAVEY RD
DAVEY RD
Davey
W BRANCHED OAK RD
BRANCHED OAK RD
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 84TH ST
N 80TH
NW 40TH ST
NW 27TH ST
NW 12TH ST
PBSJ

Figure 3-2

All of the characteristics for each basin, reach, and reservoir, for the 10-, 25-, and 100-year events were simulated. The simulations used the same rainfall distribution (SCS Type II) as were used in HEC-1 for the respective frequency events. The results of the HMS model were compared to those of HEC-1. The basins in the HMS model produced the same volumes, peak discharges, and time-to-peaks as HEC-1. However, once the discharges were routed through their respective reaches and reservoirs, the timing and peak discharges of the downstream junctions began to differ in comparison. These differences were compounded further downstream, producing greater differences between the results of the two models. Since both models used the same routing routine of Muskingum-Cunge, these differences were attributed to the differences in routing algorithms used by the two models.

3.2.2 Basin Delineation

Many of the HEC-1 delineated basin areas were maintained within HMS. However, some basins exceeded the City's desire that basins found on the upstream end of a modeled reach be approximately 150 acres in size. This included the upper 25.7 square miles (mi^2) of the Upper Little Salt Creek watershed that was described as a single subbasin in the HEC-1 model. Those basins that required further break-down were re-delineated using an extension of ArcMap titled ArcHydro. ArcHydro utilized an automated process to develop basin boundaries from a 10 meter digital elevation model (DEM). These automated boundaries were then reviewed and refined using USGS topographic maps along with LiDAR information provided by the City. A map showing the boundaries of the basins is shown in Figure 3-3. The 119 basins within the upper reaches of the Little Salt Creek watershed contain an average area 133 acres. Overall the Little Salt Creek model contains 242 basins with an average area of 121 acres.

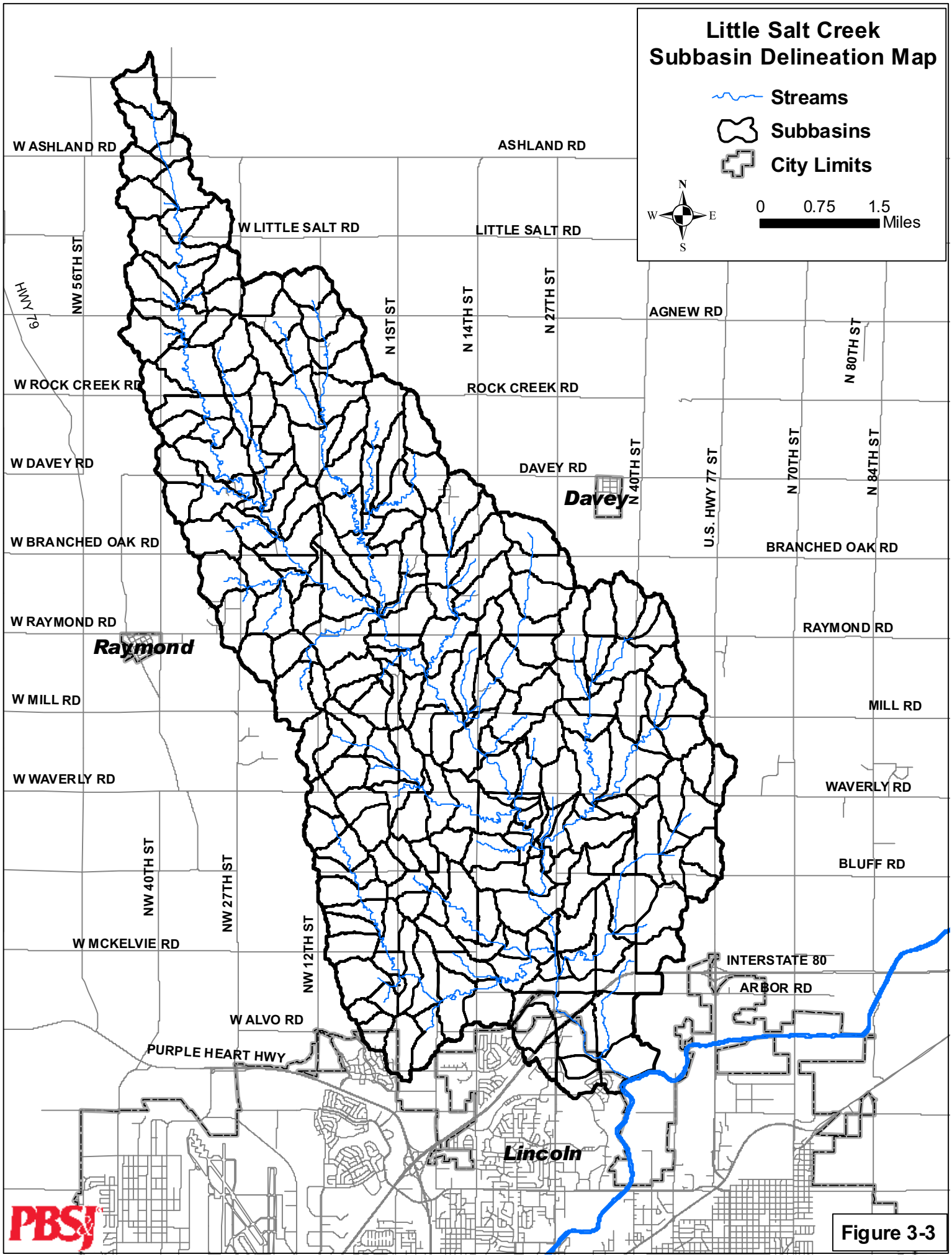
Little Salt Creek
Subbasin Delineation Map
Streams
Subbasins
City Limits
N
W
E
S
0
0.75
1.5
Miles
W ASHLAND RD
ASHLAND RD
W LITTLE SALT RD
LITTLE SALT RD
HWY 79
NW 56TH ST
N 1ST ST
N 14TH ST
N 27TH ST
AGNEW RD
N 80TH ST
W ROCK CREEK RD
ROCK CREEK RD
W DAVEY RD
DAVEY RD
Davey
N 40TH ST
U.S. HWY 77 ST
N 70TH ST
N 84TH ST
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
NW 40TH ST
NW 27TH ST
NW 12TH ST
W MCKELVIE RD
INTERSTATE 80
ARBOR RD
W ALVO RD
PURPLE HEART HWY
Lincoln
PBSJ

Figure 3-3

3.2.3 Rainfall

The SCS Type II storm distribution was used to simulate the 24-hr events of the 2-, 5-, 10-, 50-, 100-, and 500-yr return periods. Depths corresponding to these return periods were taken from the City's Drainage Criteria Manual (Rev May 10, 2004 edition) and are listed within Table 2.7 of the Manual.

Table 3.1 Rainfall depths corresponding to the each return period (note 500-yr depth is interpolated)

Return Period	Depth (in)
2-yr	3.00
5-yr	3.93
10-yr	4.69
50-yr	6.00
100-yr	6.68
500-yr	8.18

3.2.4 Runoff Volume Calculation

To calculate the volume of the runoff resulting from the corresponding design storms, the SCS Curve Number Loss method was used. This method was employed to be consistent with HEC-1. The major factors that determine the runoff curve number (CN) are the hydrologic soil group, cover type (land use), hydrologic condition, and antecedent moisture condition.

The composite curve number for each basin was calculated using digitized coverage's describing the existing land use and hydrologic soil group. The land use information describing the vegetation and use (agricultural, urban, etc.) of the watershed was obtained from the City and is displayed in Figure 3-4. The Soil Survey Geographic (SSURGO) soil data was obtained from the Natural Resources Conservation Service (NRCS) and classifies the hydrologic soil groups found within the watershed. Overlaying the land use and soil group information resulted in areas that represented a specific combination of one land use and one soil group. Using this combination and assuming a normal antecedent moisture condition (AMC II) a CN value was assigned using tables published by the NRCS. A lookup table defining the utilized CN for each land use-soil group combination is displayed in Table 3.2. After assigning the CN values to each combination, the CN for each basin was calculated using an area-weighted average for each basin.

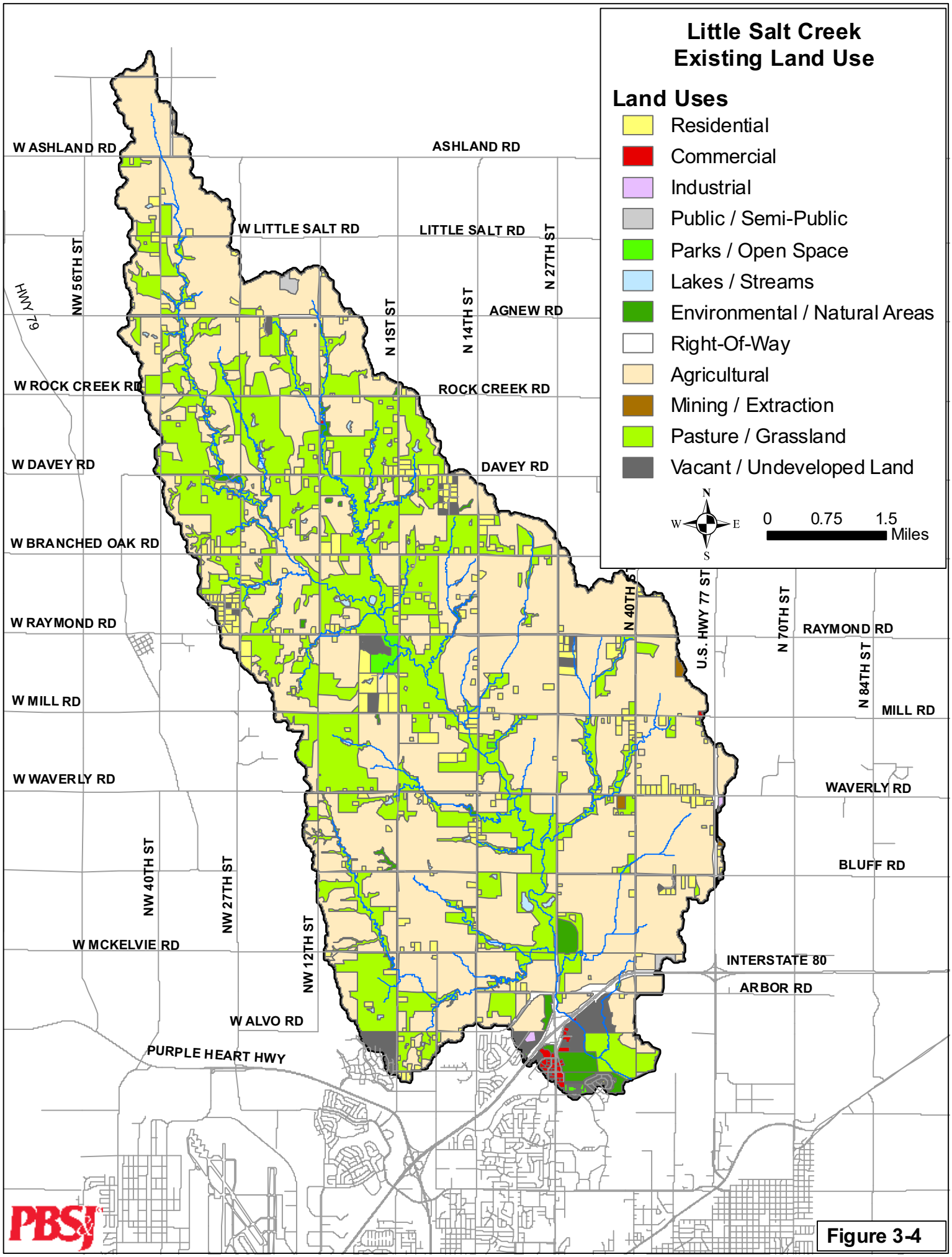
Little Salt Creek
Existing Land Use
Land Uses
Residential
Commercial
Industrial
Public / Semi-Public
Parks / Open Space
Lakes / Streams
Environmental / Natural Areas
Right-Of-Way
Agricultural
Mining / Extraction
Pasture / Grassland
Vacant / Undeveloped Land
N
W
E
S
0
0.75
1.5
Miles
W ASHLAND RD
ASHLAND RD
W LITTLE SALT RD
LITTLE SALT RD
NW 56TH ST
HWY 79
N 1ST ST
N 14TH ST
N 27TH ST
AGNEW RD
W ROCK CREEK RD
ROCK CREEK RD
W DAVEY RD
DAVEY RD
W BRANCHED OAK RD
W RAYMOND RD
N 40TH ST
U.S. HWY 77 ST
N 70TH ST
RAYMOND RD
N 84TH ST
W MILL RD
MILL RD
W WAVERLY RD
WAVERLY RD
BLUFF RD
NW 40TH ST
NW 27TH ST
NW 12TH ST
W MCKELVIE RD
INTERSTATE 80
ARBOR RD
W ALVO RD
PURPLE HEART HWY
PBSJ

Figure 3-4

Table 3.2 Lookup table used to define the curve number for each land use-soil group combination

		Hydrologic Soil Group			
Landuse Category	**Cover Type (% Imp)**	**A**	**B**	**C**	**D**
Public and Semi-Public	Open Space - Fair Condition	49	69	79	84
Parks and Open Space	Good Condition (> 75% grass)	39	61	74	80
Pasture and Grasslands	Good Condition	39	61	74	80
Agricultural	Row Crops - Contoured Good Condition	65	75	82	86
Residential, Low Density	Residential 1 acres (12%)	51	68	79	84
Residential, Urban	Residential 1/4 acres (38%)	61	75	83	87
Ag/Stream Corridor	Woods - Grass Combination - Good	32	58	72	79
Commercial	Commercial and business (85%)	89	92	94	95
Industrial	Industrial (72%)	81	88	91	93
Lakes and Streams	Water	98	98	98	98
Forest and Woodlands	Woods – Fair Condition	36	60	73	79
Other ROW	Open Space – Fair Condition	49	69	79	84
Mining and Extraction	Non-contributing Depression Areas	0	0	0	0
Vacant Land	Open Space – Fair Condition	49	69	79	84

Initial and Constant Loss Method

Due to the large amount of available storage found throughout the basin, the Initial and Constant Loss Method was used to better simulate the runoff volume from each basin. The Initial and Constant Loss Method uses a constant loss rate in inches per hour, a defined initial loss in inches, and the percentage of basin area that is impervious. However, due to the watershed being vastly composed of agriculture and grassland, the percentage of area considered impervious was assumed to be negligible.

The constant loss rate is defined as the ultimate infiltration capacity of the soils. Skaggs and Khaleel (1982) published estimates of infiltration rates based on hydrologic soil groups. This information is shown in Table 3.3. As seen in Figure 3-5, the Little Salt Creek watershed is comprised of soils within hydrologic soil group B, C, and D. To define a comprehensive constant loss rate for each basin, the same area weighted average used to estimate a basin's curve number was applied. Using the SSURGO soil data that was obtained from the NRCS, a digitized soil coverage was created. Applying the constant loss values of 0.30 in/hr, 0.15 in/hr, and 0.05 in/hr for B, C, and D soils respectively, an area-weighted average calculation was performed for each basin.

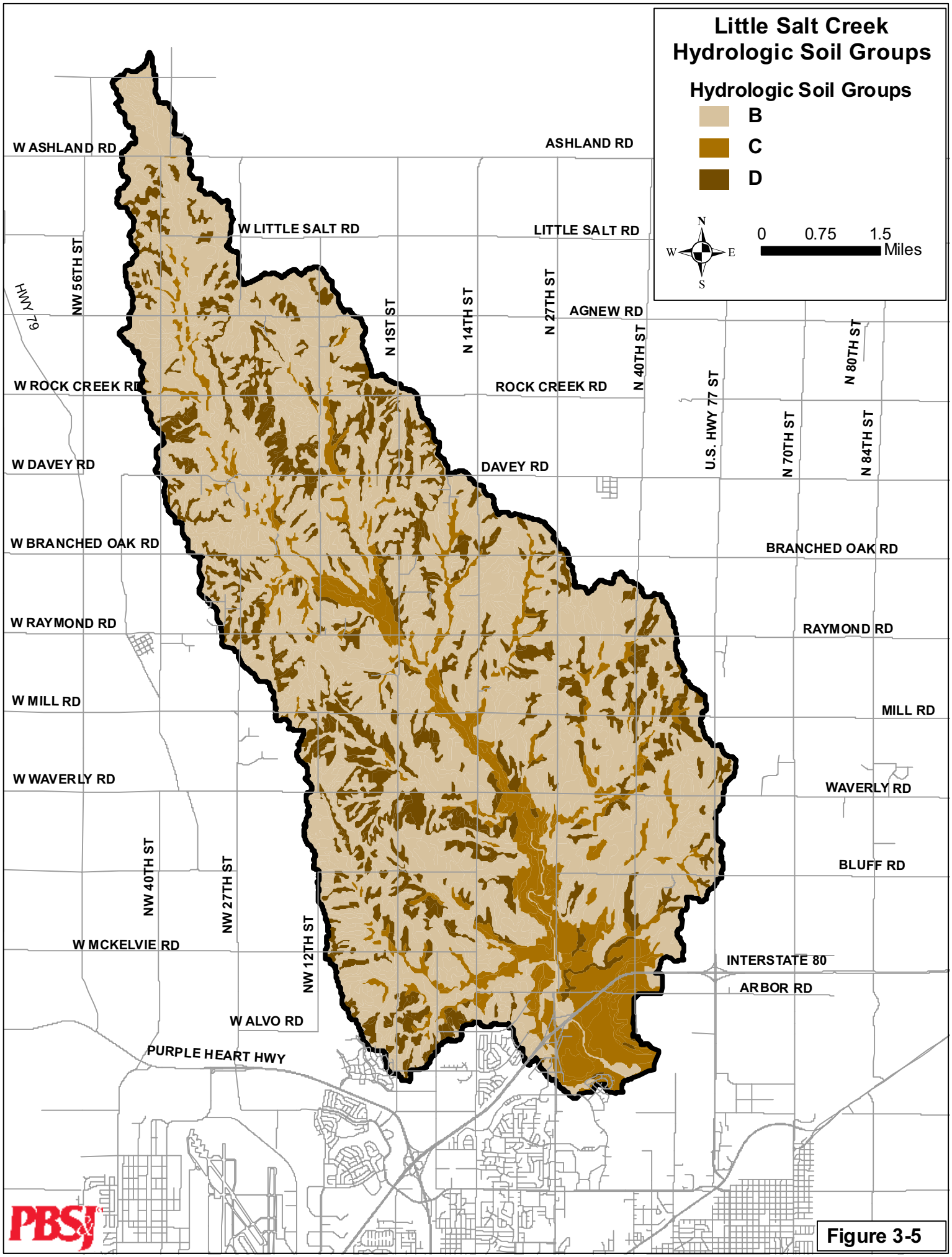
Little Salt Creek
Hydrologic Soil Groups
Hydrologic Soil Groups
B
C
D
N
W
E
S
0
0.75
1.5
Miles
W ASHLAND RD
ASHLAND RD
W LITTLE SALT RD
LITTLE SALT RD
HWY 79
NW 56TH ST
N 1ST ST
N 14TH ST
N 27TH ST
AGNEW RD
N 40TH ST
N 80TH ST
W ROCK CREEK RD
ROCK CREEK RD
U.S. HWY 77 ST
N 70TH ST
N 84TH ST
W DAVEY RD
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
NW 40TH ST
NW 27TH ST
NW 12TH ST
W MCKELVIE RD
INTERSTATE 80
ARBOR RD
W ALVO RD
PURPLE HEART HWY
PBSJ

Figure 3-5

Table 3.3 Constant loss rates as defined by Skaggs and Khaleel (1982)

Soil Group	Description	Range of Loss Rates (in/hr)
A	Deep sand, deep loess, aggregated silts	0.30 - 0.45
B	Shallow loess, sandy loam	0.15 - 0.30
C	Clay loams, shallow sandy loam, soils low in organic content, and soils usually high in clay	0.05 -0.15
D	Soils that swell significantly when wet, heavy plastic clays, and certain saline soils	0.00 - 0.05

An initial loss parameter was defined to characterize the interception and depression storage of each basin. Interception is the process of absorption of rainfall by the surface cover and vegetation before reaching the soil. Depression storage is the volume of precipitation that can be stored in depressions and ponds before contributing to the runoff volume for the basin. Until the accumulated precipitation within the basin exceeds the initial loss volume, no runoff occurs. The amount of initial loss due to interception was estimated by creating a series of sensitivity runs prior to calculating the amount of available storage for each basin. The watershed was initially modeled using the SCS Curve Number Method. By comparing the runoff volumes from the CN model with the volumes of the Initial Loss and Constant Loss model, it was discovered that 1 inch of initial loss with a constant loss of 0.3 in/hr closely approximated the results of the CN model.

To define the amount of initial loss for each basin due to depression storage, all storage ponds and large depression areas were analyzed by locating the minimum and maximum elevation of the storage areas along with the surface area of the pond corresponding to each elevation. From these values an approximate volume was estimated for each storage area. These volumes were converted to depths by dividing the storage volume by the area of the contributing basins. The depth of loss attributed to depression storage was then added to the 1 inch of initial interception loss.

3.2.5 Runoff Hydrographs (Lag Time)

The SCS Dimensionless Unit Hydrograph method was employed within HMS in order to distribute the runoff volume for each basin. This method requires the SCS lag time to be calculated. The lag time for each basin was calculated using the Curve Number Lag Method described in the "*National Engineering Handbook, Section 4" (Natural Resources Conservation Service, 2001).* This calculation was performed using an automated process available within HEC-GeoHMS. HEC-GeoHMS is an extension of ArcMap created by the Hydrologic Engineering Center (HEC) that analyzes the available digital terrain information to create drainage paths and watershed boundaries. To calculate the lag time, HEC-GeoHMS employed a DEM to estimate the hydraulic length and average land slope of each basin. The lag time for each catchment was calculated using the curve number method:

$$L = \frac{l^{0.8}(S+1)^{0.7}}{1900Y^{0.5}}$$

in which L equals the lag time in hours; *l* is defined as the hydraulic length of the catchment in feet; Y represents the average watershed land slope in percent; and

$$S = \frac{1000}{CN} - 10$$

in which CN represents the dimensionless curve number.

HMS then uses the lag time parameter to internally calculate the time of concentration (t_c) for each basin using the equation,

$$t_c = \frac{L}{0.6}$$

The time of concentration represents the time it takes for a drop of water to travel from the furthest point of the catchment to the outlet.

3.2.6 Routing

The channel characteristics within Little Salt Creek vary from low to moderately incised channels in the upper reaches of the main channel and the tributaries to deeply incised in the lower main channel. The floodplain is generally wide, with ponds and storage common within both the tributaries and the main channel. The lower portion of Little Salt Creek has been straightened, with the abandoned oxbows providing storage for out of bank flows. As noted earlier, the watershed slope is very mild in the lower portion of the basin, increasing to moderately steep in the upper main channel and tributaries.

The Muskingum-Cunge Routing method was used to route the runoff hydrographs through the watershed. This approximates the diffusion method, allowing the model to describe the physical nature of the basin and thus the attenuation potential. Within the HEC-HMS model the Muskingum-Cunge method uses up to an eight-point cross section to describe the channel and overbank geometries, roughness values, lengths and slopes. The eight-point channel cross sections, lengths and slopes were created for each reach of the Upper Little Salt Creek watershed using the LiDAR elevation grid made available by the City. The respective roughness values were obtained from field observations. The channel roughness value for the lower portion of the watershed was calibrated to a USGS stream gauge within the watershed. The USGS stream gauge information is described in model verification and the calibration is described in the Hydraulic Investigation.

3.3 Model Verification

Model verification involves utilizing stream gauge information to assess the reasonableness of the model's prediction of a basins rainfall-runoff response, both in terms of peak discharge and total volume.

The data contained within the stream gauge record is statistically analyzed to generate basin discharge-frequencies and volume-duration-frequencies. The hydrologic model is then executed with various rainfall-frequencies and the resultant peak discharge- and volume-frequencies checked against the statistical data for the stream gauge.

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 (see Figure 3-8). The stream gauge's contributing drainage area is approximately 43.6 square miles. This stream gauge has a continuous period of record of thirty seven years. Given the location and long period of record of the stream gauge, statistical analysis of the stream gauge data were performed and utilized within this study to verify the Little Salt Creek Hydrologic Model results for the respective SCS Type II storm simulations. The statistical analysis consisted of generating peak flood flow frequency and volume-duration-frequency relationships of the stream gauge data. For this study, one- and two-day volume-duration-frequency analysis were performed since some of the Little Salt Creek flood events and resulting flood hydrographs would have been captured over a two day reporting period. The verification consisted of comparing the volume and peak flow outputs of the Little Salt Creek Hydrologic Model with the flood flow frequency results.

3.3.1 Statistical Analysis of Stream Gauge Data

The peak flood flow frequency was estimated by analyzing the annual peak flow data from the stream gauge using the methods described in "Bulletin 17B, Guidelines for Determining Flood Flow Frequency" (U.S. Water Resources Council, 1981) (Bulletin 17-B). The peak flow-frequency analysis utilized a generalized skew of -0.2, as recommended for this portion of the United States within Bulletin 17-B. The volume-duration-frequency was estimated by analyzing the high annual one- and two-day flow data from the stream gauge. The volume-duration-frequency analysis utilized a generalized skew of 0.0, as recommended within Bulletin 17-B. The results of the peak flood flow frequency analysis are summarized in Table 3.4 with graphical depictions shown on Figure 3-6. The results of the volume-duration-frequency analysis are summarized in Table 3.5 with graphical depictions shown on Figure 3-7. The computer results for all flood flow frequency analysis are provided in Appendix A.

Table 3.4 Results of the peak flood flow frequency analysis

Percent Chance Exceedance	Computed Probability Flow (cfs)
0.2	35300
0.5	23400
1	16800
2	11900

5	7160
10	4660
20	2840
50	1190
80	546
90	377
95	282
99	171

Table 3.5 Results of the volume-duration-frequency analysis

	1-day Output	2-day Output
Percent Chance Exceedance	Computed Probability Volume (ac-ft)	Computed Probability Volume (ac-ft)
0.2	16800	22100
0.5	12300	16100
1	9460	12400
2	7120	9380
5	4650	6140
10	3190	4210
20	2020	2670
50	840	1110
80	350	465
90	221	295
95	152	202
99	75	100

The statistical results for the peak flow-frequency as shown on Figure 3-6 indicates that the floodplain characteristics near the gauge appear to attenuate flows that exceed approximately eight thousand cubic feet per second (cfs). This is reflected in the Weibull plot of the peak flow bending sharply for the last four data points. However, the volume-duration Weibull plots shown on Figure 3-7 do not show a bending trend, indicating that flow attenuated within the floodplain is generally returned during the recession side of the hydrograph. This floodplain characteristic confirms the use of the Muskingum-Cunge routing technique.

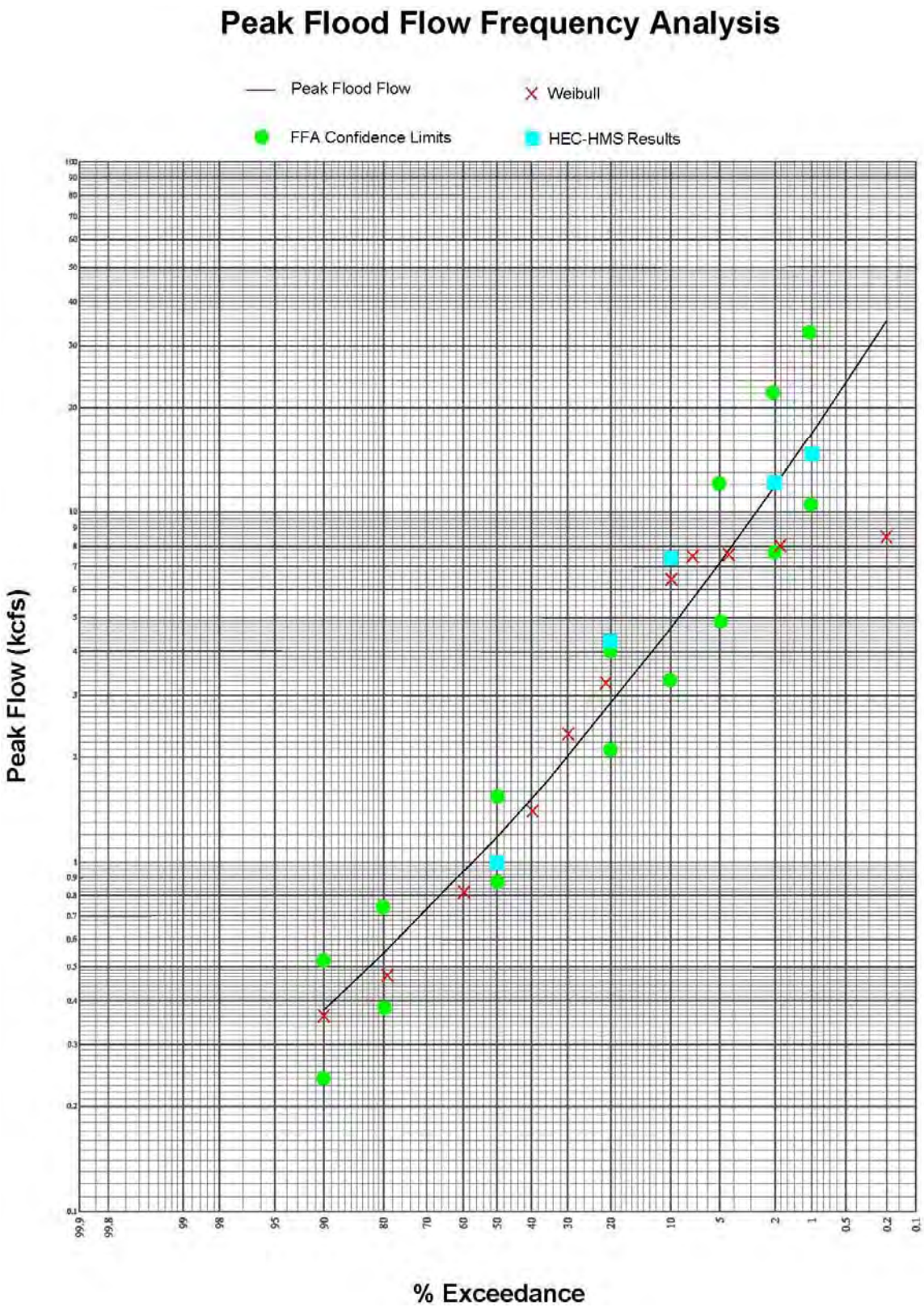

Figure 3-6: Graphical Depiction of the Peak Flood Flow Frequency Analysis

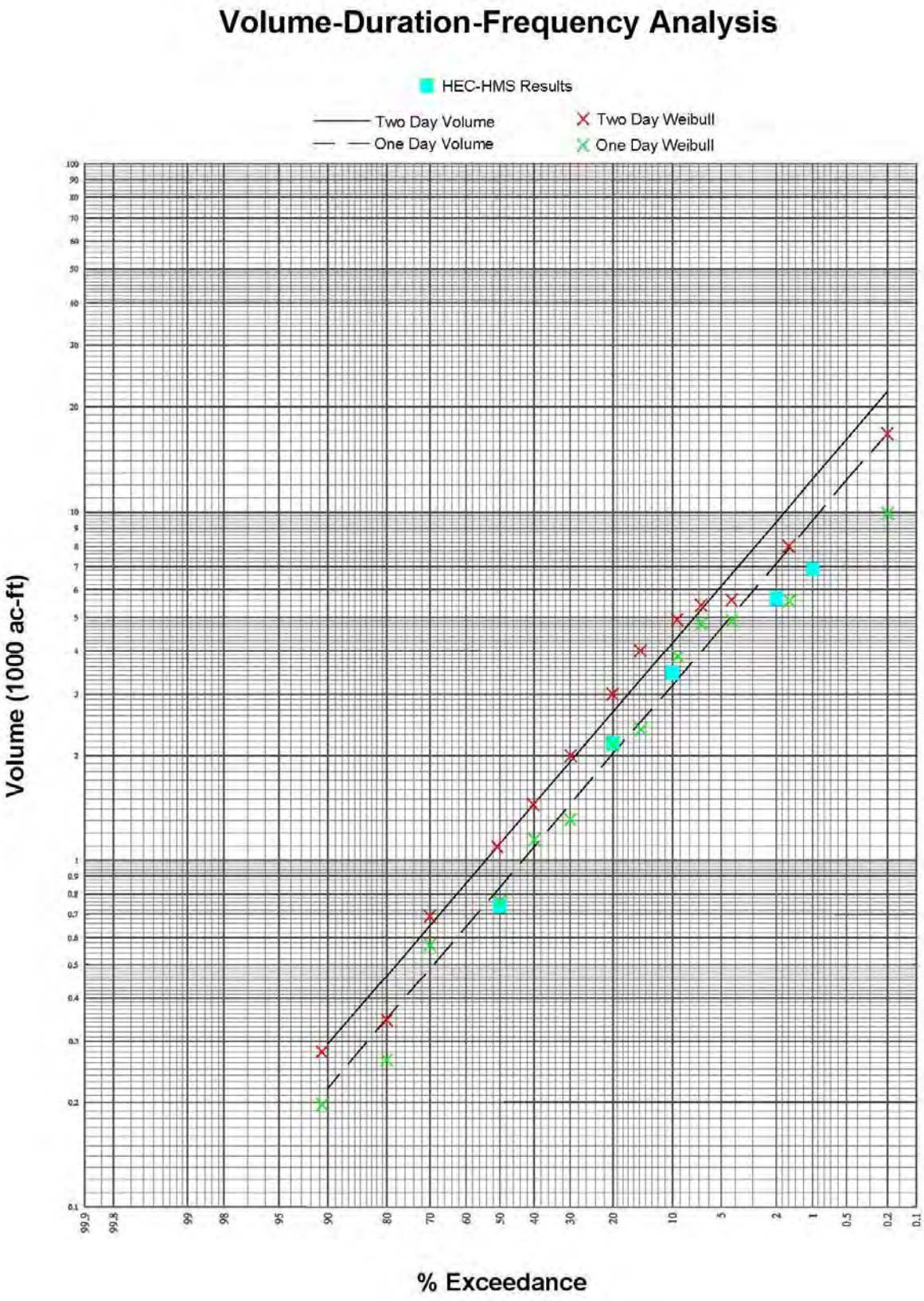

Figure 3-7: Graphical Depiction of the Volume-Duration-Frequency Analysis

3.4 Sensitivity Analysis

During the calibration of the Little Salt Creek Hydrologic model, an analysis was performed to investigate the sensitivity of the initial loss parameter. This was done by simulating the 2-, 5-, 10-, 50-, and 100-yr SCS Type II events using initial loss values that ranged from 1" to 2". The results of the sensitivity analysis are displayed in Tables 3.6 and 3.7. Upon review of these results, it was concluded that an initial loss value of 1.5" achieved the best correlation between the model results and the statistical gauge analysis.

Table 3.6 Comparison of peak flows resulting from modifications to each basin's initial loss parameter

Initial Losses	1.0"	1.3"	1.5"	1.6"	2.0"	HEC-FFA (cfs)
Event	Qpeak (cfs)					
2-yr 24-hr	3210	1850	957	734	92	1190
5-yr 24-hr	6770	5330	4290	3790	1940	2840
10-yr 24-hr	9800	8380	7430	6920	4780	4660
50-yr 24-hr	14200	13400	12700	12200	10400	11900
100-yr 24-hr	16200	15600	15000	14700	13000	16800

Table 3.7 Comparison of cumulative volumes resulting from modifications to each basin's initial loss parameter

Initial Losses	1.0"	1.3"	1.5"	1.6"	2.0"	HEC-FFA (ac-ft)
Event	Volume (ac-ft)					
2-yr 24-hr	1680	1080	721	560	98	840
5-yr 24-hr	3060	2530	2130	1920	1120	2020
10-yr 24-hr	4210	3790	3410	3200	2350	3190
50-yr 24-hr	6250	5940	5630	5440	4650	7120
100-yr 24-hr	7340	7080	6810	6650	5890	9460

3.5 Model Calibration

The calibration process of the hydrologic model consisted of comparing the model results with a gauged historical storm event.

3.5.1 Historical Storm Event Calibration

To calibrate the hydrologic model with a historical storm event, a stream gauge and the corresponding rainfall distribution are needed. This data was obtained from the aforementioned USGS Stream Gauge 06803510 situated near the downstream end of Little Salt Creek at the intersection of Arbor Road and 27th Street. Upon review of the gauge data, it was noticed that the event which had occurred on June 11, 2008 had produced a peak discharge approximating that of a 5-yr event. Due to its recent timing as well as its significant peak, the June 11, 2008 event was chosen as the calibration storm.

The rainfall distribution corresponding to the June 11th event was copied into the HEC-HMS model and applied to each basin. After simulating the June 11th rainfall the discharge values of the stream gauge were compared with the HMS model. The comparison is displayed in Figures 3-9 and 3-10. As illustrated in the figures, the HMS model calculates a peak discharge and hydrograph shape that closely resembles those of the historical gauge data. As seen in Figure 3-10, the model results have been shifted to better show a comparison of the recession limbs of the hydrographs. The similar slopes of the recession limbs prove that the hydraulic characteristics (i.e. slopes, hydraulic lengths, roughness coefficients) described within the model closely resemble those of nature.

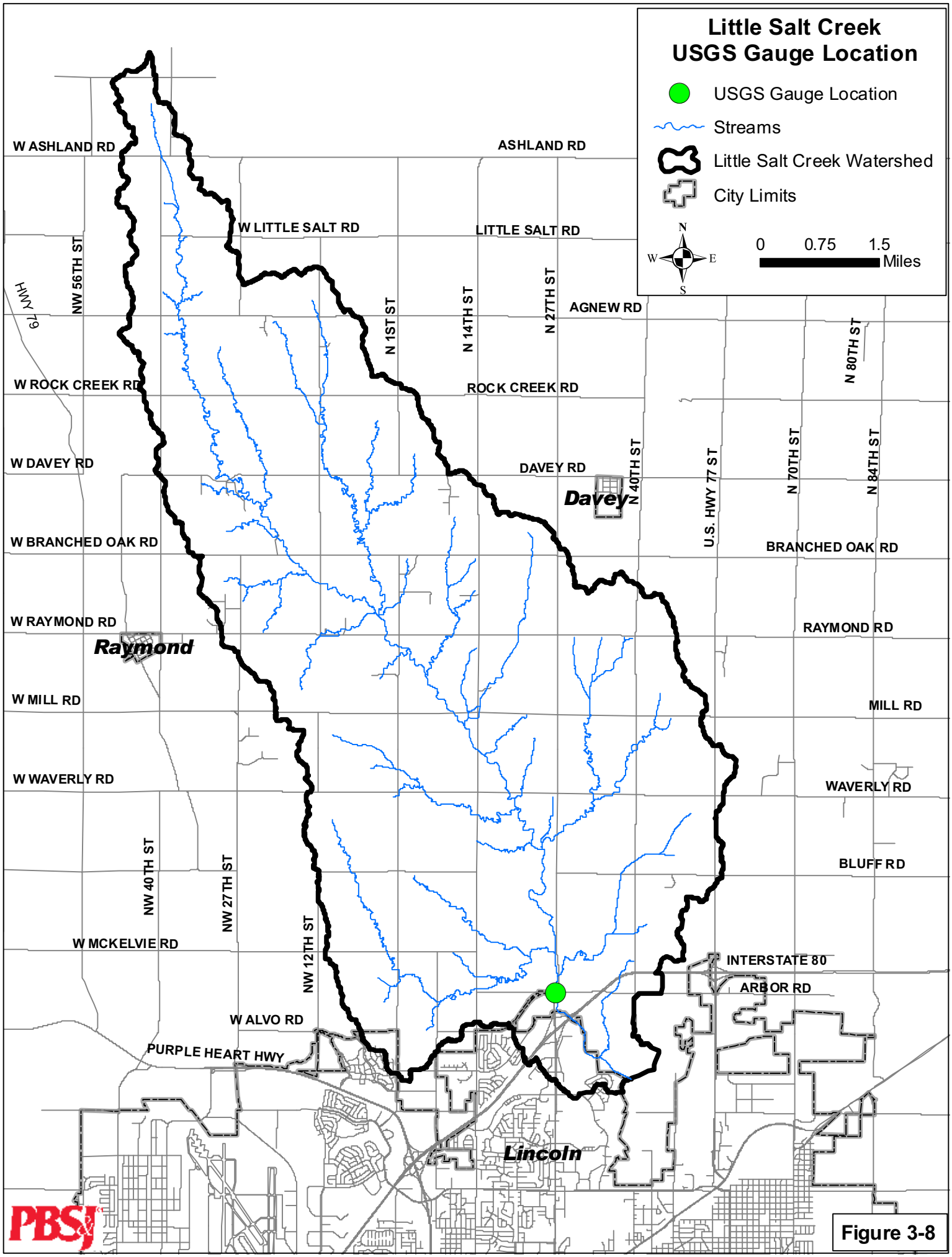
Little Salt Creek
USGS Gauge Location
USGS Gauge Location
Streams
Little Salt Creek Watershed
City Limits
N
W
E
S
0
0.75
1.5
Miles
W ASHLAND RD
ASHLAND RD
W LITTLE SALT RD
LITTLE SALT RD
HWY 79
NW 56TH ST
N 1ST ST
N 14TH ST
N 27TH ST
AGNEW RD
N 80TH ST
W ROCK CREEK RD
ROCK CREEK RD
W DAVEY RD
DAVEY RD
Davey
N 40TH ST
U.S. HWY 77 ST
N 70TH ST
N 84TH ST
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
NW 40TH ST
NW 27TH ST
NW 12TH ST
W MCKELVIE RD
INTERSTATE 80
ARBOR RD
W ALVO RD
PURPLE HEART HWY
Lincoln
PBSJ

Figure 3-8

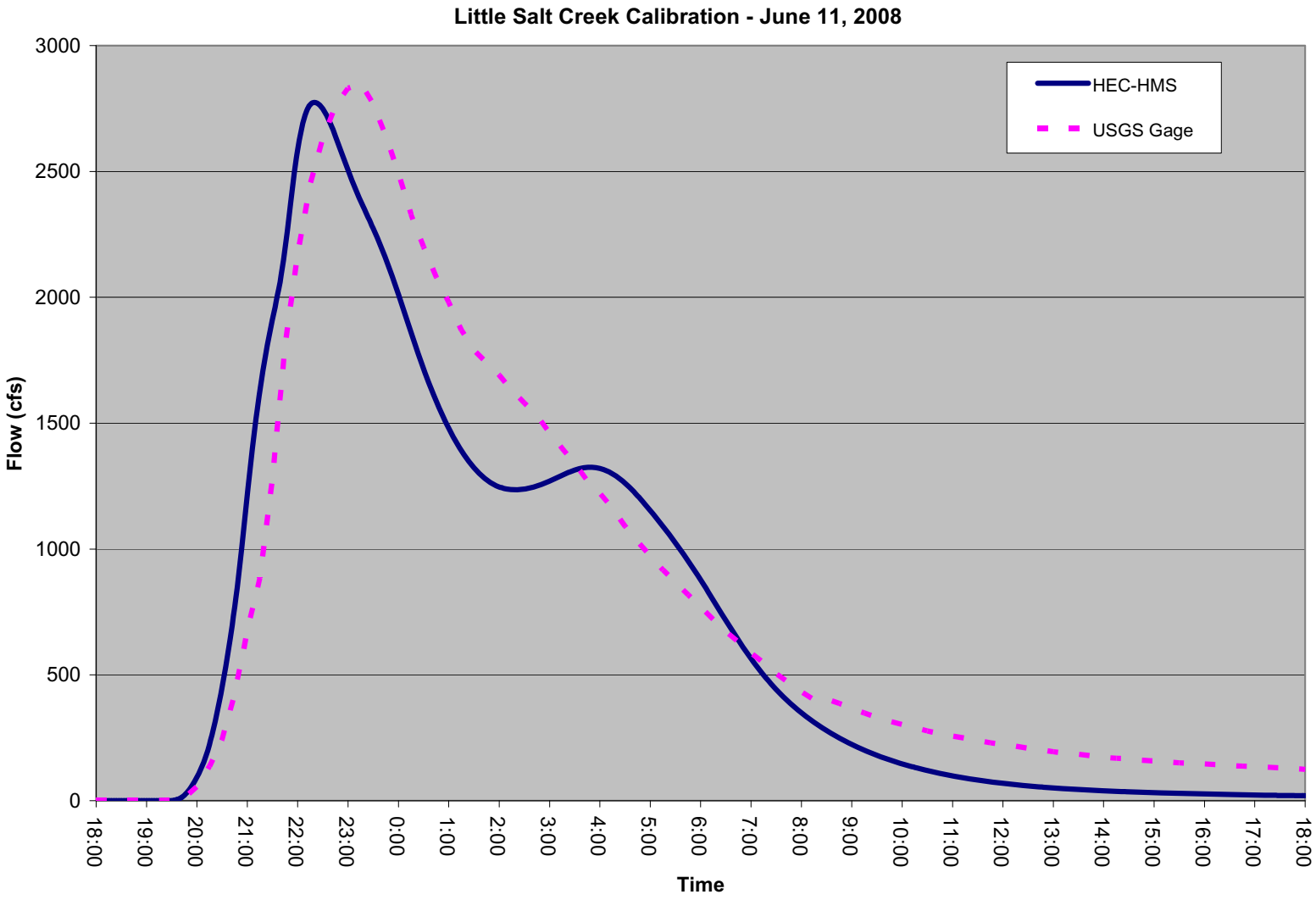

Figure 3-9: HEC-HMS calibration results compared versus the USGS gauge data

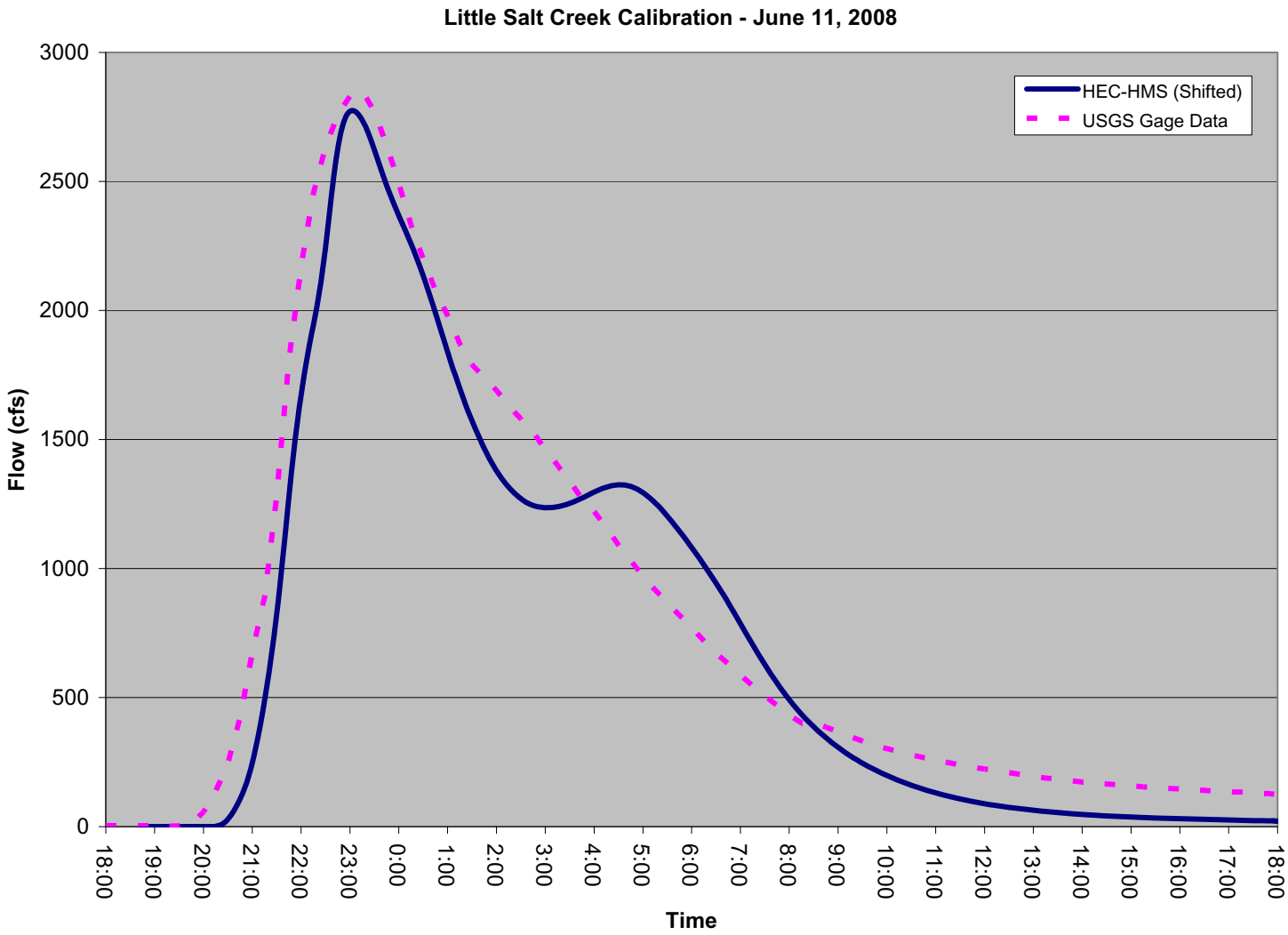

Figure 3-10: HEC-HMS calibration results compared versus the USGS gauge data. The model results have been shifted to compare the receding limbs of the hydrographs.

3.6 Modeling Results

Tables 3.8 and 3.9 present the HEC-HMS model results of the Little Salt Creek watershed under existing conditions compared to the output of the flood flow frequency analysis. The simulation results displayed in Tables 3.10 and 3.11 show the peak flow discharges at various locations of Little Salt Creek. Tables 3.12 and 3.13 show the cumulative volumes at the same locations. The locations at which these results were taken can be viewed in Figure 3-11.

Table 3.8 HEC-HMS model results compared to the flood flow frequency analysis

Percent Chance Exceedance	Computed Probability Flow (cfs)	HEC-HMS Results Flow (cfs)
0.2	35300	20909
1	16800	15000
2	11900	12700
10	4660	7430
20	2840	4290
50	1190	957

Table 3.9 HEC-HMS model results compared to the volume-duration-frequency analysis

	1-day Output	2-day Output	
Percent Chance Exceedance	Computed Probability Volume (ac-ft)	Computed Probability Volume (ac-ft)	HEC-HMS Results Volume (ac-ft)
0.2	16800	22100	9470
1	9460	12400	6810
2	7120	9380	5630
10	3190	4210	3410
20	2020	2670	2130
50	840	1110	721

Table 3.10 HEC-HMS model resultant peak flows for the 2-, 5-, and 10-yr return periods

Location ID	Stream	Description	2-year	5-year	10-year
			Peak Discharge (cfs)		
1	Little Salt Creek	Mouth of Little Salt Creek	1090	4390	7570
2	Little Salt Creek	Crossing at Waverly Rd	741	2160	3800
3	Little Salt Creek	Crossing at Mill Rd	781	2370	4100
4	Little Salt Creek	Crossing at Raymond Rd	833	2540	4160
5	Little Salt Creek	Crossing at Branched Oak Rd	539	1700	2820
6	Little Salt Creek	Crossing at Rock Creek Rd	670	1820	2830
7	Little Salt Creek	Crossing at Little Salt Rd	367	941	1400
8	Trib 15	Stream confluence north of 7th St. and Alvo Rd.	125	856	1478
9	Trib 20	Stream confluence east of 27th St. and Waverly Rd.	51.0	988	2047
10	Trib 65	Stream crossing west of 1st St. and Branched Oak Rd.	463	1290	1990

Table 3.11 HEC-HMS model resultant peak flows for the 50-, 100-, and 500-yr return periods

Location ID	Stream	Description	50-year	100-year	500-year
			Peak Discharge (cfs)		
1	Little Salt Creek	Mouth of Little Salt Creek	12000	14400	20000
2	Little Salt Creek	Crossing at Waverly Rd	7240	9200	14100
3	Little Salt Creek	Crossing at Mill Rd	7450	9360	14000
4	Little Salt Creek	Crossing at Raymond Rd	7340	9050	13200
5	Little Salt Creek	Crossing at Branched Oak Rd	4930	6130	8750
6	Little Salt Creek	Crossing at Rock Creek Rd	4430	5160	6720
7	Little Salt Creek	Crossing at Little Salt Rd	2080	2380	3020
8	Trib 15	Stream confluence north of 7th St. and Alvo Rd.	2830	3592	5137
9	Trib 20	Stream confluence east of 27th St. and Waverly Rd.	4045	5105	7225
10	Trib 65	Stream crossing west of 1st St. and Branched Oak Rd.	3170	3710	4970

Table 3.12 HEC-HMS model resultant cumulative volumes for the 2-, 5-, and 10-yr return periods

Location ID	Stream	Description	2-year	5-year	10-year
			Total Volume (ac-ft)		
1	Little Salt Creek	Mouth of Little Salt Creek	789	2270	3620
2	Little Salt Creek	Crossing at Waverly Rd	496	1240	1920
3	Little Salt Creek	Crossing at Mill Rd	404	1020	1590
4	Little Salt Creek	Crossing at Raymond Rd	336	849	1320
5	Little Salt Creek	Crossing at Branched Oak Rd	159	400	622
6	Little Salt Creek	Crossing at Rock Creek Rd	120	270	396
7	Little Salt Creek	Crossing at Little Salt Rd	42.2	95.1	139
8	Trib 15	Stream confluence north of 7th St. and Alvo Rd.	22.9	138	236
9	Trib 20	Stream confluence east of 27th St. and Waverly Rd.	11.8	141	266
10	Trib 65	Stream crossing west of 1st St. and Branched Oak Rd.	99.6	239	371

Table 3.13 HEC-HMS model resultant cumulative volumes for the 50-, 100-, and 500-yr return periods

Location ID	Stream	Description	50-year	100-year	500-year
			Total Volume (ac-ft)		
1	Little Salt Creek	Mouth of Little Salt Creek	5930	7170	9950
2	Little Salt Creek	Crossing at Waverly Rd	3140	3760	5170
3	Little Salt Creek	Crossing at Mill Rd	2620	3150	4350
4	Little Salt Creek	Crossing at Raymond Rd	2180	2630	3640
5	Little Salt Creek	Crossing at Branched Oak Rd	1020	1230	1700
6	Little Salt Creek	Crossing at Rock Creek Rd	603	708	944
7	Little Salt Creek	Crossing at Little Salt Rd	212	248	330
8	Trib 15	Stream confluence north of 7th St. and Alvo Rd.	412	504	704
9	Trib 20	Stream confluence east of 27th St. and Waverly Rd.	486	601	855
10	Trib 65	Stream crossing west of 1st St. and Branched Oak Rd.	616	746	1040

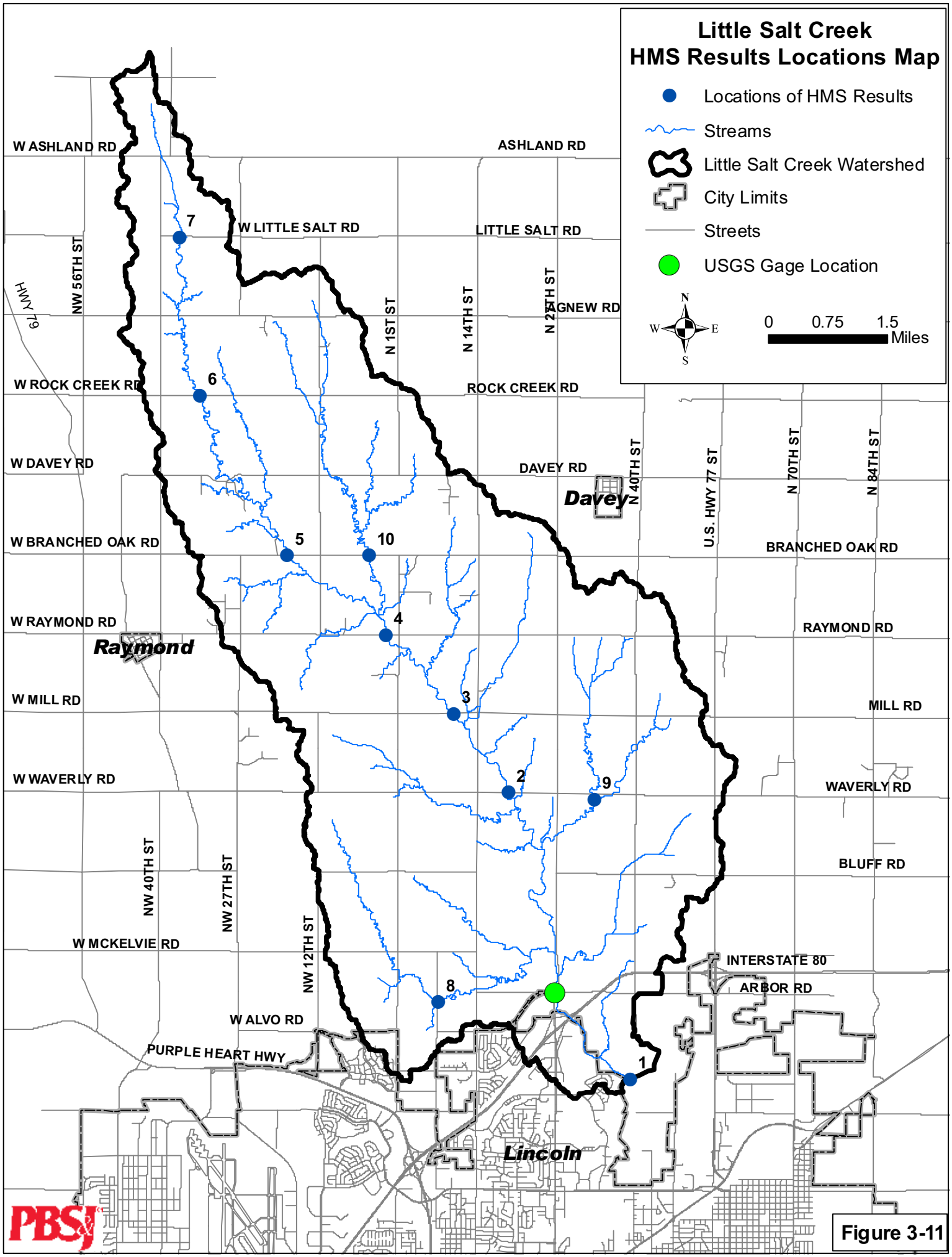
Little Salt Creek
HMS Results Locations Map
Locations of HMS Results
Streams
Little Salt Creek Watershed
City Limits
Streets
USGS Gage Location
N
W
E
S
0
0.75
1.5
Miles
W ASHLAND RD
ASHLAND RD
W LITTLE SALT RD
LITTLE SALT RD
NW 56TH ST
HWY 79
N 1ST ST
N 14TH ST
N 27TH ST
AGNEW RD
W ROCK CREEK RD
ROCK CREEK RD
W DAVEY RD
DAVEY RD
Davey
N 40TH ST
U.S. HWY 77 ST
N 70TH ST
N 84TH ST
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
NW 40TH ST
NW 27TH ST
NW 12TH ST
W MCKELVIE RD
INTERSTATE 80
ARBOR RD
W ALVO RD
PURPLE HEART HWY
Lincoln
1
2
3
4
5
6
7
8
9
10
PBSJ

Figure 3-11

3.7 Future Land Use

Future land use conditions were analyzed to predict the hydrologic effects of urbanization on the Little Salt Creek watershed. This involved the estimation of future buildout within the watershed. For the purpose of this study, full buildout of the watershed was not assumed. Instead, buildout of the watershed was defined by growth tiers. The growth tier boundaries and future land uses were provided by the Lincoln-Lancaster County Planning Department and are displayed in Figure 3-12. Under the 2030 development plan, it was assumed that only Tier 1 and Tier 2 would have changes to the land uses. These developments were considered to be two separate scenarios. The first scenario considered only the changes within Tier 1. The second scenario considered the modifications located within Tier 1 and Tier 2.

Within the Little Salt Creek watershed, the change in hydrologic response due to future conditions was modeled using the following process: initially determine the NRCS soil-cover complex curve number (CN) of each subbasin for both existing conditions and, if applicable, for changed future conditions; then determine the volume of runoff difference between the future and existing conditions CN values for each such changed subbasin as well as the change to a subbasin lag time; finally, modify the respective changed subbasin initial loss value by the difference between the future and existing volume of runoff. Thus a subbasin that is predicted to have more impervious area under future conditions was modeled as losing initial storage volume due to the loss of pervious area. In some cases the future land use will actually gain more storage due to the land use changing from, e.g., row crops to grasslands or parks. These subbasins had initial storage added within the future conditions model to reflect the assumed future changes.

This section presents the techniques to modify the hydrologic model for changed watershed land use. Section 6 will present modeling results for anticipated future expansion of the watershed. This analysis will include low flow assessments with regard to water quality (increased volume of storm water leading to increase loading of heavy metals, oils and nutrients) as well as flood flow assessments.

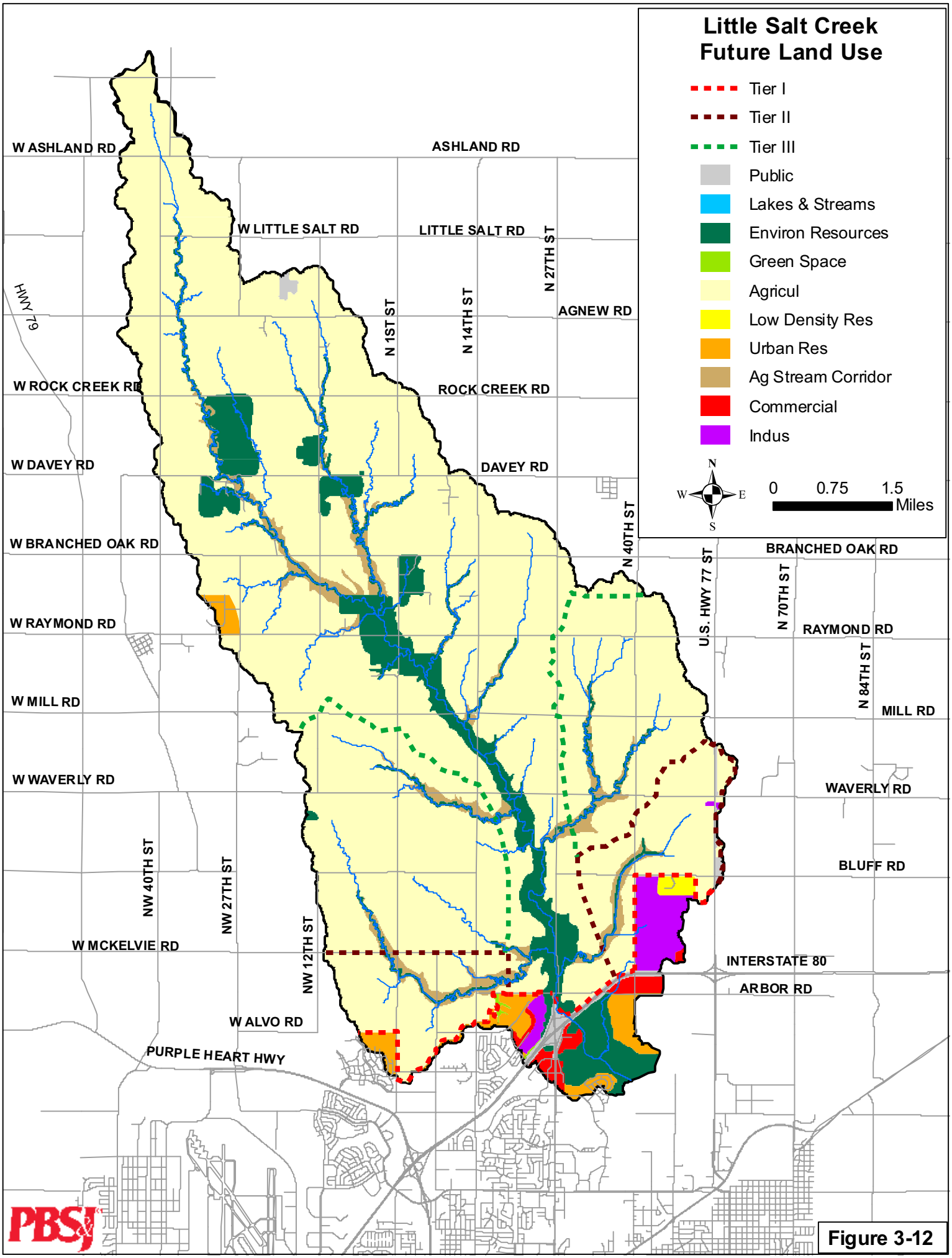
Little Salt Creek
Future Land Use
Tier I
Tier II
Tier III
Public
Lakes & Streams
Environ Resources
Green Space
Agricul
Low Density Res
Urban Res
Ag Stream Corridor
Commercial
Indus
N
W
E
S
0
0.75
1.5
Miles
W ASHLAND RD
ASHLAND RD
W LITTLE SALT RD
LITTLE SALT RD
N 27TH ST
N 1ST ST
N 14TH ST
AGNEW RD
HWY 79
W ROCK CREEK RD
ROCK CREEK RD
W DAVEY RD
DAVEY RD
N 40TH ST
W BRANCHED OAK RD
BRANCHED OAK RD
U.S. HWY 77 ST
N 70TH ST
W RAYMOND RD
RAYMOND RD
N 84TH ST
W MILL RD
MILL RD
W WAVERLY RD
WAVERLY RD
BLUFF RD
NW 40TH ST
NW 27TH ST
NW 12TH ST
W MCKELVIE RD
INTERSTATE 80
ARBOR RD
W ALVO RD
PURPLE HEART HWY

Figure 3-12

3.7.1 Calculation of Existing and Future Curve Numbers

For basins contained within Tier 1, calculated CNs were based on the future land uses displayed within Figure 3-12. For basins overlapping the Tier 1 boundary, the composite CN was calculated from existing land uses (areas outside Tier 1) and future land uses (areas within Tier 1).

The composite curve number for each basin was calculated using digitized coverage's describing the existing and future land uses as well as the hydrologic soil groups. As previously mentioned, the existing and future land use information describing the vegetation and use (agricultural, urban, etc.) of the watershed were obtained from the City and are displayed in Figures 3-4 and 3-12. The hydrologic soil groups found within the watershed were obtained in SSURGO format from the NRCS. Overlaying the land use and soil group information resulted in composite areas that represented a specific combination of one land use and one soil group. Using this combination and assuming a normal antecedent moisture condition (AMC II) a CN value was assigned using tables published by the NRCS. A lookup table defining the utilized CN for each land use-soil group combination is displayed in Table 3-14. After assigning the CN values to each combination, the CN for each basin was calculated using an area-weighted average for each basin.

Table 3-14 Lookup table used to define the curve number for each land use-soil group combination

		Hydrologic Soil Group				
Land Use Category	**Cover Type (% Impervious)**	**A**	**B**	**C**	**D**	**W**
Ag/Stream Corridor	Woods - Grass Combination - Good	32	58	72	79	98
Agricultural	Row Crops - Contoured Good Condition	65	75	82	86	98
Tier 2	Future Land Uses Applied to Ag Lands	61	75	83	87	98
Commercial	Commercial and business (85%)	89	92	94	95	98
Forest and Woodlands	Woods - Fair Condition	36	60	73	79	98
Industrial	Industrial (72%)	81	88	91	93	98
Lakes and Streams	Water	98	98	98	98	98
Mining and Extraction	Non-contributing Depression Areas	0	0	0	0	0
Natural/Environmentally Sensitive	Wetlands	98	98	98	98	98
Other ROW	Open Space - Fair Condition	49	69	79	84	98
Parks and Open Space	Good Condition (> 75% grass)	39	61	74	80	98
Pastures and Grasslands	Good Condition	39	61	74	80	98
Public and Semi-Public	Open Space - Fair Condition	49	69	79	84	98
Residential, Low Density	Residential 1 acre (12%)	51	68	79	84	98
Residential, Urban	Residential 1/4 acres (38%)	61	75	83	87	98
Vacant Land	Open Space - Fair Condition	49	69	79	84	98

For Tier 2, a future land use category was developed based on a typical square mile of development as set by the Lincoln-Lancaster County Planning Department. Table 3-15 summarizes the land use category percentages used for the future land use, which was applied to the existing conditions agricultural land use areas located within Tier 2.

Table 3-15 Breakdown of future land uses applied to agricultural lands within Tier 2

Land Use Category	Percentage of Area (%)
Commercial	11
Parks and Open Space	11
Public and Semi-Public	3
Residential, Urban	75

Using the land use breakdown displayed in Table 3-15, a composite CN for the agricultural lands defined within Tier 2 was calculated. This was performed by multiplying the fraction of each land use category by its corresponding CN and then summing the values. Using this technique, the future conditions CNs corresponding to these current agricultural lands with hydrologic soil groups A, B, C, and D were found to be 61, 75, 83, and 87, respectively. These values were then utilized to calculate a composite curve number for each basin located within Tier 2. There were multiple locations where basins overlapped the Tier 2 boundaries. In such cases, the areas of the basin outside Tier 2 utilized the existing land use classification, while the areas within the Tier 2 boundary were classified as future land use. In the cases where a basin included areas located within Tier 1 and Tier 2, a composite CN representing the future land use conditions within Tier 1 and Tier 2 was calculated.

3.7.2 Calculation of Changes to Initial Storage

As previously mentioned within Section 3.2.4 of this report, the Initial and Constant Loss Method was used to simulate the runoff volume for each basin. Therefore, a relation between the change in CN and the change in initial loss was made. The future land use CNs were compared to the existing CNs for those subbasins that were modified within Tier 1 and Tier 2. The difference between the future and existing CNs were assumed to be due to a change in the initial loss value.

To calculate the change in initial loss, the following equation relating runoff volume for a given rainfall depth and CN was used:

$$Q = \frac{(CN(P+2)-200)^2}{CN(CN(P-8)+800)}$$

in which CN equals the dimensionless CN value, P represents the total rainfall in inches, and Q equals the resulting runoff in inches. This equation is referenced in “Engineering Hydrology, Principles and Practices” (Ponce, V., 1989). For this particular study, a rainfall value of 2.35” was utilized. The rainfall depth of 2.35” was implemented due to the fact that it produced a runoff of 0.5” for the entire watershed under existing conditions. This depth will be used for the Water Quality Assessment presented in Section 6. Also, the initial storage depth for all curve numbers within the Little Salt Creek watershed would have been satisfied prior to 2.35” rainfall. Therefore, any changes to the initial storage to reflect future conditions would be readily apparent.

After calculating the runoff (Q) for each basin within Tier 1 and Tier 2 with the existing and future land use CNs, the difference in runoff (Q_d) was calculated using the following:

$$Q_d = Q_e - Q_f$$

where Q_e and Q_f correspond to the runoff resulting from the existing and future CNs for each basin, respectively. This difference (Q_d) was then added to the existing initial loss value. Tables 3-16 and 3-17 display the adjusted initial loss values for the Tier 1 and Tier 2 scenarios.

Table 3- 16 Comparison of curve numbers, calculated runoff, and initial loss values for basins within Tier 1 using 2.35" of rainfall

	CN		Q (in)			Init Loss (in)	
NAME	Existing	Future	Existing	Future	Diff (in)	Existing	Future
LSC000500	79	90	0.74	1.40	-0.66	1.50	0.84
LSC000505	80	87	0.79	1.19	-0.40	1.50	1.10
LSC000510	77	89	0.65	1.32	-0.68	1.50	0.82
LSC000600	98	98	2.12	2.12	0.00	1.50	1.50
LSC000700	83	87	0.94	1.19	-0.24	1.50	1.26
LSC000705	81	85	0.84	1.06	-0.22	1.50	1.28
LSC001015	77	82	0.65	0.89	-0.24	2.00	1.76
LSC001025	76	76	0.61	0.61	0.00	2.00	2.00
LSC001510	73	76	0.49	0.61	-0.12	1.50	1.38
LSC021005	77	87	0.65	1.19	-0.54	2.00	1.46
LSC031000	75	74	0.56	0.53	0.04	2.00	2.04
LSC031010	75	75	0.56	0.56	0.00	2.00	2.00
LSC031505	74	79	0.53	0.74	-0.21	2.00	1.79
LSC041515	73	81	0.49	0.84	-0.35	1.50	1.15
LSC0MC000	76	94	0.61	1.73	-1.12	1.50	0.38
LSC0MC005	81	95	0.84	1.82	-0.98	1.50	0.52
LSC0MC007	78	85	0.69	1.06	-0.37	1.50	1.13
LSC0MC010	77	80	0.65	0.79	-0.14	1.50	1.36

Table 3-17 Comparison of curve numbers, calculated runoff, and initial loss values for basins within Tier 2 using 2.35" of rainfall

	CN		Q (in)			Init Loss (in)	
NAME	Existing	Future	Existing	Future	Diff (in)	Existing	Future
LSC000505	80	87	0.79	1.19	-0.40	1.50	1.10
LSC001010	79	79	0.74	0.74	0.00	2.00	2.00
LSC001015	77	80	0.65	0.79	-0.14	2.00	1.86
LSC001020	71	74	0.42	0.53	-0.11	2.00	1.89
LSC001025	76	76	0.61	0.61	0.00	2.00	2.00
LSC001030	75	76	0.56	0.61	-0.04	2.00	1.96
LSC001035	73	76	0.49	0.61	-0.12	2.00	1.88
LSC001040	75	77	0.56	0.65	-0.08	2.00	1.92
LSC001045	76	77	0.61	0.65	-0.04	2.00	1.96
LSC001050	76	76	0.61	0.61	0.00	2.00	2.00
LSC001505	74	77	0.53	0.65	-0.12	1.50	1.38
LSC001510	73	76	0.49	0.61	-0.12	1.50	1.38
LSC001515	78	79	0.69	0.74	-0.05	2.00	1.95
LSC001520	74	77	0.53	0.65	-0.12	2.00	1.88
LSC001525	77	79	0.65	0.74	-0.09	2.00	1.91
LSC001530	70	77	0.39	0.65	-0.26	2.00	1.74
LSC001540	75	78	0.56	0.69	-0.13	2.00	1.87
LSC011000	84	86	1.00	1.12	-0.12	1.50	1.38
LSC011005	76	77	0.61	0.65	-0.04	1.50	1.46
LSC011010	76	76	0.61	0.61	0.00	1.50	1.50
LSC011500	75	79	0.56	0.74	-0.17	1.50	1.33
LSC011505	76	77	0.61	0.65	-0.04	1.50	1.46
LSC021000	81	80	0.84	0.79	0.05	2.00	2.05
LSC021500	76	76	0.61	0.61	0.00	2.00	2.00
LSC031000	75	74	0.56	0.53	0.04	2.00	2.04
LSC031005	75	77	0.56	0.65	-0.08	2.00	1.92
LSC031010	75	76	0.56	0.61	-0.04	2.00	1.96
LSC031500	74	79	0.53	0.74	-0.21	2.00	1.79
LSC031505	74	80	0.53	0.79	-0.26	2.00	1.74
LSC041500	69	74	0.35	0.53	-0.17	2.00	1.83
LSC041505	68	77	0.32	0.65	-0.32	2.00	1.68
LSC041510	64	77	0.22	0.65	-0.43	1.50	1.07
LSC041515	73	80	0.49	0.79	-0.30	1.50	1.20
LSC041520	69	77	0.35	0.65	-0.29	1.50	1.21

3.7.3 Guidelines for Modifying the Hydrologic Model Initial Storage to Account for Future Land Use Changes

Based on the above analysis, Table 3-18 presents general guidelines to modify the existing conditions model as the basin continues to develop.

Table 3-18 Guideline for modifying subbasin initial storage depth based on change in curve number

Existing Condition CN Value at or lower than 74	
Difference Between Future Condition and Existing Condition CN Value	**Change in Initial Storage Depth (Added if Future CN is Smaller than Existing CN)**
0 – 1	0
2 – 3	0.1
4 – 5	0.2
6 – 8	0.3
9 - 14	0.4
Existing Condition CN Value Greater than 74	
0 - 1	0
2 - 3	0.1
4 - 5	0.2
6 - 8	0.4
9 - 10	0.5
11 - 12	0.7
13 - 15	1.0
> 15	1.1

The above process is two-step: obtain the curve number for a subbasin, then modify the initial storage value to reflect the change. This process is recommended for Little Salt Creek due to the amount of storage that has been constructed within the watershed. Using the curve number method alone does not account for this man-made storage. Had this storage been provided by only a few structures, then these structures could have been incorporated into the model – allowing the use of the curve number method to be utilized within the hydrologic model. However, the storage within Little Salt Creek is contained in many small cells throughout the watershed, making it more difficult to describe within a hydrologic model. Each of these storage cells would need to have the principal and emergency spillways surveyed and the stage-storage volume measured separately. These storage cells could just not be ignored either. Based on the runoff analysis for the USGS gauge located within the basin, the constructed storage does have a significant effect. However, since the future development will be required to maintain this storage, the method outlined above will remain in effect as the Little Salt Creek develops.

3.7.4 Modifying the Hydrologic Model Lag Time to Account for Future Land Use Changes

Finally, a watershed that is becoming urbanized will generally have a quicker hydrologic response time due to an increase in impervious surfaces. This response time is described within the Little Salt Creek watershed hydrologic model as the lag time. This is the time from the centroid of the rainfall event until the time to peak of the flood hydrograph at the point of interest. The lag time is calculated based on the following NRCS equation:

$$L = \frac{l^{0.8}\left(S+1\right)^{0.7}}{1900Y^{0.5}}$$

in which L equals the lag time in hours; *l* is defined as the hydraulic length of the catchment in feet; Y represents the average watershed land slope in percent; and

$$S = \frac{1000}{CN} - 10$$

in which CN represents the dimensionless curve number.

For the Little Salt Creek watershed, Tables 3-19 and 3-20 present the multiplying factor for subbasins having a change from an existing curve number to a future curve number. These tables were based on the above equation.

Table 3-19 Look up table for the lag time multiplying factor due to changes in curve number (future CNs ranging from 62-80)

Existing CN	Future CN																		
	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
62	1.00	0.98	0.95	0.93	0.91	0.89	0.87	0.85	0.83	0.81	0.79	0.77	0.75	0.73	0.71	0.69	0.67	0.65	0.64
63	1.02	1.00	0.98	0.95	0.93	0.91	0.89	0.87	0.85	0.83	0.81	0.79	0.77	0.75	0.73	0.71	0.69	0.67	0.65
64	1.05	1.02	1.00	0.98	0.95	0.93	0.91	0.89	0.87	0.85	0.82	0.80	0.78	0.76	0.74	0.72	0.70	0.69	0.67
65	1.07	1.05	1.02	1.00	0.98	0.95	0.93	0.91	0.89	0.87	0.84	0.82	0.80	0.78	0.76	0.74	0.72	0.70	0.68
66	1.10	1.07	1.05	1.02	1.00	0.98	0.95	0.93	0.91	0.89	0.86	0.84	0.82	0.80	0.78	0.76	0.74	0.72	0.70
67	1.12	1.10	1.07	1.05	1.02	1.00	0.98	0.95	0.93	0.91	0.89	0.86	0.84	0.82	0.80	0.78	0.76	0.74	0.72
68	1.15	1.13	1.10	1.07	1.05	1.02	1.00	0.98	0.95	0.93	0.91	0.88	0.86	0.84	0.82	0.80	0.77	0.75	0.73
69	1.18	1.15	1.13	1.10	1.07	1.05	1.02	1.00	0.98	0.95	0.93	0.91	0.88	0.86	0.84	0.82	0.79	0.77	0.75
70	1.21	1.18	1.15	1.13	1.10	1.08	1.05	1.02	1.00	0.98	0.95	0.93	0.90	0.88	0.86	0.84	0.81	0.79	0.77
71	1.24	1.21	1.18	1.16	1.13	1.10	1.08	1.05	1.02	1.00	0.98	0.95	0.93	0.90	0.88	0.86	0.83	0.81	0.79
72	1.27	1.24	1.21	1.18	1.16	1.13	1.10	1.08	1.05	1.03	1.00	0.98	0.95	0.93	0.90	0.88	0.85	0.83	0.81
73	1.30	1.27	1.24	1.21	1.19	1.16	1.13	1.10	1.08	1.05	1.03	1.00	0.97	0.95	0.93	0.90	0.88	0.85	0.83
74	1.34	1.31	1.28	1.25	1.22	1.19	1.16	1.13	1.11	1.08	1.05	1.03	1.00	0.97	0.95	0.92	0.90	0.87	0.85
75	1.37	1.34	1.31	1.28	1.25	1.22	1.19	1.16	1.13	1.11	1.08	1.05	1.03	1.00	0.97	0.95	0.92	0.90	0.87
76	1.41	1.38	1.34	1.31	1.28	1.25	1.22	1.19	1.16	1.14	1.11	1.08	1.05	1.03	1.00	0.97	0.95	0.92	0.90
77	1.45	1.41	1.38	1.35	1.32	1.29	1.26	1.23	1.20	1.17	1.14	1.11	1.08	1.05	1.03	1.00	0.97	0.95	0.92
78	1.49	1.45	1.42	1.39	1.35	1.32	1.29	1.26	1.23	1.20	1.17	1.14	1.11	1.08	1.06	1.03	1.00	0.97	0.95
79	1.53	1.49	1.46	1.42	1.39	1.36	1.33	1.30	1.26	1.23	1.20	1.17	1.14	1.11	1.09	1.06	1.03	1.00	0.97
80	1.57	1.54	1.50	1.47	1.43	1.40	1.36	1.33	1.30	1.27	1.24	1.21	1.18	1.15	1.12	1.09	1.06	1.03	1.00

Table 3-19 Look up table for the lag time multiplying factor due to changes in curve number (future CNs ranging from 62-80)

Existing CN	Future CN																		
	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
81	1.62	1.58	1.54	1.51	1.47	1.44	1.41	1.37	1.34	1.31	1.27	1.24	1.21	1.18	1.15	1.12	1.09	1.06	1.03
82	1.67	1.63	1.59	1.55	1.52	1.48	1.45	1.41	1.38	1.35	1.31	1.28	1.25	1.22	1.18	1.15	1.12	1.09	1.06
83	1.72	1.68	1.64	1.60	1.57	1.53	1.49	1.46	1.42	1.39	1.35	1.32	1.29	1.25	1.22	1.19	1.16	1.12	1.09
84	1.77	1.73	1.69	1.65	1.61	1.58	1.54	1.50	1.47	1.43	1.40	1.36	1.33	1.29	1.26	1.23	1.19	1.16	1.13
85	1.83	1.79	1.75	1.71	1.67	1.63	1.59	1.55	1.51	1.48	1.44	1.41	1.37	1.34	1.30	1.27	1.23	1.20	1.17
86	1.89	1.85	1.81	1.77	1.72	1.68	1.64	1.61	1.57	1.53	1.49	1.45	1.42	1.38	1.34	1.31	1.27	1.24	1.20
87	1.96	1.92	1.87	1.83	1.79	1.74	1.70	1.66	1.62	1.58	1.54	1.50	1.47	1.43	1.39	1.36	1.32	1.28	1.25
88	2.03	1.99	1.94	1.89	1.85	1.81	1.76	1.72	1.68	1.64	1.60	1.56	1.52	1.48	1.44	1.41	1.37	1.33	1.29
89	2.11	2.06	2.01	1.97	1.92	1.88	1.83	1.79	1.75	1.70	1.66	1.62	1.58	1.54	1.50	1.46	1.42	1.38	1.34
90	2.19	2.14	2.09	2.05	2.00	1.95	1.91	1.86	1.82	1.77	1.73	1.68	1.64	1.60	1.56	1.52	1.48	1.44	1.40
91	2.29	2.24	2.18	2.13	2.08	2.03	1.99	1.94	1.89	1.85	1.80	1.76	1.71	1.67	1.62	1.58	1.54	1.50	1.46
92	2.39	2.34	2.28	2.23	2.18	2.13	2.08	2.03	1.98	1.93	1.88	1.83	1.79	1.74	1.70	1.65	1.61	1.56	1.52
93	2.50	2.45	2.39	2.34	2.28	2.23	2.17	2.12	2.07	2.02	1.97	1.92	1.87	1.83	1.78	1.73	1.69	1.64	1.59
94	2.63	2.57	2.51	2.46	2.40	2.34	2.29	2.23	2.18	2.13	2.07	2.02	1.97	1.92	1.87	1.82	1.77	1.72	1.68
95	2.78	2.72	2.66	2.59	2.53	2.47	2.42	2.36	2.30	2.25	2.19	2.14	2.08	2.03	1.98	1.92	1.87	1.82	1.77
96	2.96	2.89	2.82	2.76	2.69	2.63	2.57	2.51	2.44	2.39	2.33	2.27	2.21	2.16	2.10	2.04	1.99	1.93	1.88
97	3.17	3.09	3.02	2.95	2.88	2.81	2.75	2.68	2.62	2.55	2.49	2.43	2.37	2.31	2.25	2.19	2.13	2.07	2.01
98	3.43	3.35	3.27	3.20	3.12	3.05	2.98	2.91	2.84	2.77	2.70	2.63	2.57	2.50	2.44	2.37	2.31	2.24	2.18

Table 3-20 Look up table for the lag time multiplying factor due to changes in curve number (future CNs ranging from 81-98)

Existing CN	Future CN																	
	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98
62	0.62	0.60	0.58	0.56	0.55	0.53	0.51	0.49	0.47	0.46	0.44	0.42	0.40	0.38	0.36	0.34	0.32	0.29
63	0.63	0.61	0.60	0.58	0.56	0.54	0.52	0.50	0.49	0.47	0.45	0.43	0.41	0.39	0.37	0.35	0.32	0.30
64	0.65	0.63	0.61	0.59	0.57	0.55	0.53	0.52	0.50	0.48	0.46	0.44	0.42	0.40	0.38	0.35	0.33	0.31
65	0.66	0.64	0.62	0.60	0.59	0.57	0.55	0.53	0.51	0.49	0.47	0.45	0.43	0.41	0.39	0.36	0.34	0.31
66	0.68	0.66	0.64	0.62	0.60	0.58	0.56	0.54	0.52	0.50	0.48	0.46	0.44	0.42	0.39	0.37	0.35	0.32
67	0.69	0.67	0.65	0.63	0.61	0.59	0.57	0.55	0.53	0.51	0.49	0.47	0.45	0.43	0.40	0.38	0.36	0.33
68	0.71	0.69	0.67	0.65	0.63	0.61	0.59	0.57	0.55	0.52	0.50	0.48	0.46	0.44	0.41	0.39	0.36	0.34
69	0.73	0.71	0.69	0.67	0.64	0.62	0.60	0.58	0.56	0.54	0.52	0.49	0.47	0.45	0.42	0.40	0.37	0.34
70	0.75	0.73	0.70	0.68	0.66	0.64	0.62	0.59	0.57	0.55	0.53	0.51	0.48	0.46	0.43	0.41	0.38	0.35
71	0.77	0.74	0.72	0.70	0.68	0.65	0.63	0.61	0.59	0.56	0.54	0.52	0.49	0.47	0.45	0.42	0.39	0.36
72	0.79	0.76	0.74	0.72	0.69	0.67	0.65	0.63	0.60	0.58	0.56	0.53	0.51	0.48	0.46	0.43	0.40	0.37
73	0.81	0.78	0.76	0.73	0.71	0.69	0.66	0.64	0.62	0.59	0.57	0.55	0.52	0.49	0.47	0.44	0.41	0.38
74	0.83	0.80	0.78	0.75	0.73	0.71	0.68	0.66	0.63	0.61	0.58	0.56	0.53	0.51	0.48	0.45	0.42	0.39
75	0.85	0.82	0.80	0.77	0.75	0.72	0.70	0.67	0.65	0.62	0.60	0.57	0.55	0.52	0.49	0.46	0.43	0.40
76	0.87	0.84	0.82	0.79	0.77	0.74	0.72	0.69	0.67	0.64	0.62	0.59	0.56	0.53	0.51	0.48	0.44	0.41
77	0.89	0.87	0.84	0.82	0.79	0.76	0.74	0.71	0.69	0.66	0.63	0.61	0.58	0.55	0.52	0.49	0.46	0.42
78	0.92	0.89	0.86	0.84	0.81	0.78	0.76	0.73	0.70	0.68	0.65	0.62	0.59	0.56	0.53	0.50	0.47	0.43
79	0.94	0.92	0.89	0.86	0.83	0.81	0.78	0.75	0.72	0.70	0.67	0.64	0.61	0.58	0.55	0.52	0.48	0.45
80	0.97	0.94	0.91	0.89	0.86	0.83	0.80	0.77	0.74	0.72	0.69	0.66	0.63	0.60	0.57	0.53	0.50	0.46

Table 3-20 Look up table for the lag time multiplying factor due to changes in curve number (future CNs ranging from 81-98)

Existing CN	Future CN																	
	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98
81	1.00	0.97	0.94	0.91	0.88	0.85	0.83	0.80	0.77	0.74	0.71	0.68	0.65	0.61	0.58	0.55	0.51	0.47
82	1.03	1.00	0.97	0.94	0.91	0.88	0.85	0.82	0.79	0.76	0.73	0.70	0.67	0.63	0.60	0.56	0.53	0.49
83	1.06	1.03	1.00	0.97	0.94	0.91	0.88	0.85	0.81	0.78	0.75	0.72	0.69	0.65	0.62	0.58	0.54	0.50
84	1.10	1.06	1.03	1.00	0.97	0.94	0.90	0.87	0.84	0.81	0.78	0.74	0.71	0.67	0.64	0.60	0.56	0.52
85	1.13	1.10	1.07	1.03	1.00	0.97	0.93	0.90	0.87	0.83	0.80	0.77	0.73	0.70	0.66	0.62	0.58	0.53
86	1.17	1.14	1.10	1.07	1.03	1.00	0.97	0.93	0.90	0.86	0.83	0.79	0.76	0.72	0.68	0.64	0.60	0.55
87	1.21	1.18	1.14	1.11	1.07	1.04	1.00	0.96	0.93	0.89	0.86	0.82	0.78	0.74	0.70	0.66	0.62	0.57
88	1.26	1.22	1.18	1.15	1.11	1.07	1.04	1.00	0.96	0.93	0.89	0.85	0.81	0.77	0.73	0.69	0.64	0.59
89	1.30	1.27	1.23	1.19	1.15	1.11	1.08	1.04	1.00	0.96	0.92	0.88	0.84	0.80	0.76	0.71	0.67	0.62
90	1.36	1.32	1.28	1.24	1.20	1.16	1.12	1.08	1.04	1.00	0.96	0.92	0.88	0.83	0.79	0.74	0.69	0.64
91	1.41	1.37	1.33	1.29	1.25	1.21	1.17	1.13	1.08	1.04	1.00	0.96	0.91	0.87	0.82	0.77	0.72	0.67
92	1.48	1.43	1.39	1.35	1.30	1.26	1.22	1.18	1.13	1.09	1.04	1.00	0.95	0.91	0.86	0.81	0.76	0.70
93	1.55	1.50	1.46	1.41	1.37	1.32	1.28	1.23	1.19	1.14	1.09	1.05	1.00	0.95	0.90	0.85	0.79	0.73
94	1.63	1.58	1.53	1.49	1.44	1.39	1.34	1.30	1.25	1.20	1.15	1.10	1.05	1.00	0.95	0.89	0.83	0.77
95	1.72	1.67	1.62	1.57	1.52	1.47	1.42	1.37	1.32	1.27	1.22	1.16	1.11	1.06	1.00	0.94	0.88	0.81
96	1.83	1.77	1.72	1.67	1.61	1.56	1.51	1.45	1.40	1.35	1.29	1.24	1.18	1.12	1.06	1.00	0.93	0.86
97	1.96	1.90	1.84	1.78	1.73	1.67	1.61	1.56	1.50	1.44	1.38	1.32	1.26	1.20	1.14	1.07	1.00	0.92
98	2.12	2.06	2.00	1.93	1.87	1.81	1.75	1.69	1.63	1.56	1.50	1.44	1.37	1.30	1.23	1.16	1.08	1.00