Section 3
Hydrologic Model Development

3.1 Introduction

This section provides a detailed description of the methodology used to develop the existing conditions hydrologic model for the Deadmans Run Watershed Study. The modeling was performed using USACE's HEC-HMS Version 3.0.

3.2 Hydrology Methodology

The HEC-HMS model was used to simulate runoff volumes and hydrographs resulting from design storms for 2-, 10-, 50-, 100- and 500-year return periods using the design storms outlined in the City's *Drainage Criteria Manual*. The hydrology methodology contains six primary components: subarea delineation, rainfall, runoff volume, runoff hydrographs, routing and storage.

3.2.1 Subarea Delineation

The Deadmans Run Watershed was delineated into approximately 40 subareas with an average area of 150 acres. Subarea delineation was initially performed using ArcView, HEC-GeoHMS, and DEM developed from the 1997 contour data provided by the City. The HEC-GeoHMS tool runs within ArcView and uses DEM to delineate subareas and to determine the overland flow path for each subarea. Another major advantage of using the HEC-GeoHMS tool was that it automates the HEC-HMS model development.

Using the HEC-GeoHMS tool, the approximate locations for subarea outlets, such as stream crossings, tributaries, and major lakes/ponds, were located using ArcView and available GIS data. The HEC-GeoHMS tool used these points to automatically delineate the subarea boundaries based on DEM. The preliminary HEC-HMS model was created based on the automated subbasin delineations.

The subarea boundaries were manually checked against contours, drainage structure locations, and the City's Urban Drainage Study (UDS) to accurately define the subareas based on the enclosed systems. The preliminary HEC-HMS model was manually modified to reflect updated subarea boundaries.

Subareas draining to Deadmans Run were given a unique alphanumeric name with the format DR-BB. "DR" is the two-letter code for the Deadmans Run Watershed. "BB" is a two-digit subarea number. Subarea names from the City's UDS were used to maintain consistency between the studies.

3.2.2 Rainfall

The Soil Conservation Service (SCS), now called the Natural Resources Conservation Service (NRCS), design storm with a Type II distribution was used to simulate rainfall events for each return interval. This method requires the rainfall depth for a storm duration of 24 hours. Table 3-1 summarizes the design rainfall depths for 24-hour events from the *City of Lincoln Drainage Criteria Manual* (*Manual*) dated February 22, 2000 (revised May 10, 2004) that were used in the HEC-HMS model. The peak intensity was derived by distributing the rainfall depth over a 24-

hour period using the Type II distribution and 6-minute increments. The peak intensity in inches per hour was calculated by multiplying ten 6-minute increments together. Extrapolations to the 500-year storm were conducted using the Gumbel distribution.

Table 3-1
Rainfall Duration Depths

Return Interval	Rainfall Depth (inches)	Peak Intensity (in/hr)
2-Year	3.00	3.31
10-Year	4.69	5.18
50-Year	6.00	6.62
100-Year	6.68	7.37
500-Year	8.05	8.89

3.2.3 Runoff Volume

The SCS curve number (CN) loss rate option in the HEC-HMS model was used to generate runoff volumes for each subarea. The SCS option uses an initial abstraction value and composite CN to estimate runoff volumes from each subarea for a particular design rainfall event.

Initial abstraction is defined as losses from rainfall before runoff begins. Initial abstraction is a function of the composite CN and is commonly calculated using Equation 1.

$$Ia = 0.2(1000/CN - 10) \qquad \text{Equation 1}$$

The CN is a function of the land use condition and hydrologic soil group (HSG). For each subarea, a composite CN was developed using GIS by overlaying the soils and land use coverages and spatially analyzing the percent of each surface type and soil condition in each subarea. Runoff CN tables from the *Manual* were used to assign a CN to each soil and land use combination. The CNs listed are for average antecedent runoff conditions.

Existing Land Use

For existing land use conditions, the digital land use data supplied by the City were used to determine a runoff CN. Figure 3-1 shows the existing land uses and Table 3-2 lists the percentage for each category. Table 3-3 shows the land use categories and the assigned CN value from the *Manual*. Several land use categories do not correspond directly with cover types located in the *Manual*. CNs for these land uses were assigned by determining an average percent impervious and calculating a composite CN.

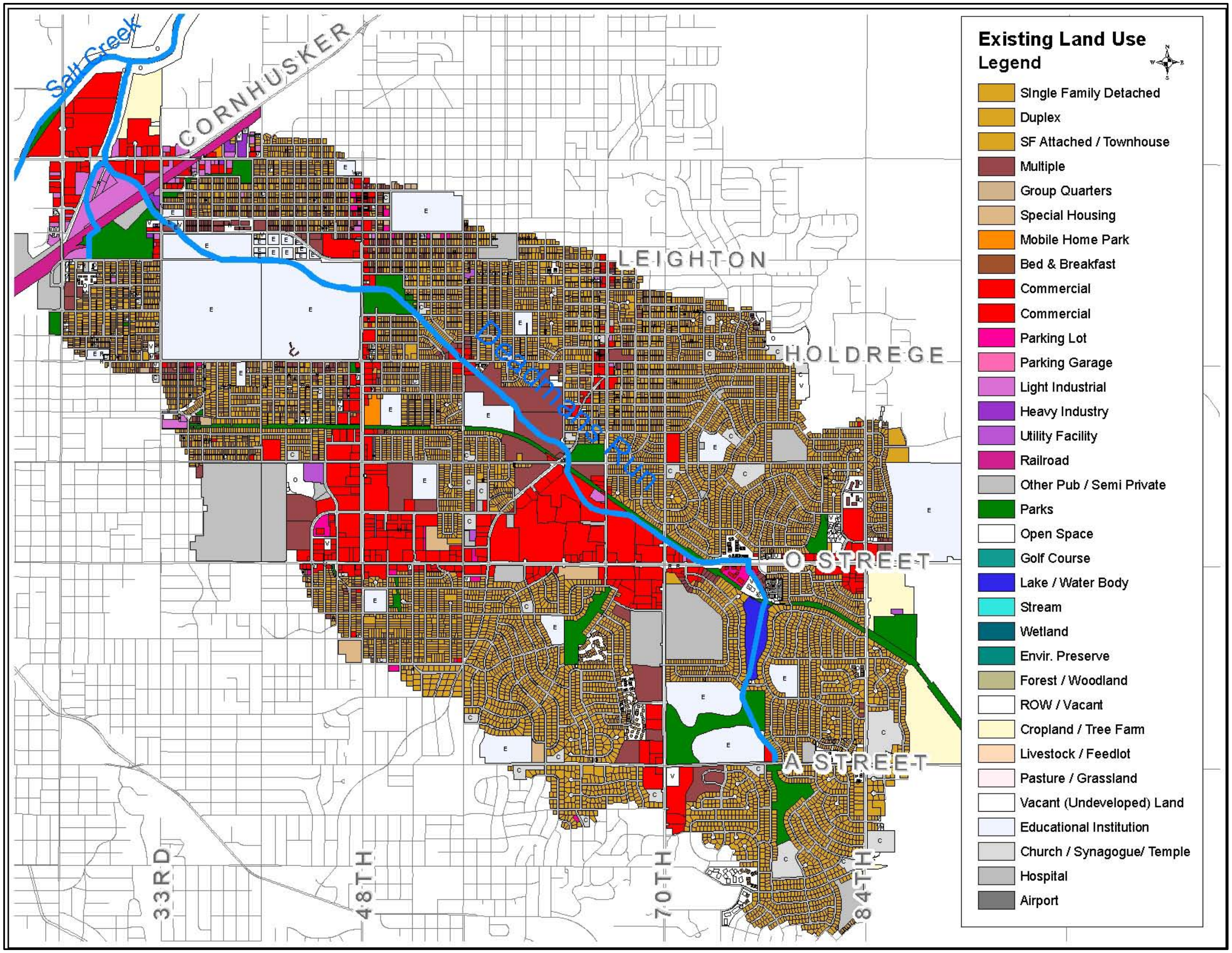

Figure 3-1
Deadmans Run Existing Conditions Land Use

Table 3-2
Existing Land Use Percentages

Land Use Category	***Percentage of Watershed Area***
Single Family (detached)	40.9
Educational Institution	12.9
Commercial NEC	12.0
Public and Semi	7.7
Apartments (w/number of units)	4.9
Park Land	4.8
Open Space	3.2
Agricultural Production: Crops/Tree Farm	2.2
Church, Synagogue, or Temple	2.1
Hospital	1.5
Railroad	1.4
Light Industrial	1.3
Vacant (Undeveloped) Land	1.1
Duplex	1.0
Stream/Creek	0.5
Attached Single Family (Townhouses)	0.5
Special Housing	0.5
Lake	0.4
Parking Lot (PL)	0.4
Utility Facility (e.g., communication tower)	0.2
Vacated ROW (retained by public entity)	0.1
Mobile Home including parks, courts (w/number of units)	0.1
Group Quarters	0.1
Heavy Industrial	0.1
Commercial w/Residential Unit(s) above	<0.1

As shown in Table 3-3, all agricultural land uses were designated a cover description of straight row crops in good hydrologic condition. Streams/Creeks, Lakes, and Wetlands were given a CN of 98. Land uses that do not correspond directly with a cover type were assigned a CN based on approximate average percent impervious and generally accepted engineering practice.

The category Single Family (detached) includes residential lots of varying sizes; however, the *Manual* CN tables have lot sizes broken into 1/8 acre, 1/4 acre, 1/3 acre, 1/2 acre, 1 acre and 2 acres. Single Family (detached) land use was assigned to one of these six land use CN categories based on the actual lot size. The lot size was calculated using GIS. For example, if a single-family (detached) land use parcel has an area of 1 acre, it was assigned a CN for 1- acre residential.

Table 3-3
Curve Numbers for Deadmans Run Watershed

Lincoln/Lancaster County Land Use	***Cover Type (% Imp)***	***HSG***			
		A	***B***	***C***	***D***
Agricultural Production: Crops/Tree Farm	Row Crops - Straight Row Good Condition	67	78	85	89
Airport	Compacted Soil	72	82	87	89
Apartments (w/number of units)	Residential 1/8 acre or less (65%)	77	85	90	92
Attached Single Family (Townhouses)	Residential 1/8 acre or less (65%)	77	85	90	92
Church, Synagogue, or Temple	Churches/Schools (75%)	84	89	92	94
Commercial NEC or w/residential above	Commercial and business (85%)	89	92	94	95
Duplex	Residential 1/8 acre or less (65%)	77	85	90	92
Educational Institution	Churches/Schools (75%)	84	89	92	94
Forest/Woodland	Woods - Fair Condition	36	60	73	79
Golf Course	Open Space - Good Condition	39	61	74	80
Group Quarters	Residential 1/8 acre or less (65%)	77	85	90	92
Heavy Industrial	Industrial (72%)	81	88	91	93
Hospitals	Churches/Schools (75%)	84	89	92	94
Lake and Wetlands	Water	98	98	98	98
Light Industrial	Industrial (72%)	81	88	91	93
Mobile Home including parks, courts (w/number of unit)	Residential 1/8 acre or less (65%)	77	85	90	92
Open Space	Open Space - Fair Condition	49	69	79	84
Park Land	Open Space - Fair Condition	49	69	79	84
Parking Lot (PL)/Street	Impervious (100%)	98	98	98	98
Pasture/Grassland	Pasture - Fair Condition	49	69	79	84
Public & Semi-Public NEC (e.g., cemetery)	Open Space - Fair Condition	49	69	79	84
Railroad	Gravel Covered Surface	76	85	89	91
Single Family (detached)	Residential 1/8 acre or less (65%)	77	85	90	92
	Residential 1/4 acre (38%)	61	75	83	87
	Residential 1/3 acre (30%)	57	72	81	86
	Residential 1/2 acre (25%)	54	70	80	85
	Residential 1 acre (20%)	51	68	79	84
	Residential 2 acres (12%)	51	68	79	84
Special Housing	Residential 1/8 acre or less (65%)	77	85	90	92
Stream/Creek	Water	98	98	98	98
Urban Residential	Residential 1/3 acre (30%)	57	72	81	86
Utility Facility (e.g., communication tower)	Commercial and business (85%)	89	92	94	95
VACANT (UNDEVELOPED) LAND	Open Space - Fair Condition	49	69	79	84
Vacated ROW (retained by public entity)	Open Space - Fair Condition	49	69	79	84

Hydrologic Soil Groups

HSGs by soil types were determined from the NRCS Lancaster County Soil Survey. Figure 3-2 shows the HSGs for the Deadmans Run Watershed. The HSG was used to assign a composite CN based on land cover for each subarea. Table 3-4 shows the soil types and their associated HSG for soils in Lancaster County, Nebraska. For soil types where HSGs are provided for drained and undrained conditions, the drained HSG was used to provide stormwater runoff values. For example, Colo soil type has an HSG designation of B/D where B is for drained conditions and D is for undrained. All Colo soils were categorized as having a HSG of B. Urban land complexes with mixed soil types used the more poorly drained complex. For example, the Crete-Sharpsburg (HSGs C-B) complex used an HSG of C.

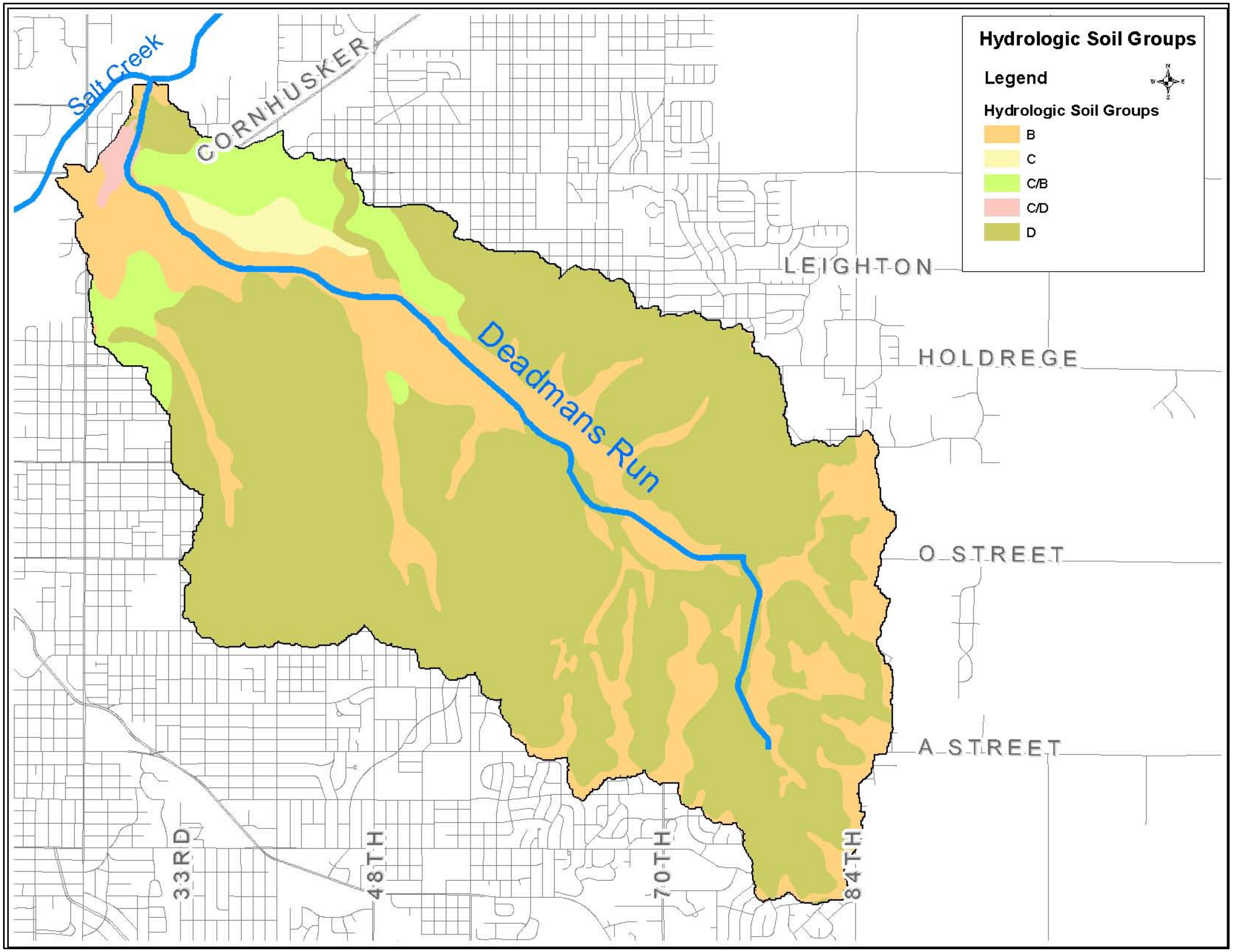

Figure 3-2
Deadmans Run Hydrologic Soil Groups

Table 3-4
Lancaster County Hydrologic Soil Groups

Soil Type	HSG	Soil Type	HSG	Soil Type	HSG	Soil Type	HSG
Aksarben	B	Fillmore	D	Nodaway	B	Wabash	D
Burchard	B	Geary	B	Pawnee	D	Water	D
Butler	D	Judson	B	Salmo	C/D	Wymore	D
Colo	B/D	Kennebec	B	Sharpsburg	B	Yutan	B
Crete	C	Malmo	D	Shelby	B	Zook	C/D
Crete-Sharpsburg	C/B	Mayberry	D	Steinauer	B		
Dickinson	B	Morrill	B	Urban Land	D		
Aksarben	B	Fillmore	D	Nodaway	B		

3.2.4 Runoff Hydrographs (Lag Time)

The SCS Dimensionless Unit Graph was used to distribute the runoff volume to a unit hydrograph. The determination of an SCS lag time was required for this method. Consistent with the methodology of TR-55, the lag time for a subarea was assumed to equal 0.6 times the time of concentration. The time of concentration, in turn, is defined as the time required for water to travel to the subarea outlet from the most hydraulically distant point in the subarea.

The time of concentration for each subarea was calculated using the methodology outlined in TR-55. For each subarea, the longest flow path to the subarea outlet was determined using DEM and ArcView/ArcInfo tools that divided the flow path into four elements:

- Sheet flow
- Shallow concentrated flow
- Secondary channel
- Primary channel

The travel times associated with each of the four elements were added to calculate the time of concentration for the subarea. The methodology described below was used to evaluate the existing surface conditions in the watershed.

Sheet Flow

Sheet flow is assumed to occur at the most hydraulically distant portion of the flow path. Using aerial photographs and contour data, the engineer estimated the sheet flow length. Physical data are required to calculate the travel time associated with sheet flow using the TR-55 methodology, including flow length, slope, and overland flow roughness coefficient. The sheet flow length was calculated using GIS. A composite overland flow roughness value was estimated by calculating a weighted roughness value using typical literature values for each surface condition and the length of sheet flow associated with each surface condition. The surface condition was determined from the aerial photos. Typical literature values are listed in Table 3-5. The engineer used Equation 2 to calculate whether the sheet flow length is acceptable. If the sheet flow length estimated using GIS does not conform to Equation 2, the engineer redigitized the sheet flow length until the equation was satisfied.

$$L <= (100*S^{0.5})/N \qquad \text{Equation 2}$$

Source: *Hydrologic Analysis and Design*, R.H. McCuen 2004

Table 3-5
Sheet Flow and Shallow Concentrated Flow Values

Surface Conditions	Overland Flow Roughness Coefficient	Shallow Flow Paved/Unpaved
Business-Heavy Commercial	0.06	Paved
Business-Light Commercial	0.08	Paved
Single Family I	0.23	Unpaved
Single Family II	0.17	Paved
Multi-Family Areas	0.13	Paved
Churches and Schools	0.10	Paved
Industrial-Light Areas	0.13	Paved
Industrial-Heavy Areas	0.09	Paved
Industrial-Parks, Cemeteries	0.22	Unpaved
Industrial-Railroad Yard	0.19	Paved
Undeveloped Areas (Permanent)	0.40	Unpaved
Impervious: Asphalt, Concrete, Roofs, etc.	0.011	Paved
Turfed	0.24	Unpaved
Wet Detention Basins	0.05	NA
Unknown Developed	0.17	Paved

Shallow Concentrated Flow

Shallow concentrated flow occurs between the areas of sheet flow and open channel flow. Shallow concentrated flow for urban areas may include gutters, swales, and sometimes small ditches. Open channels are assumed to begin where channels are visible on aerial photographs and include major conveyances, including creeks and rivers. To calculate the travel time associated with shallow concentrated flow by the TR-55 methodology, physical data including the shallow concentrated flow length, slope, and surface conditions along the path are required. Table 3-5 was used to derive a paved/unpaved coefficient (C) based on land use. Equation 3 was used to estimate the average velocity.

$$V = C*(Slope^{0.5}) \qquad \text{Equation 3}$$

The process for calculating the time of concentration for shallow concentrated flow was the same as performed for sheet flow.

Secondary Channel Flow and Primary Channel Flow

Secondary channel flow occurs between the end of shallow concentrated flow and the flow path intersection with the primary stream network, while primary channel flow occurs along the primary stream network to the subarea outlet. The primary stream network is the main channel of Deadmans Run and its tributaries that receive runoff from areas approximately 150 acres in size and greater. Depending upon location, a subarea may have one or both of these channel flow features. For example, a headwater subarea will probably include only flow length associated with the secondary stream network and none associated with the primary stream network.

Secondary channel flow in Deadmans Run Watershed includes storm sewers that convey only a small portion of large storm events. The rest of the peak flow travels by streets, lawns, and so on, to the outlet. Therefore, careful consideration of the hydraulic flow path and subsequent travel time were made. A pilot study within the watershed was analyzed to determine the impact of identifying secondary channel flow using the pipe network versus using overland flow of street grades. The pilot study results revealed negligible differences between the subbasin times of concentration for each secondary channel flow. Therefore, the flow path for secondary channel flow was delineated based on overland topography and the pipe network.

For both primary and secondary channel flow, travel time was calculated based on flow path length and velocity. Manning's equation was used to estimate average flow velocity in open channels and pipe flow. Average flow velocity in open channels was determined for bank-full elevation, channel slope, and the cross-sectional geometry developed from the GIS. Average flow velocity in pipes was determined assuming pipes at full capacity. Slope data were calculated by using the upstream and downstream elevations of the stream or pipe segment length in GIS.

3.2.5 Routing (Muskingum-Cunge)

The Muskingum-Cunge Routing method was used to route runoff through the watershed. An 8-point channel cross section was developed for each routed reach using the ArcView profiler tool and the elevation contours. The channel length and slope were also determined using ArcView and DEM.

3.2.6 Storage

The following stormwater detention facilities that provide significant flood control storage, identified on Figure 3-3, were included in the HEC-HMS model as a reservoir hydrologic element:

- Wyuka Cemetery including the ponds at 46th and "R" Street, and 42nd and Vine Street
- Taylor Park attenuation near Taylor Park Drive and 66th Street
- Dialysis Center of Lincoln, Inc. detention facility at Sycamore Drive north of "O" Street
- Russwood Park north and south detention facilities near Russwood Boulevard and Trail Ridge Court
- Saint Elizabeth's detention facility at 70th Street and "L" Street
- Wedgewood Lake
- Carriage Hill near Coachmens Drive and Carriage Hill Court

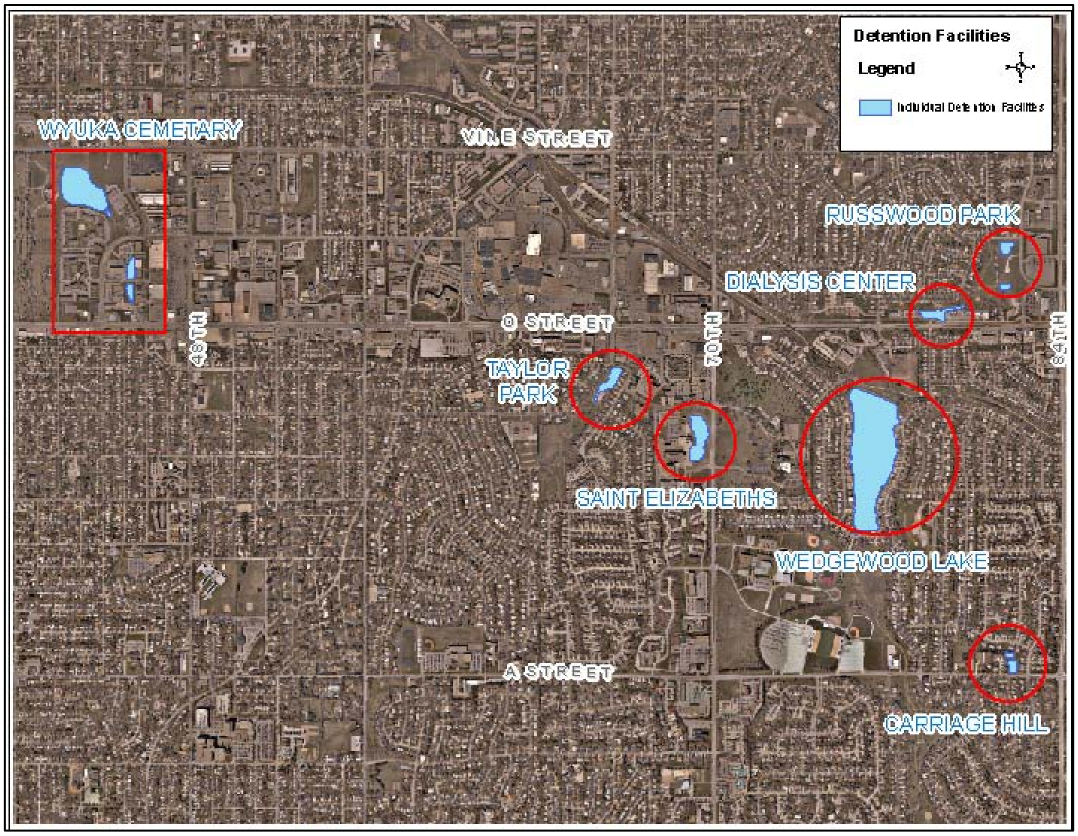

Figure 3-3
Stormwater Detention Facilities

3.2.7 Deadmans Run West Tributary

Available topographic data indicate the main channel may overflow the left overbank near 33rd and Leighton during high flows. The overflow is routed into a tributary that receives additional flow from contributing drainage. The tributary begins at 29th Street and Leighton Street and flows north draining under the railroad via a series of culverts approximately 1,500 feet to the southwest of the main channel. The tributary channel is routed approximately 2,000 feet downstream of the railroad culverts running parallel to State Fair Park Drive and ultimately discharging into Deadmans Run via a culvert just south of Cornhusker Highway. This tributary is referred to as the Deadmans Run West Tributary. Figure 3-4 depicts the tributary location, sources, and direction of flow.

The tributary receives two sources of inflow, contributing drainage and overflow from the main channel. The Deadmans Run West Tributary was included in both the hydrologic and hydraulic models to accurately represent the physical characteristics of the area. The hydrologic model routed the main channel without consideration of the overflow during high events (i.e., divergence nodes were not used in HEC-HMS). The hydraulic model incorporated the flow diversion from the main channel to the tributary by using an iterative process to balance stages between the two areas and is discussed in greater detail in Section 4.

Figure 3-4
Deadmans Run West Tributary

3.2.8 Flow Diversions

A total of five flow diversions were included in the HEC-HMS model where pipe networks crossed subbasin ridge lines. All pipe networks were considered, but only those that crossed ridge lines carrying more than 10 percent of the total peak flow from the drainage area were included in the hydrologic model. Rating curves for the pipe flow were calculated using Mannings equation for various flow depths within the pipe. Upon reaching maximum flow capacity within the pipe, the HEC-HMS model routed any additional flow based on overland flow topography.

3.3 Model Calibration and Verification

Precipitation information is available from the University of Nebraska's Institute of Agriculture and Natural Resources for a period of record spanning August 1986 to the present. However, because of insufficient stream flow data for the main channel, the HEC-HMS model was not calibrated using historical data. For verification purposes, the HEC-HMS model results were compared to the Lancaster County Flood Insurance Study (FIS), the City of Lincoln's UDS peak flows, the Army Corps of Engineers Section 22 report, Nebraska USGS regression equations, and rational method flows for the individual subbasins. Historical photos and eyewitness accounts of flooding during storm events were used in the verification process. The public open house meetings were used to facilitate the gathering of this information. Table 3-6 provides a comparison of the HEC-HMS results compared to effective FIS flow information at various locations along the main channel of Deadmans Run.

Table 3-6
100-Year Flow Comparisons

Location No.	Description	FEMA	HMS Model[1]	Percent Change
1	At mouth	9,660	9,078	-7
2	At 38th Street	8,410	8,193	-6
3	Below 48th Street	8,530	8,628	2
4	Above 48th Street	7,210	7,426	3
5	At Cotner	5,780	6,350	11
6	Below 66th Street	4,980	5,764	20
7	Above 66th Street	3,330	5,534	73
8	Below "O" Street	2,790	3,066	9
9	Above "O" Street	1,760	1,876	5
10	At "A" Street	1,360	1,007	-29

1 - Peak flow rates based on existing land use conditions

Table 3-6 reveals peak flows matching the previous FEMA FIS within 10 percent in many locations. Larger differences in peak flows, specifically at "A" Street and above 66th Street, can be attributed to the difference in drainage area delineations between the previous FEMA study and the HEC-HMS model, as shown in Table 3-7. Other discrepancies in peak flow were attributed to the use of updated FEMA tools and methods as well as a more detailed hydrologic analysis during this study.

Table 3-7
Drainage Area Comparisons

Location No.	Description	FEMA	HMS Model[1]	Percent Change
1	At mouth	9.3	9.6	3
2	At 38th Street	9.3	6.9	-25
3	Below 48th Street	6.9	6.6	-5
4	Above 48th Street	5.7	5.7	0
5	At Cotner	4.8	4.3	-11
6	Below 66th Street	4.0	3.6	-10
7	Above 66th Street	2.3	3.4	47
8	Below "O" Street	2.3	1.9	-17
9	Above "O" Street	1.2	1.2	3
10	At "A" Street	1.1	0.4	-61

1 - Peak flow rates based on existing land use conditions

3.4 Model Results

Table 3-8 presents the HEC-HMS modeling results under existing land use conditions. The stormwater peak flow rates are provided at the same major locations as reported in the Lancaster County FIS. The electronic copy of the final hydrologic model is included in Appendix A under the Computer Models, Hydrology folder. The peak flow rates under existing conditions were used as hydraulic model input as described in the following section.

Table 3-8
HEC-HMS Modeling Results

Location No.	Description	2-year	10-year	50-year	100-year	500-year
1	At mouth	3,127	5,853	7,933	9,078	11,823
2	At 38th Street	2,529	4,686	6,954	8,193	10,738
3	Below 48th Street	3,052	4,917	7,280	8,628	11,325
4	Above 48th Street	2,390	4,405	6,349	7,426	9,663
5	At Cotner	2,080	3,993	5,541	6,350	8,308
6	Below 66th Street	1,985	3,684	5,053	5,764	7,748
7	Above 66th Street	1,897	3,503	4,825	5,534	7,487
8	Below "O" Street	1,031	1,940	2,671	3,066	3,943
9	Above "O" Street	689	1,202	1,619	1,876	2,400
10	At "A" Street	330	637	880	1,007	1,261