Chapter 8

DEVELOPMENT OF THE COLLECTION SYSTEM HYDRAULIC MODEL

8.1 INTRODUCTION

The fundamental definition of a model is “a representation of a physical entity.” A collection system hydraulic flow model is thus a simplified representation of the real collection system. The amount of simplification will define the applicability of the model in a given situation. In general, collection system flow models can assess the current level of performance for the collection system based on population and land use. Collection system models can also perform “what if” scenarios to project the impact and performance of the system due to future development or population and land use changes.

8.2 DYNAMIC HYDRAULIC MODEL DEVELOPMENT

In order to accurately model a sanitary sewer system, it is necessary that the computer model be able to account for the time wastewater takes to flow from one manhole or structure to the next. For this to be accomplished, the model needs to be dynamic and capable of calculating the flow velocity based on the contributed flows at each input point to determine the time for this flow to reach the next input flow point. Inflows are added at each input point and the total flow is then used to calculate the travel time to the next downstream manhole or structure. The model then determines the water surface elevation at each manhole or junction structure so that the depth of flow and velocity can be determined.

XP-SWMM, a commercial version of the United States Environmental Protection Agency (U.S. EPA) SWMM dynamic model was used for the hydraulic modeling on this project. XP SWMM, marketed by XP-software, is a dynamic-state analysis tool and is an extremely powerful program for the design and analysis of flows in pipe networks. Since its inception, SWMM has been used in thousands of sanitary sewer system and stormwater studies throughout the world. Typical applications include designing control strategies for minimizing combined sewer overflows and evaluating the impact of inflow and infiltration on such systems.

8.2.1 Data Collection

The dynamic hydraulic model was developed based on data collected from the City’s Geographical Information System (GIS), field survey data, as-built drawings, historical flow data, and additional input from City staff. The existing collection system model includes pipelines with a diameter of 18 inches and greater including the manholes, junction structures, and lift stations associated with the pipes included in the model. The GIS information used to develop the hydraulic model included:

1. Manhole invert elevation.
2. Ground surface elevation.
3. Manholes ID based on the City's Foreman's Maps.
4. Physical sewer manholes (nodes) location (located using Cartesian Coordinates).
5. Pipe Size.
6. Pipe Length.

In addition to the physical data, current and future wastewater flows were reviewed. This data included information relating to wastewater lift stations, WWTF influent data, and information from the City's ongoing flow monitoring program.

8.2.1.1 Pipe Network

The sanitary sewer system model was based on an inventory of sanitary piping and facilities identified in the City's computer aided drafting/design (CAD) files. Where critical data was missing, field surveys were conducted. In general, the upstream, 15-inch or smaller sewers were not included in the model. The trunk sewers included in the hydraulic model have been shown previously in Figure 4.1.

A series of steps were undertaken to convert the City's two-dimensional CAD files to a GIS database. Pipes in the model are represented by line segments and are defined by an upstream manhole, a downstream segment of pipe and a downstream manhole. Most models consider manholes and wet wells as "nodes", and pipes, force mains, pumping stations, and control structures as "links". The hydraulic model of the City's wastewater collection and conveyance system include gravity flow pipes and manholes. The key data for the pipes and manholes in the model are listed in Table 8.1:

Table 8.1 Key Hydraulic Model Data
Wastewater Facilities Master Plan Update - 2007
City of Lincoln, Nebraska

Pipes (links)	Manholes (nodes)
Pipe Name	Manhole Name
Upstream Manhole	Ground Surface Elevation
Downstream Manhole	Manhole Invert Elevation
Length	X-Coordinate
Cross Section Type	Y-Coordinate
Pipe Diameter	
Upstream Invert	
Downstream Invert	

The data from the GIS that was input into the hydraulic model included pipe length, diameter, invert elevations, and rim elevations. Slopes in the hydraulic model were

calculated based on invert elevations and pipe length provided in the GIS. A Manning's "n" value of 0.013 was used for all pipes. Diversion structures and lift stations are represented in the SWMM model.

8.2.1.2 Quality Control of Pipe Network Data

Pipe network attribute data were verified through quality control procedures in an effort to minimize the amount of erroneous information incorporated into the model. The manhole database was checked for quality control first, by following the procedures below:

1. Verified XY coordinates through a GIS.
2. Checked for duplicate manhole IDs.
3. Checked for manholes with duplicate XY coordinates.
4. Ensured that rim elevations were greater than manhole invert elevation.
5. Verified that all appropriate manholes were referenced in the pipe database.

After verifying the manhole database, the following procedures were used to provide quality control for the information in the pipe database:

1. Checked for duplicate pipe IDs.
2. Verified pipe lengths using a GIS.
3. Ensured that all the manholes referenced in the pipe database were included in the manhole database.
4. Highlighted pipes where downstream invert elevations were greater than upstream invert elevations and verified with field data.

Once the quality control checks outlined above were performed, manholes and pipes with missing data (i.e., IDs, elevations, sizes, lengths, etc.) were documented and resolved.

8.2.1.3 Wastewater Lift Stations

Not all of the Cities lift stations were included in the collection system model. Only the lift stations that either received or delivered wastewater to a sewer that was 18-inches or larger in diameter are included in the model. These lift stations are identified in Table 8.2.

Table 8.2 Collection System Lift Stations included in the Hydraulic Model Wastewater Facilities Master Plan Update - 2007 City of Lincoln, Nebraska		
Lift Station	**Basin Served**	**Discharge Manhole**
C-8 (W. 'P' St & Sun Valley Blvd.)	West "O" St	A5-42
C-9 (W. 'E' St & SW 6th St)	Middle Creek	A4-206
C-11 (Industrial Ave. & Dan Ave.)	Little Salt	C7-427

The data collected for the lift stations include wetwell volume and invert, pump start and stop elevations, and pump curves. The pump curves used to simulate flow from the lift station are included in the Appendix C.

8.2.1.4 Land Use

In this analysis, a direct approach based on existing developed land and future growth tiers was used to generate peak wet weather flows. The existing developed land and growth tires are discussed in Section 3 of this report.

8.2.1.5 Flow Monitoring Data

Since 1999, the City has an extensive flow monitoring program to monitor the wastewater flows throughout the sanitary system. This program consists of continuous recording flow meters installed at strategic manhole locations in the trunk sewer system. At these locations, the upstream tributary area can be determined. The City also monitors precipitation amounts and intensity of rainfall events throughout the City. Data from rainfall gauges maintained by the University of Nebraska and other rain gauges at City fire stations is used to correlate rainfall with peak sanitary sewer flow events. To date the City has collected valuable information on the flows at these locations and associated areas. Due to the drought conditions over the last few years this data is limited to dry weather flows.

Historic flow monitoring data for two precipitation events were used to calibrate the model. The first event occurred during the week of July 24, 1993 where it rained for five consecutive days. This resulted in peak influent flows to Theresa Street WWTF in excess of 80 mgd on July 24, 1993. The second event occurred on July 20, 1996 where 6-inch of rain fell over the Beal Slough Basin. This rainfall resulted in a metered peak flow of 16.44 mgd in the Beal Slough Trunk Sewer System.

8.2.2 Establishment of Network Connectivity

After completing quality control procedures for the pipe network data, an evaluation of the pipe network connectivity was conducted. The project team utilized two primary resources to establish the City's pipe network connectivity:

1. The pipe network database.
2. The pipe GIS layer.

The City's database of pipes and manholes was the primary data source for the project, but when questions arose, the GIS layer depicting all the sewer lines in the system was typically the next level of quality control investigated. By using the GIS, the project team was able to effectively review the connectivity data. When more in-depth connectivity questions arose, the project team reviewed hard copy system maps and as-built drawings to make the final determination.

8.3 HYDRAULIC MODEL FLOW INPUTS

In this study, peak wet-weather flows were computed using an existing empirical equation discussed in Section 8.3.2 below. As described later in this report, the only input to the equation is developable acreage. The approach used to generate the peak wet-weather flows are discussed below.

8.3.1 Manning's Equation

The Manning's Equation is one of the most common flow formulas for analyzing open channel and gravity flow pipe systems. Due to the acceptance of this equation for gravity flow systems it is also used for this modeling effort. The equation modified to English Units is shown below.

$$V = \frac{1.49}{n} R^{2/3} S^{1/2}$$

Where:

V = Average velocity (ft/sec)

R = Hydraulic radius (ft)

S = Slope of the Energy Grade Line (ft/ft)

'n' = Roughness coefficient

The roughness coefficient value for ‘n’ varies depending on the type of pipe material and interior condition of the pipe. For example, glass would have an ‘n’ value of 0.010 while earth channels would have an ‘n’ value of 0.020. There has been much debate about the appropriate ‘n’ value used for different piping materials in wastewater collection systems. To complicate the debate, the slime layer that thrives on the wetted portions of the sanitary sewer piping also contributes to roughness and affects the actual value of ‘n’.

Due to the unknowns at this time, such as the actual type of the pipe installed, the number of joints in the piping system, and the affect that the slime layer will have on the ‘n’ value, a conservative value of 0.013 has been adopted for this project, which is the most commonly used ‘n’ value for the evaluation and design of sanitary sewer systems.

8.3.2 Peak Flow Equation

The City’s flow equation for peak design flow was utilized to determine the flow inputs for the dynamic model. The peak flow equation was developed by City wastewater staff using flow data based on a ‘wetter than normal’ precipitation period in 1993 and the resultant peak flows received in the system and at wastewater treatment facilities. The use of this equation has been used to size and evaluate collection system piping since adopted by the City. The equation takes the form shown below:

$$Q = 0.01726\ A^{(0.8)} + 0.003\ A$$

Where:
Q = wastewater flow in cfs
A = Area in acres.

The underlying data the City used to support this design flow equation is as follows:

1. Equation form is by Babbitt & Bauman, “Sewerage and Sewage Treatment”, 7th Edition, John Wiley & Sons, Inc., 1953.
2. Dwelling unit density is 2.79 dwelling units per acre (per City Planning Department).
3. Population density is 2.48 persons per dwelling unit (per City Planning Department).
4. Historical average per capita flow rate is 119 gallons per capita per day (gpcd), including dry weather wastewater flow.
5. Peak to Average Ratio is 5.
6. Inflow and infiltration flow is 1,935 gpd per acre.

The aforementioned equation was developed by City staff after analyzing data obtained from the watershed tributary to the Theresa Street WWTF as well as corresponding flow monitoring records. A graphical representation of this equation is shown in Figure 8.1.

8.3.3 Comparison of Peak Flow Equations

The use of the City’s flow equation has been reviewed several times over the last few years by different consulting engineers and agencies. The peak flow equation was reviewed as

part of the work effort associated with this Master Plan Update. The equation was compared to methods used by other communities' peak design flow calculation methodologies. The four cities and wastewater districts included in this comparison included Tulsa, Oklahoma, Johnson County Wastewater (Johnson County, Kansas), the City of Lee's Summit, Missouri, and the City of Wichita, Kansas.

Peak design flow generally consists of three components: dry weather flow, infiltration, and inflow. Each entity surveyed included these components in their peak flow determination, but the magnitude of each component was found to vary by location. Each entity included in this review utilized a peak design flow based on developable land area within a basin/sub-basin, results of system modeling or evaluation of existing data and consideration of dry weather, infiltration and inflow sources.

As a comparison the peak wastewater flow, determined by each entities respective methodology, from 100 to 4,000 acres is presented in Figure 8.2 and Table 8.3 below. As shown the City of Lincoln's peak flow equation is not the most conservative, and correlates well with the other municipalities with similar precipitation patterns.

It should be re-emphasized that such peak flow equations are highly dependent on local conditions such as the precipitation patterns, the physical configuration of the collection system, the age of the collection system, groundwater, RDI/I and similar parameters. Due to these local conditions it is expected that the methodology and the results of the peak flow equations will vary from community to community.

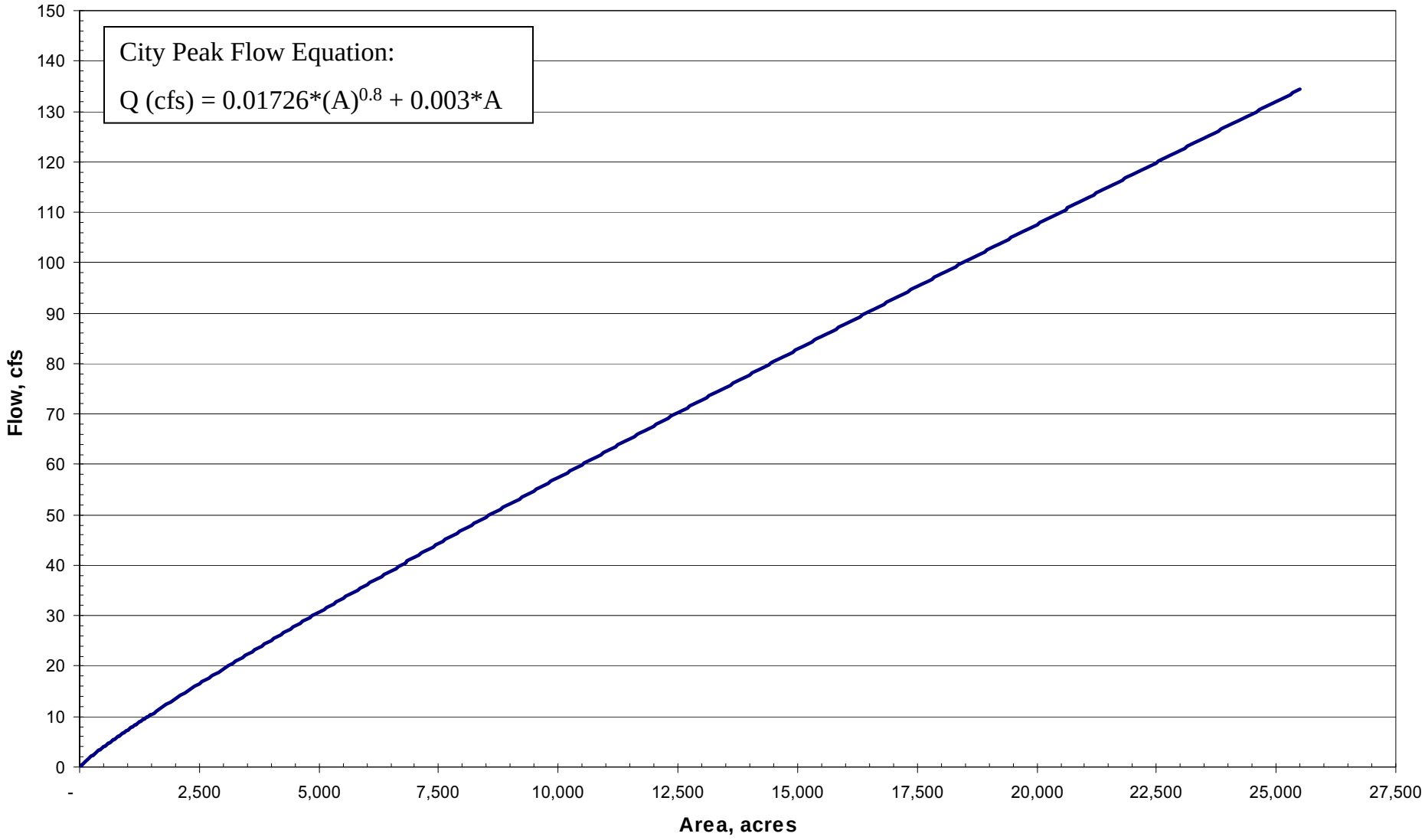

Figure 8.1
City Peak Flow Equation Curve
Wastewater Facilities Master Plan Update - 2007
City of Lincoln, Nebraska

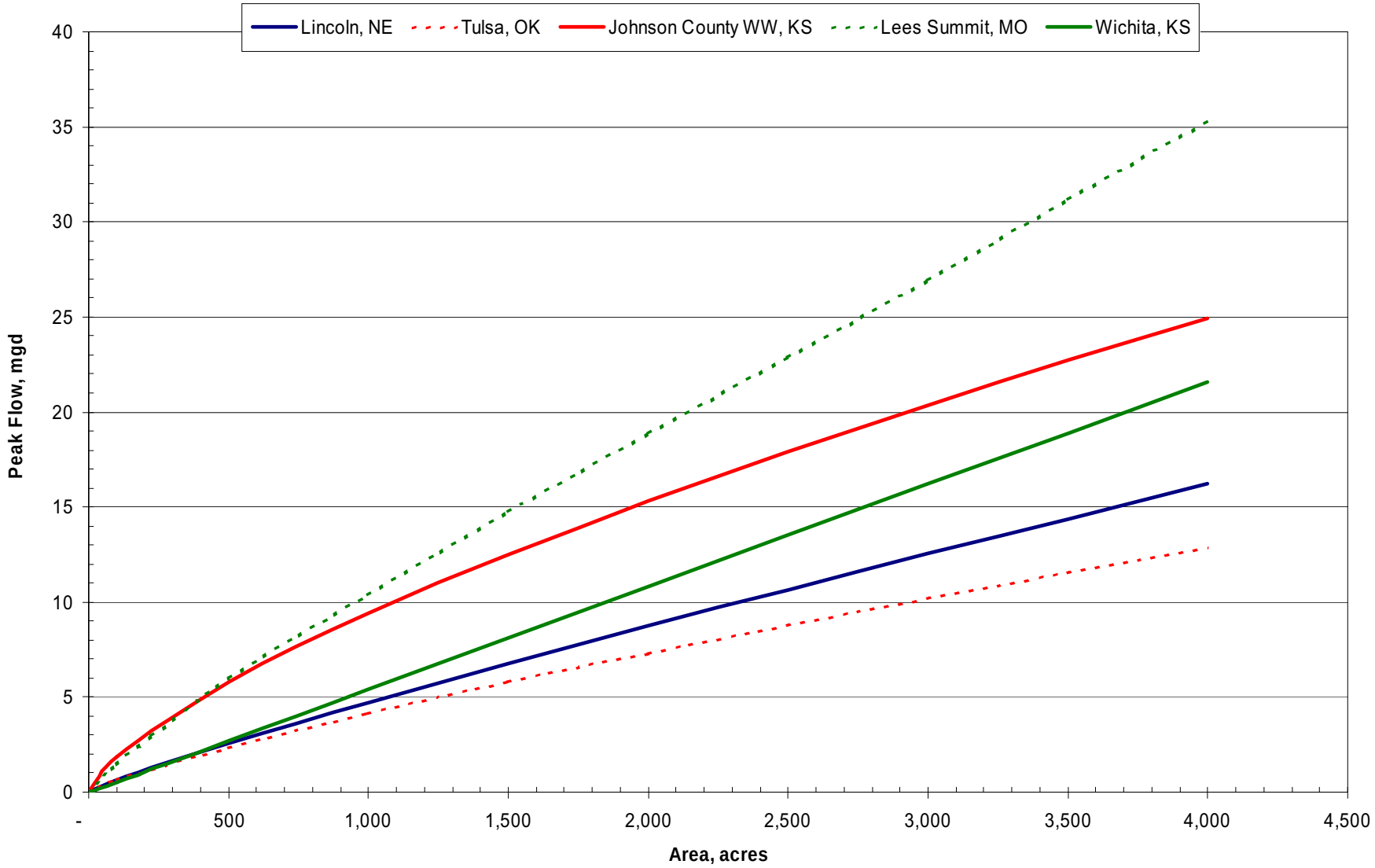

Figure 8.2
Peak Wastewater Design Flow Equation Comparison
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Table 8.3	Peak Wastewater Design Flow Equation Comparison Wastewater Facilities Master Plan Update - 2007 City of Lincoln, Nebraska				
	Peak Wastewater Flow (mgd)				
Area	**Lincoln, NE**	**Tulsa, OK**	**JCW, KS**	**Lee's Summit, MO**	**Wichita, KS**
100	0.64	0.63	1.87	1.49	0.54
500	2.57	2.35	5.79	6.00	2.7
1,000	4.73	4.14	9.42	10.37	5.4
1,500	6.77	5.77	12.52	14.75	8.1
2,000	8.74	7.30	15.33	18.89	10.8
2,500	10.66	8.75	17.93	22.84	13.5
3,000	12.54	10.16	20.38	26.94	16.2
3,500	14.39	11.52	22.71	31.16	18.9
4,000	16.22	12.85	24.95	35.30	21.6

8.3.4 Flow Inputs

The inflow to each trunk sewer was determined using the total tributary area to the trunk sewer system at the manholes or junction structures where sub-basin flows discharge to the main trunk sewer. The peak flow equation was utilized in such a manner that as additional sub-basin flows enter the trunk sewer, the area of the sub-basins contributing to the flows are combined. The City's peak flow equation has a built-in dampening factor to the peak flow that decreases the flow per acre as the area increases. This feature mimics the actual observed damping effect due to the time of travel in the collection system. Therefore, once the sub-basin areas are combined the flows are recalculated and the appropriate input flow is introduced at the input node.

8.3.5 Development of Peak Flow Diurnal Curve

The historic flow monitoring data gathered and reviewed for Theresa Street and Beal Slough were used to develop peak weather diurnal curves for all basins evaluated. All basins with the exception of Beal Slough were assigned the diurnal curve developed from the 1993 flow monitoring data for Theresa Street. The Beal Slough basin was assigned the diurnal curve developed using the July 1996 flow monitoring data in the Beal Slough basin. The diurnal curves developed from this data are shown in Figures 8.3 and 8.4.

8.4 MODEL CALIBRATION

Model calibration is a crucial component of the hydraulic modeling effort. The model calibration to known flow metering data is required and necessary to ensure the most

accurate results possible. The calibration process consists of calibrating to both dry and wet weather flow events. Dry weather flow calibration ensures an accurate depiction of base sanitary flow generated within the study area, based on land use. The wet weather flow calibration consists of calibrating the hydraulic model to a specific storm event to quantify the peak and volume of inflow and infiltration into the collection system. The amount of inflow and infiltration allowed to enter the collection system is essentially the difference between the wet weather flow and dry weather flow components.

8.4.1 Wet Weather Flow Calibration

The wet weather flow calibration enables the modeled collection system to accurately estimate peak flows in a collection system during a peak precipitation/rainfall event. Wet weather flow calibration generally consists of two steps:

1. Determining a rainfall event that characterizes the most significant impact on the collection system facilities, preferably during wet antecedent soil moisture conditions; and
2. Creating a database of inflow and infiltration flow parameters for each pipe for this rainfall event.

In this analysis, wet weather flows were estimated using the flow equation and therefore no rainfall event was considered. The purpose of wet weather calibration is to prepare a model and resultant piping system to handle the peak flows associated with rainfall events. The ultimate goal of the wet weather flow calibration was for the modeled data to match the storm peaks from the 1993 and 1996 flow monitoring data discussed in Section 8.2.1.5 above.

Peak wet weather flows are generally considered to be in good calibration if model flows and monitored flows are within 15 percent. Table 8.3 shows good calibration of wet weather peak flow.

Table 8.3 Wet Weather Calibration Results
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City of Lincoln, Nebraska

Site	Measured Peak Flow (cfs)	Modeled Peak Flow (cfs)	Absolute Error (%)
Beal Slough	39	34	12.8
Theresa Street	80	78	2.5

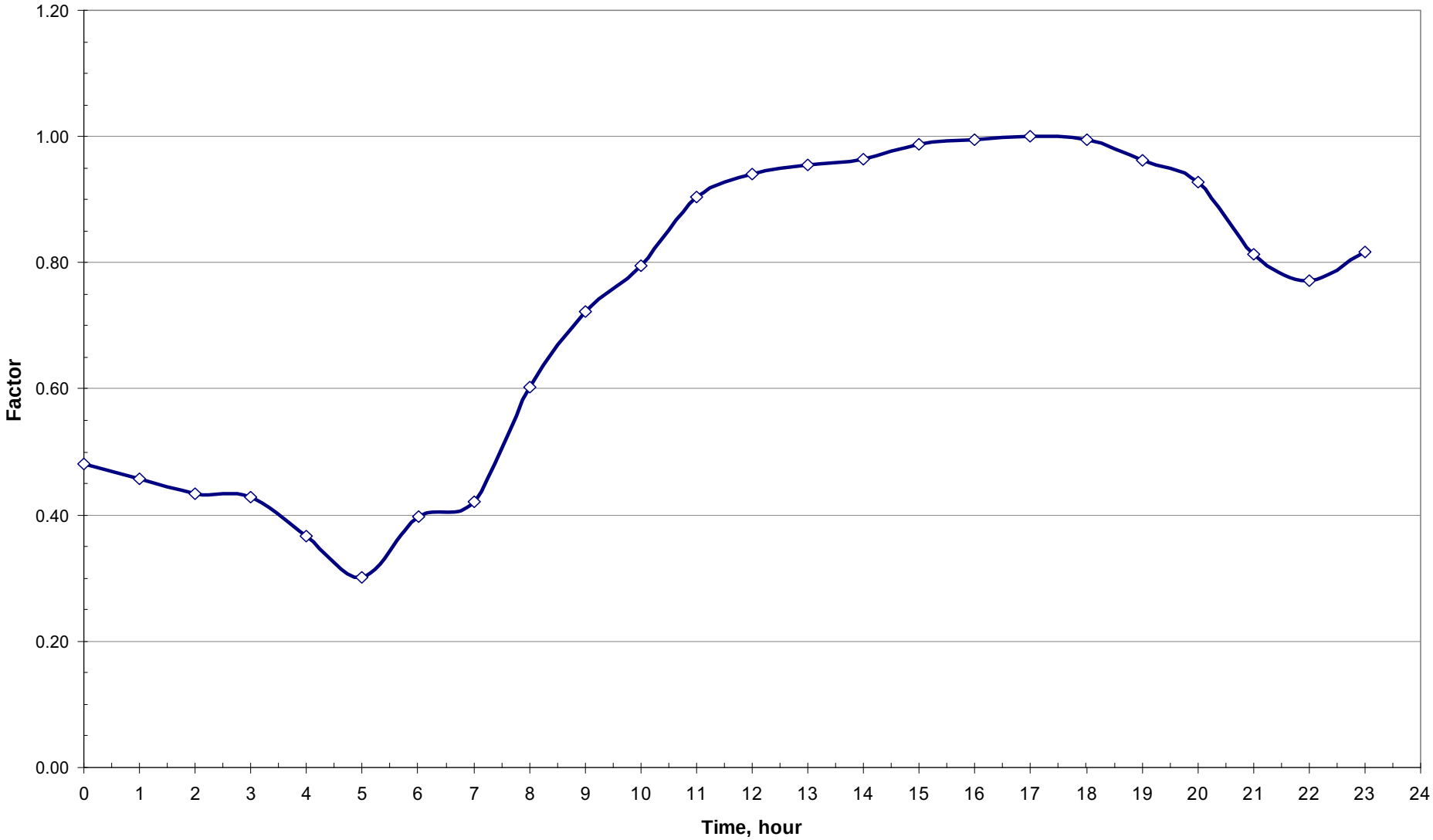

Figure 8.3
Ratio of Theresa Street Instantaneous Flow and Peak Wet Weather Flow
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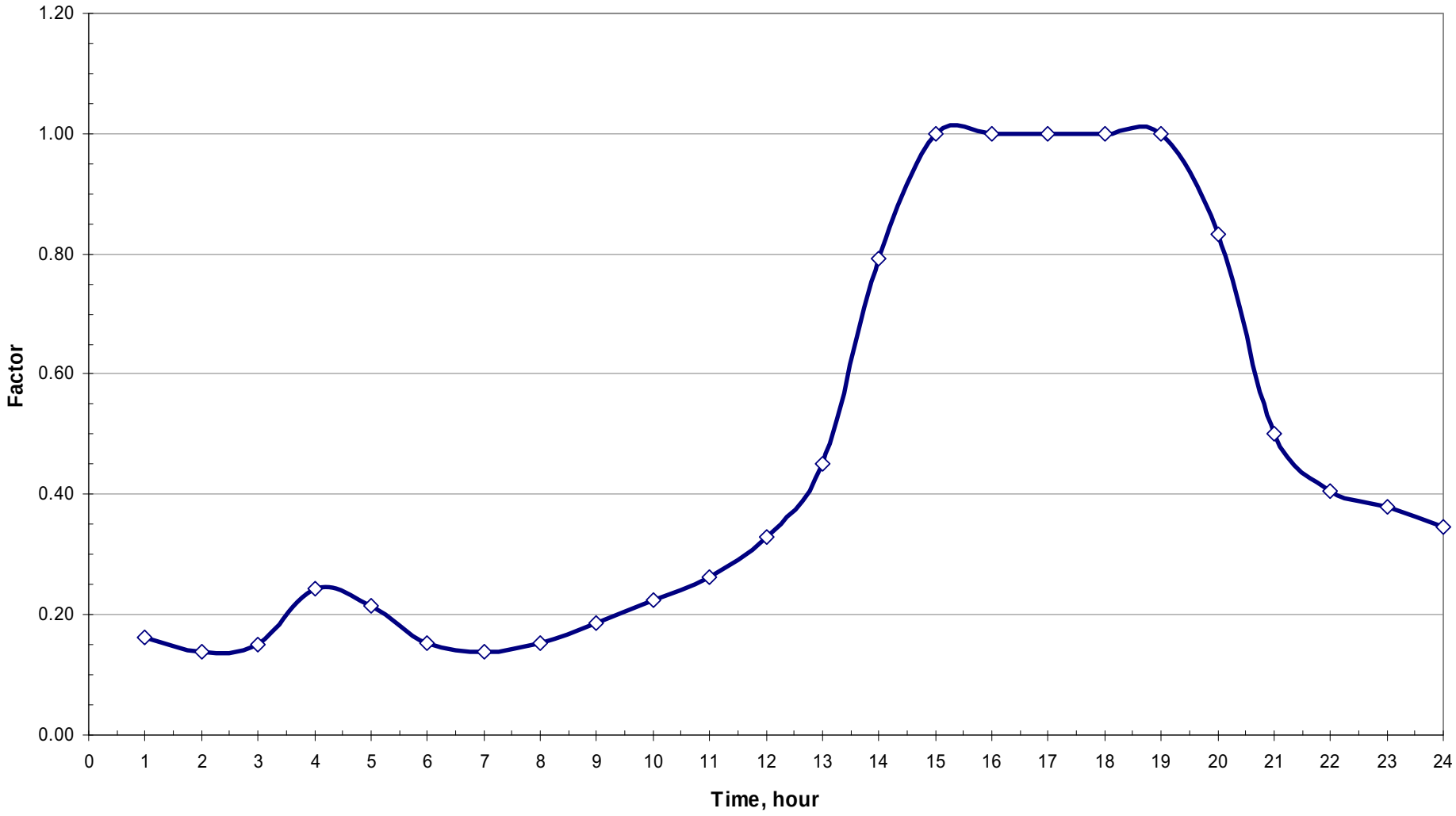

Figure 8.4
Ratio of Beal Slough Instantaneous Flow and Peak Wet Weather Flow
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