VI. Model Development

A. Purpose

The primary purpose of choosing one computer model for the master planning evaluation of the Three Mile Creek and Five Mile Creek watersheds in Leavenworth, Kansas, is to help assure consistency of the hydrologic and hydraulic modeling. The model selected will serve as the basis for the following: estimating flows at various locations in the watershed; identifying inadequate underground systems, bridges, open channels and culverts; locating existing and potential future flooding areas; estimating the necessary detention volumes for curtailing peak flows; identifying locations for detention basins; quantifying the effects of potential improvements; and developing planning level costs to improve the conveyance system.

B. Criteria and Evaluation

Several models were evaluated for applicability: the Penn State Urban Runoff Model (PSRM); the U.S. Army Corps of Engineers' HEC-1 and HEC-2; the Soil Conservation Service's (SCS) TR-20 and TR-55; the US EPA Stormwater Management Model (SWMM); XP Software's XP-SWMM; and the P8 Urban Catchment Model. The two key factors considered were the ability to model both open channel/culvert systems and underground systems, and the ability to model the hydraulics to account for backwater effects. A secondary factor was the model's ability to perform water quality modeling. Modeling the water quality has become necessary for some systems as a result of the EPA's 1990 enactment of the National Pollutant Discharge Elimination System (NPDES) regulations. These regulations require monitoring the quality of stormwater runoff being discharged to "waterways of the United States." The communities initially affected by the regulations were those with a population of 250,000 or greater. Thus, Leavenworth is presently not subject to this regulation. In the ever-changing regulatory environment however, the City could one day be required to monitor and evaluate its water quality constituents. Based on these factors, the list of applicable models was reduced to HEC-1 and HEC-2, SWMM, XP-SWMM, and P8. A brief description of each model is presented below:

1. XP-SWMM

XP-SWMM was developed by XP Software and is an enhancement of EPA's SWMM model. XP-SWMM is supported by XP Software, is very flexible, provides the capability to model open channel/culvert systems and underground conveyance systems, takes into account backwater effects and models water quality in the same "block" (routine), serves as a graphical interface to the EPA SWMM computational engine, and is user-friendly. In addition, the graphical locations of the structures in the model can be referenced to county or state plane coordinates, thus providing a properly scaled plan view of the network. However, XP-SWMM is new to the modeling arena, and is not public domain software.

2. EPA Stormwater Management Model (SWMM)

The SWMM model was developed and is supported by the US EPA, is public domain software, is accepted by FEMA for the hydrologic analyses conducted during flood insurance studies, is very flexible; can be used to model open channel/culvert systems and underground conveyance systems; takes into account backwater effects; and models water quality. However, the backwater effects and water quality are modeled using separate "blocks" (routines) requiring separate data files, and the SWMM model can be very difficult and cumbersome to set up and use.

3. HEC-1 and HEC-2

In the HEC-1 and HEC-2 combination, HEC-1 performs the hydrologic modeling to be used as input to HEC-2 for the hydraulic modeling. HEC-1 and HEC-2 were developed and are supported by the US Army Corps of Engineers, are public domain software, are accepted by the Federal Emergency Management Agency (FEMA) for flood insurance studies; and can be used to model open channel/culvert systems; and take into account backwater effects. However, they cannot be used for direct modeling of underground conveyance systems or for modeling water quality.

4. P8 Urban Catchment Model

The "Program for Predicting Polluting Particle Passage through Pits, Puddles, and Ponds" (P8) was developed by William Walker, Jr., PhD, for IEP, Inc. P8 is a water quality model, with its routines based on the algorithms from the EPA SWMM model. Although it performs the basic hydrologic analyses of rainfall and runoff, for practical purposes it performs no hydraulic analyses. The strengths of the P8 model for water quality modeling are that the quality data are based on the Nationwide Urban Runoff Program and it models structural Best Management Practices (BMPs) such as wet and dry detention basins, infiltration basins, and infiltration swales. P8 would, therefore, be used for water quality modeling only.

The results of the evaluation and the considerations discussed above indicate that EPA SWMM and XP-SWMM are the most appropriate models for this and future studies. XP-SWMM was selected for the Stormwater Master Plan. The controlling factors in the selection of XP-SWMM over the other models, particularly EPA SWMM, were its overall user-friendliness, graphics capabilities, and the ability to import and export data to and from the model.

C. Project Description

Existing and future Geographic Information System (GIS) requirements related to this project were identified. Work for this project was completed to benefit the development of the City's GIS. Other data, e.g., maintenance data, may be collected by the City in the future. Appropriate methods and formats for storing the data were identified. A brief memorandum summarizing the recommended level of effort and the tasks that should be implemented by the City to ensure that all work done on this project will be compatible for inclusion into the future GIS had been previously submitted to the City and is included in Appendix M. Where practical, to facilitate future use in the GIS, the data collected and developed under this project were stored in digital form.

Using the information from the stormwater questionnaires; a review of existing data; and during meetings with the City staff, the Citizen's Stormwater Committee, and other residents, locations of known historic flooding were identified for more detailed modeling. A map was prepared, depicting known flooding problems and the portions of the stormwater conveyance system requiring detailed evaluation. The majority of the development and storm sewer systems in the Leavenworth city limits lie within one of two major watersheds--Three Mile Creek and Five Mile Creek. According to the Corps of Engineers' Flood Plain Information report, the names of these two streams signify their distance from the famous flagpole at Ft. Leavenworth to the north. Since Three Mile and Five Mile Creeks discharge separately to the Missouri River, a separate computer model was developed for each watershed to simulate storm events and the response of the stormwater conveyance network. In addition to the storm sewer networks and drainage channels in these two watersheds, there are two subsystems which drain directly to the Missouri River between the Three Mile and Five Mile Creek outlets; four subsystems in the northeast corner of the City; and eight subsystems within the Leavenworth city limits which drain south of the Five Mile Creek watershed toward Lansing. Computer models were developed for the larger of these external watersheds. Stormwater conveyance systems in these areas consist of single cross-road culverts and were evaluated by manual methods.

Based on input from City staff and the data reviewed, a schematic identifying the extent of the conveyance system to be modeled was developed. All mapping and data pertinent to the storm drainage system, including digital mapping from M.J. Harden, and pertinent storm system information such as top-of-structure elevations and depth-to-flowline for most structures, numbering system, x-y coordinates, and pipe sizes and types, was provided by the City. This information was incorporated into the GIS from which a large part of the model data was extracted.

Representative elements of the existing storm drainage system, both open channel and closed conduit, were visually examined to define typical system operating and maintenance conditions.

Based on the selection of the XP-SWMM model and the data collected, input data files were developed for the surface characteristics and schematic stormwater conveyance systems in the Three Mile and Five Mile Creek watersheds. All 24 inch and larger diameter pipe and pipe-equivalent elements were modeled. Selected 18 inch diameter pipes were included if they were downstream from larger pipes in the same subsystem or located adjacent to historical flooding problem areas identified from City records, the stormwater questionnaire, stormwater hotline calls, other complaint calls, or other records. The Three Mile and Five Mile Creek models were configured to simulate typical storm events over the stormwater conveyance system. These model runs were verified using historic flow data and by comparing to other computational methods, as described in Section G of this chapter. The verified models were used with additional design storm events to quantify flooding problem areas, and to identify and evaluate conveyance system improvements, as described in Chapter VIII of this report.

1. Three Mile Creek Watershed

Three Mile Creek, a right-bank tributary, joins the Missouri River near river mile 396.5, at approximately two-thirds of the distance between St. Joseph and Kansas City. At Kansas City, the Missouri River has collected flows from approximately 485,200 square miles of its 529,000 square mile watershed. The majority of the Three Mile Creek watershed, which covers approximately 3,970 acres, or 6.2 square miles, is within the city limits, except for tributary areas west of 22nd Street and north of Metropolitan Avenue. Three Mile Creek originates in the northwest portion of the basin and flows eastward and southeastward. Ten tributaries and storm sewer subsystems discharge to Three Mile Creek on the left bank and nine on the right bank, including a major tributary named South Branch. The South Branch originates in the southwest portion of the basin and joins the main branch of Three Mile Creek about 250 feet upstream from the 10th Street bridge.

Current land use in the Three Mile Creek watershed ranges from undeveloped land in the western portions, to low-density residential in the west-central areas, to medium- and high-density residential in the eastern third surrounding the City's central business district. Development is expected to continue westward, with the same general land use distribution. Parks and pockets of open areas are scattered throughout the developed watershed. The surface topography is dominated by hills and the natural valleys of tributary streams. The high bluffs along the Missouri River's right bank protect the watershed, except for the Three Mile Creek flood plain, from extreme high water on the Missouri River.

It is believed that flooding problems in the older areas in the Three Mile Creek watershed are attributed to inadequate maintenance of drainageways and failing conveyance structures, and to development in or near historic drainageways. In other areas, inadequate bridges and driveway drainage tubes are causing localized flooding and back-up of storm flows.

2. Five Mile Creek Watershed

Five Mile Creek, a right-bank tributary originates in the northwest portion of the basin, joins the Missouri River near river mile 395.5, south and slightly east of the Three Mile Creek outlet. The main stream of Five Mile Creek is more than 5.5 miles long (the length of the main branch of Three Mile Creek is 3.1 miles).

The Five Mile Creek watershed covers 5,934 acres, or 9.3 square miles, and is located directly south of the Three Mile Creek watershed. Except for small pockets in external watersheds, nearly all of the City of Leavenworth is within the Three Mile and Five Mile Creek watersheds. The western third of the Five Mile Creek watershed is currently outside the city limits, but with the implementation of the West Leavenworth Annexation Plan, it will be incorporated by the City.

Development in the Five Mile Creek watershed is less dense and widespread than in the Three Mile Creek watershed. Land use ranges from undeveloped in the west to low-density residential in the central and eastern portions, with large parks and open areas, and institutions such as schools, hospitals, a college, and business establishments. Growth is proceeding to the south and west, especially along the proposed West Leavenworth Trafficway right-of-way. High-intensity commercial and industrial development has been projected for the southernmost strip along Eisenhower Road. Surface topography is similar to that of the Three Mile Creek watershed, with elevations ranging from more than 1,100 feet to approximately 760 feet above mean sea level in the Missouri River flood plain.

As in the Three Mile Creek watershed, high bluffs along the east side protect Leavenworth from flooding on the Missouri River, except at the outlet to the river. The wastewater treatment plant is located in this flood plain, and is likely to be affected by high water caused by a major storm event. It is believed that flooding in older areas is caused by inadequate, or the lack of, culvert inlets, whereas areas of new growth are experiencing problems due to greater expectations than supported by current design standards.

3. External Watersheds

Two storm sewer subsystems within the small right-bank tributary watershed between Three Mile and Five Mile Creeks discharge directly to the Missouri River. Many of the responses to the stormwater questionnaires received from this watershed refer to minor driveway tube problems. The constructed facilities follow the natural drainageways.

The infrastructure facilities in the northeast corner of the City, situated on the high bluffs overlooking the river, also discharge directly to the Missouri River.

South of the Five Mile Creek watershed, eight subsystems within the city limits discharge to the south. All of these subsystems are at the headwaters of tributaries to Seven Mile Creek. No complaints or historical flooding records were received for these subsystems.

The single-conduit subsystems in these external watersheds were not incorporated into any computer models, but were reviewed and evaluated by manual methods. The larger and/or more complex subsystems were evaluated by XP-SWMM.

D. Hydrology

1. Introduction

The hydrologic modeling for Leavenworth was conducted by the Runoff block of XP-SWMM. The Runoff block was originally developed in EPA SWMM to simulate both the generation of rainfall runoff from a drainage basin, and the routing of flows and contaminants to the sewer lines, according to the reference manual. The drainage basin is represented by an aggregate of idealized subcatchments and gutters. The program accepts a rainfall or snowfall hyetograph and makes a step-by-step accounting of snowmelt, infiltration losses in pervious areas, surface detention, overland flow, channel flow, and the constituents washed into inlets, leading to the calculation of a number of inlet hydrographs and pollutographs. The Runoff block generates surface and subsurface runoff based on hyetographs, antecedent conditions, land use, and topography.

The Runoff block may be run for periods ranging from minutes to years. Precipitation may be entered at constant or variable time intervals, for single events less than a few weeks' duration, or may be read from the National Weather Service (NWS) or other rainfall records for continuous simulation.

The drainage basin may be divided into a maximum of 5,000 subcatchments and 1,000 inlets. Each subcatchment is assigned surface and subsurface parameters. Infiltration is computed using the Horton, Green-Ampt, or SCS method, with optional subsurface routing.

Overland flow hydrographs are generated by the non-linear reservoir routing method using Manning's equation and lumped continuity and depression storage. Inlet flows and pollutographs are stored on the interface file for input to the subsequent routing block. Other hydrograph generation techniques available in the Runoff block include the Kinematic wave method, Laurenson Non-Linear method, SCS Unit Hydrograph method, Other Unit Hydrographs, and the Rational formula.

2. Hydrologic Data Requirements

The Three Mile and Five Mile Creek watersheds were divided into subareas, or subcatchments, which served as the basic unit of land for the hydrologic analysis. To provide the necessary detail while keeping the mapping to a minimum, the subareas were delineated on 1 inch = 100 feet topographic maps with 2-foot contour intervals, which were provided by M.J. Harden & Associates, Inc., and were based on spring 1992 aerial photography.

The requirements of the subarea boundary delineation on the maps included identifying a reasonably-sized tributary area draining to the major structures; keeping the size of each subarea manageable; and assuring that each subarea had a defined drainage system to convey flows to the major conveyance system. Therefore, the subarea delineation ended at a storm sewer inlet, at a major structure on the channel, or at a minor drainage system (swales and smaller channels). Based on these criteria, there are 342 subareas in the Three Mile Creek basin averaging approximately 12 acres; the smallest is 0.5 acre and the largest, 684 acres. There are 472 subcatchments in the Five Mile Creek watershed, with the smallest, average, and largest sizes of 0.2 acre, 13 acres, and 1,007 acres.

The hydrologic data requirements for the subareas are listed below:

- *Size.* The size of each subarea, in acres, was determined based on topography (from GIS) and the layout of the conveyance system being modeled.
- *Width.* The width of each subarea, in feet, was determined from its general shape. The model idealizes each subarea as a rectangle; therefore, estimating a subarea's width enables the model to calculate its length. The length is used by the model as the length of overland flow in calculating the surface runoff, and thus, the time of concentration. The XP-SWMM and EPA SWMM manuals present discussions on estimating the width of the subareas.
- *Percent Imperviousness.* The percent imperviousness for each subarea was estimated based on land use. Information on existing and future land uses was provided by the City Planning Department and incorporated into the GIS, as indicated on Figures VI-1 and VI-2. A composite value was determined from the combination of land uses within each subarea. Table VI-1 presents the value for percent of imperviousness by land use. The reference for these values is Urban Hydrology for Small Watersheds, Soil Conservation Service, 1986.
- *Average Drainage Area Ground Slope.* The ground slope was calculated by averaging the ground slopes at several separate and representative locations in each subarea from the contours generated in GIS.

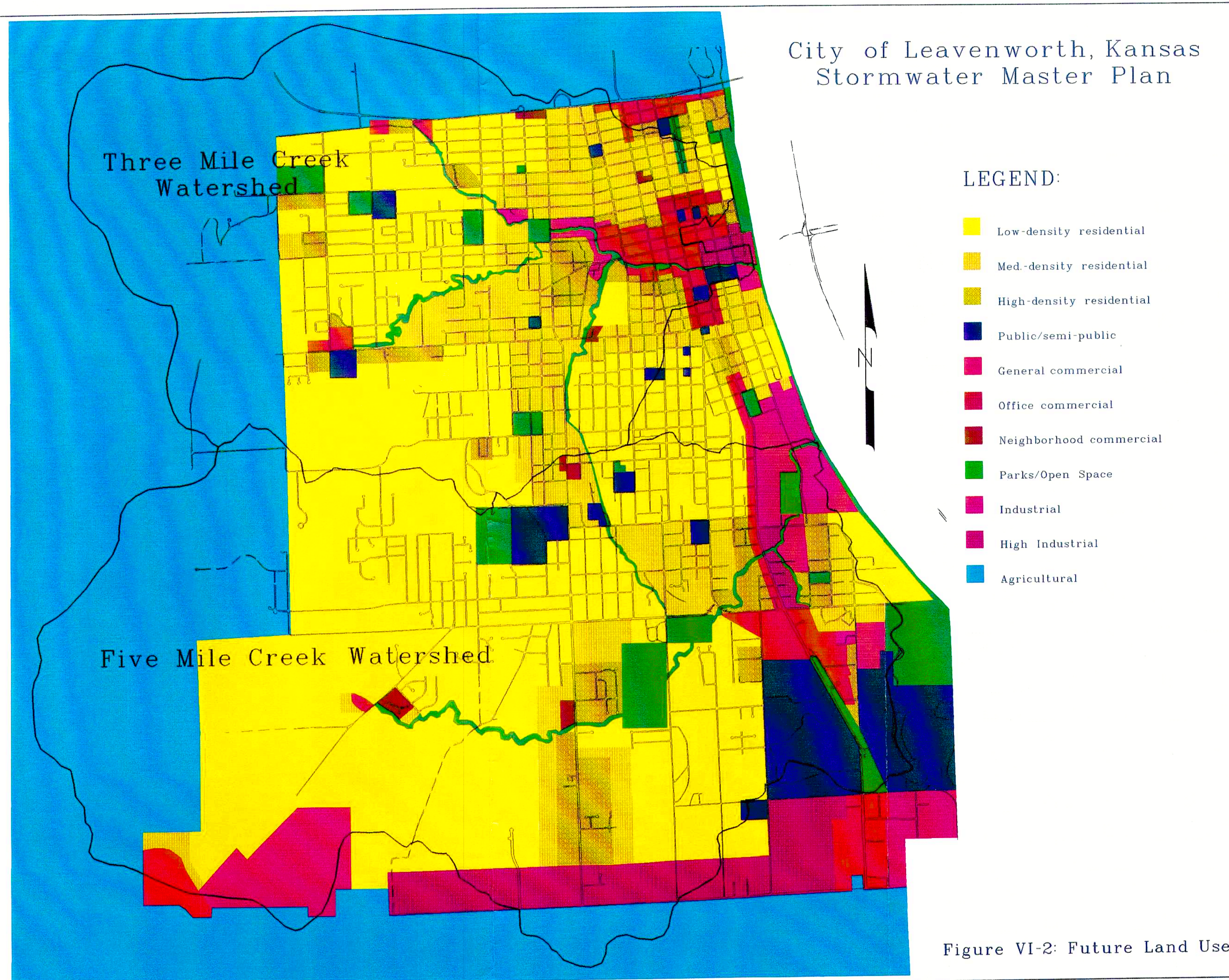
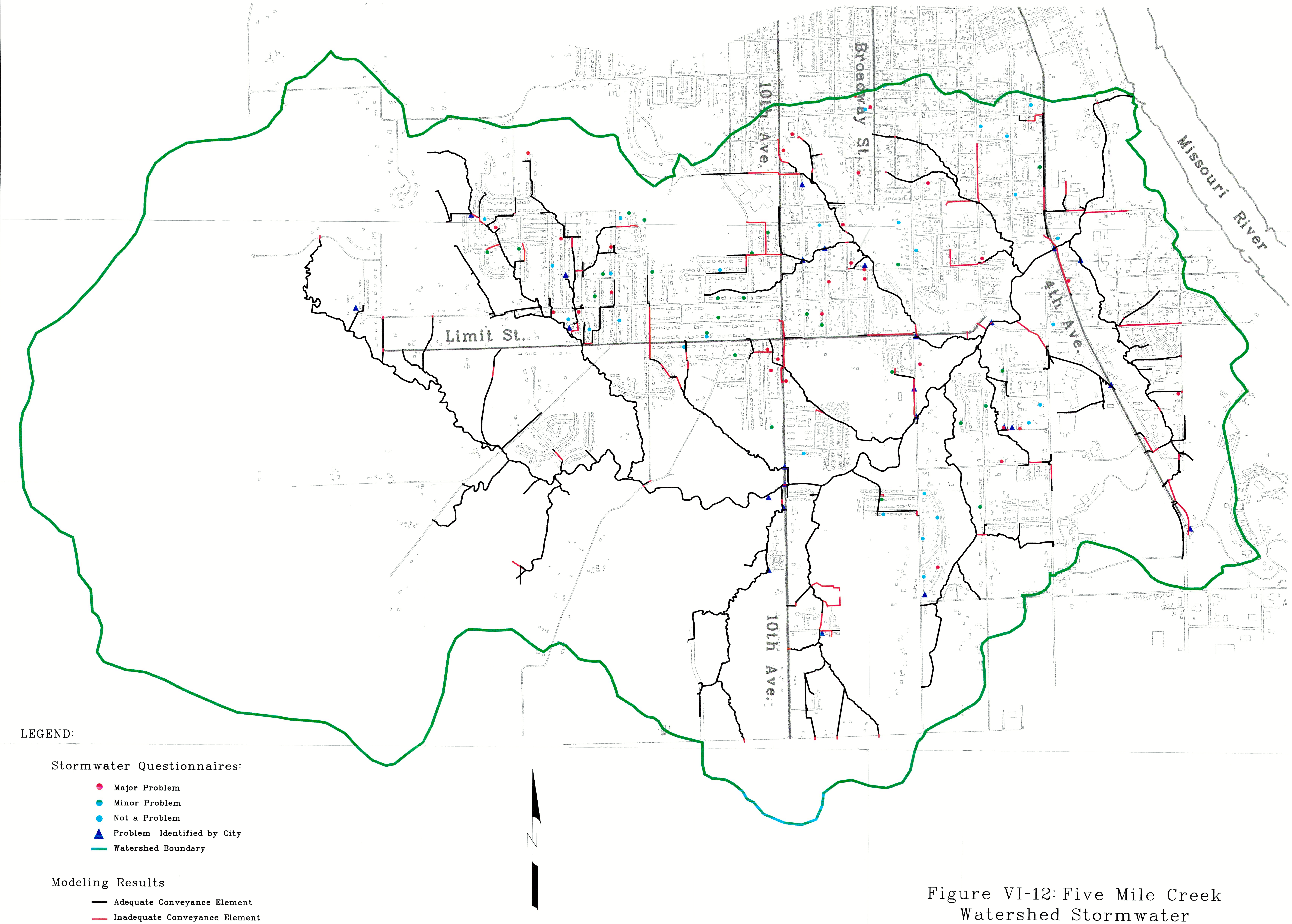


Figure VI-2: Future Land Use

Figure VI-11: Three Mile Creek Watershed Stormwater Questionnaire and Modeling Results



LEGEND:

Stormwater Questionnaires:

- Major Problem
- Minor Problem
- Not a Problem
- Problem Identified by City
- Watershed Boundary

Modeling Results

- Adequate Conveyance Element
- Inadequate Conveyance Element

Figure VI-12: Five Mile Creek Watershed Stormwater Questionnaire and Modeling Results

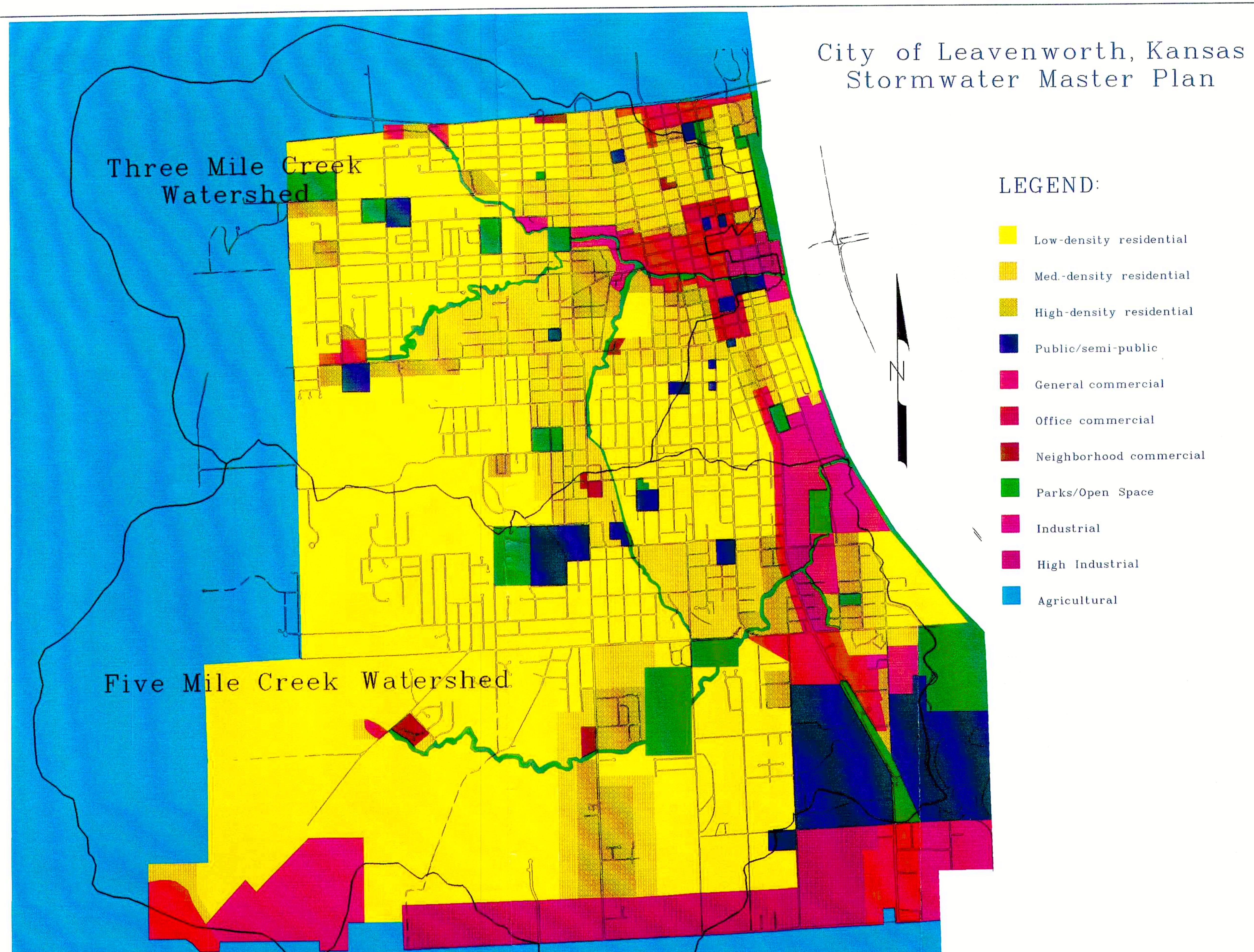


Figure VI-2: Future Land Use

Table VI-1 Imperviousness by Land Use	
Land Use/Zoning	Imperviousness (percent)
Business	
downtown	95
neighborhood	85
Residential	
single-family	35
multi-family	60
apartments	60
churches and schools	75
Industrial	
heavy	80
light	60
Other	
impervious: asphalt concrete, roofs	100
railroad yard	25
parks, cemeteries	10
pervious: turfed, agricultural, undeveloped	0

- *Manning's Roughness Coefficients.* Values of Manning's roughness coefficient are not as well known for overland flow as for channel flow because of the considerable variability in ground cover, very shallow depths, etc. Estimates of these values are available in textbooks.

  Impervious Area Overland Flow Roughness Coefficient (Manning's "n"). In the absence of field data, the impervious area roughness coefficient value presented in Table VI-2 was used.

Pervious Area Overland Flow Roughness Coefficient (Manning's "n"). In the absence of field data, the pervious area roughness coefficient value presented in Table VI-2 was used.

Table VI-2 Hydrologic Parameters	
Variable	Value
1. Manning's Overland Flow Roughness Coefficients	
pervious areas	0.3
impervious areas	0.02
2. Depression Storage, inches	
pervious areas	0.2
impervious areas	0.06
3. Percent Zero Detention	25

- *Depression Storage.* The depth in inches, to which small surface depressions must be filled before runoff will occur. It represents the loss caused by phenomena such as surface ponding, interception, and evaporation.
  Impervious Area Depression Storage. In the absence of field data, the impervious area depression storage value presented in Table VI-2 was used.
  Pervious Area Depression Storage. In the absence of field data, the pervious area depression storage value presented in Table VI-2 was used.
- *Zero Detention.* The percentage of the subcatchment impervious area with immediate runoff, 0-100 percent. The term "zero detention" is equivalent to "immediate runoff." In the absence of field data, the percent zero detention value presented in Table VI-2 was used.
- *Infiltration.* The infiltration routines available in XP-SWMM include the Horton and the Green-Ampt methods. Because the Horton method is older and better established than Green-Ampt, and data for it are more readily available, it was selected as more applicable. Data was extracted from the State Soil Geographic Data Base (STATSGO) and merged with the GIS so that the Horton parameters, including the Maximum and Asymptotic Infiltration Rate and Decay Rate, could be retrieved for each subcatchment.

Max Infiltration Rate (F_o). This parameter depends primarily on soil type, initial moisture content, and surface vegetation. A composite value was determined from the combination of soil types within each subarea. The values range from 1.34 in/hr to 1.90 in/hr.

Min (Asymptotic) Infiltration Rate (F_c). This parameter is essentially the saturated hydraulic conductivity, or permeability, of soils. A composite value was determined from the combination of soil types within each subarea. The values range from 0.41 in/hr to 0.57 in/hr.

Decay Rate of Infiltration (OC). This parameter is the rate of decrease of infiltration capacity, and is independent of initial moisture content. According to the XP-SWMM manual, most reported values are in the range 3-6 cycles/hour. In the absence of field data, an average decay rate of 0.00115 cycles/second was used.

3. Rainfall

Because reliable recent rain gauge data were not available for this study, historical recorded data were evaluated. The average rainfall intensity values in inches per hour from "Rainfall Frequency-Duration-Intensity for Leavenworth, Kansas," Table 1 in the 1967 Black & Veatch study, were compared with the values in "Rainfall Intensity Tables for Counties in Kansas," Kansas Department of Transportation, 1991. As indicated on Figures VI-3 and VI-4 for the 5-year and 10-year storms, respectively, the average of absolute values of the percent difference between the two intensity tables was approximately 5 percent. The KDOT rainfall intensity tables were used in this study because they are based on more recent data, and because they cover other return periods in addition to the 5-year and 10-year storms.

Three computation methods were evaluated for a storm duration of 24 hours, a rainfall interval of 15 minutes, and for return periods of 10, 100, and 500 years. Graphical results of the comparison are presented on Figures VI-5 through VI-7. The time distribution of an actual storm can be irregular. Nevertheless, the hydrologist must compute rainfall amounts from historical recorded rainfall intensity tables for that region and rearrange the incremental values to represent a reasonable storm pattern. Specific arrangements have been adopted by certain firms and agencies. The composite design storm is generated so that the maximum rainfall over any time span centered around the storm peak equals the design storm depth indicated for the corresponding duration in the rainfall intensity table. The U.S. Soil Conservation Service uses one distribution for storms west of the Sierra Nevada and Cascade Mountains (SCS Type 1) and another for

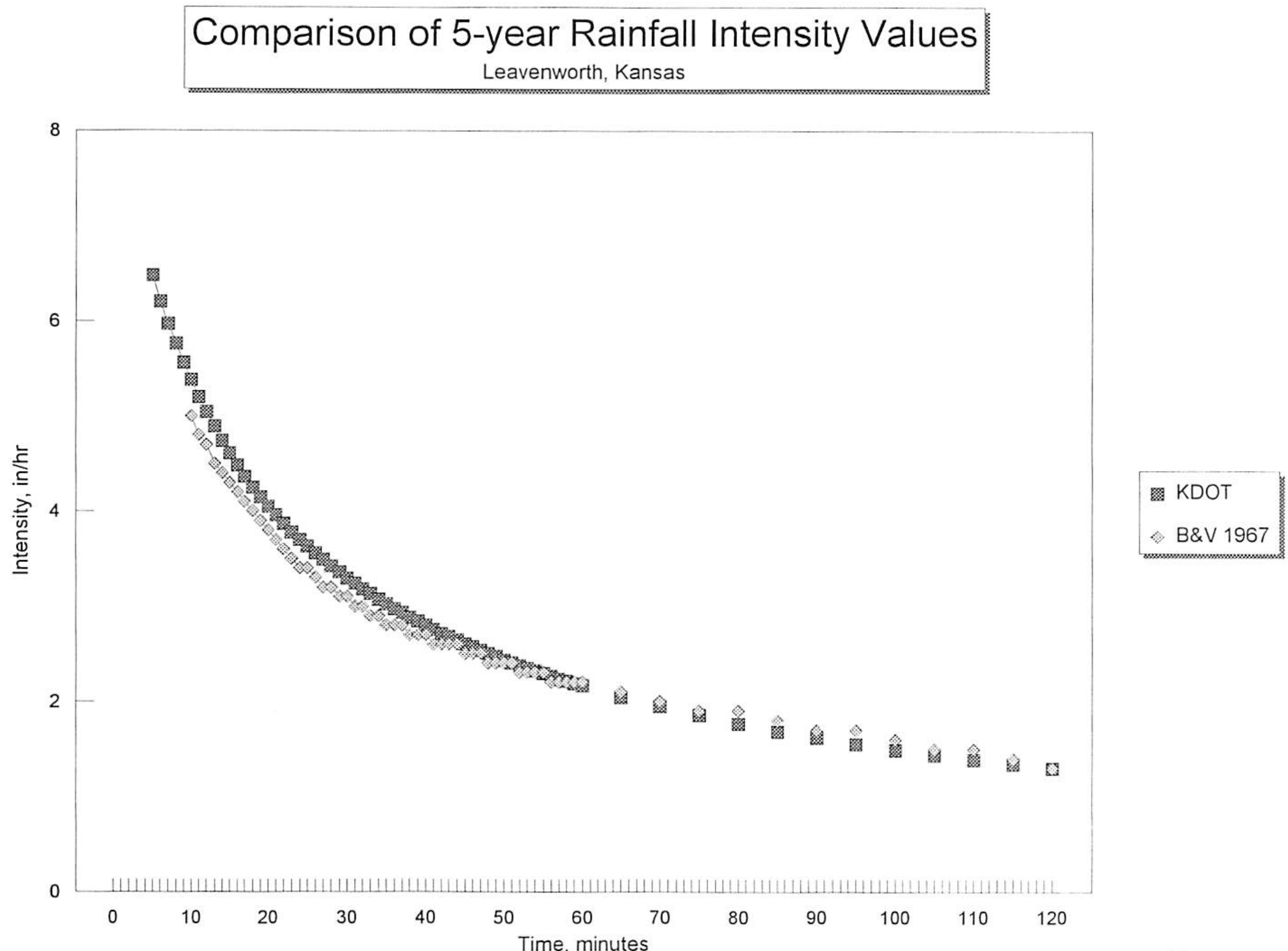

Comparison of 5-year Rainfall Intensity Values
Leavenworth, Kansas
Intensity, in/hr
8
6
4
2
0
0
10
20
30
40
50
60
70
80
90
100
110
120
Time, minutes
KDOT
B&V 1967

Figure VI-3

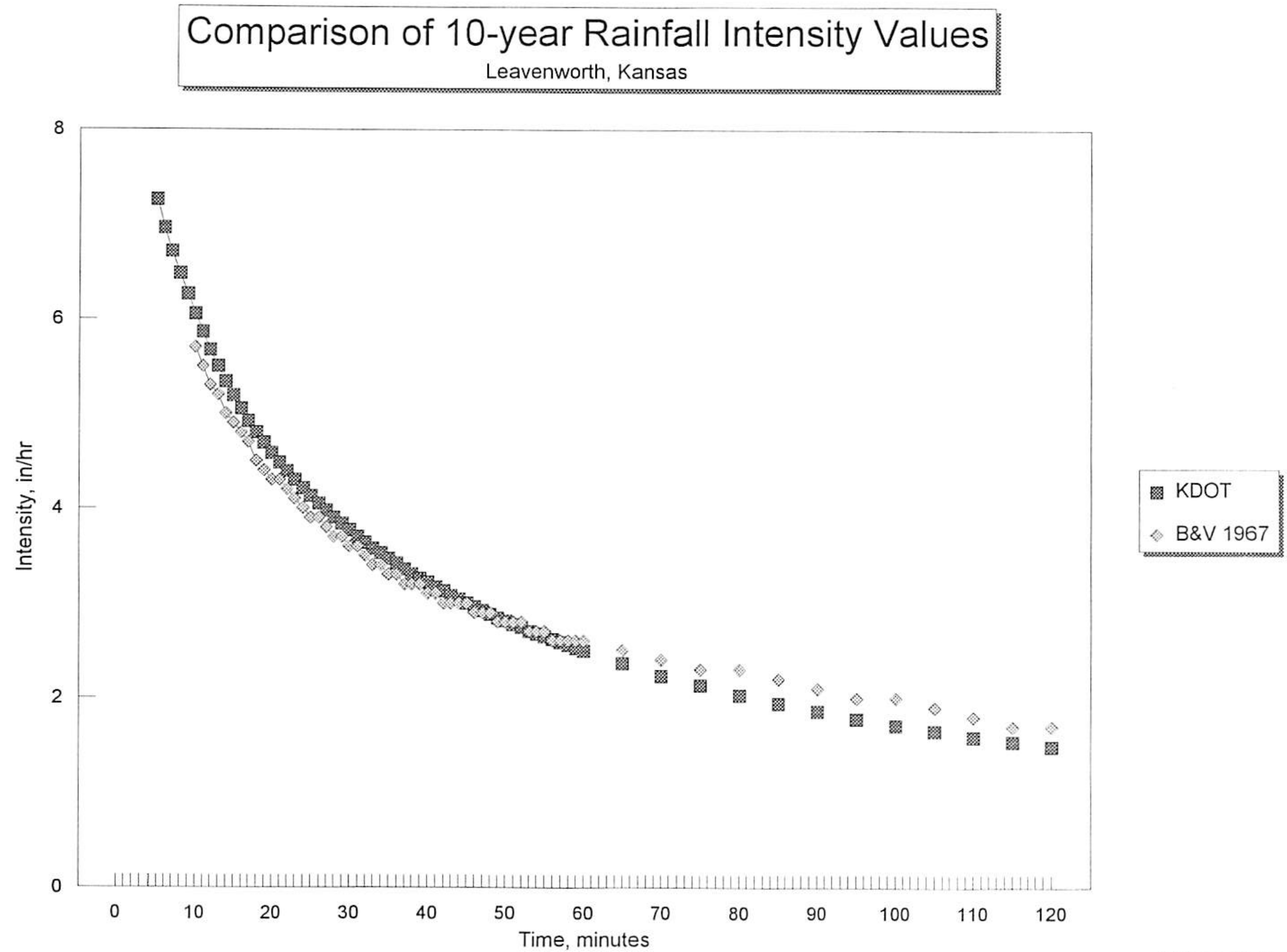
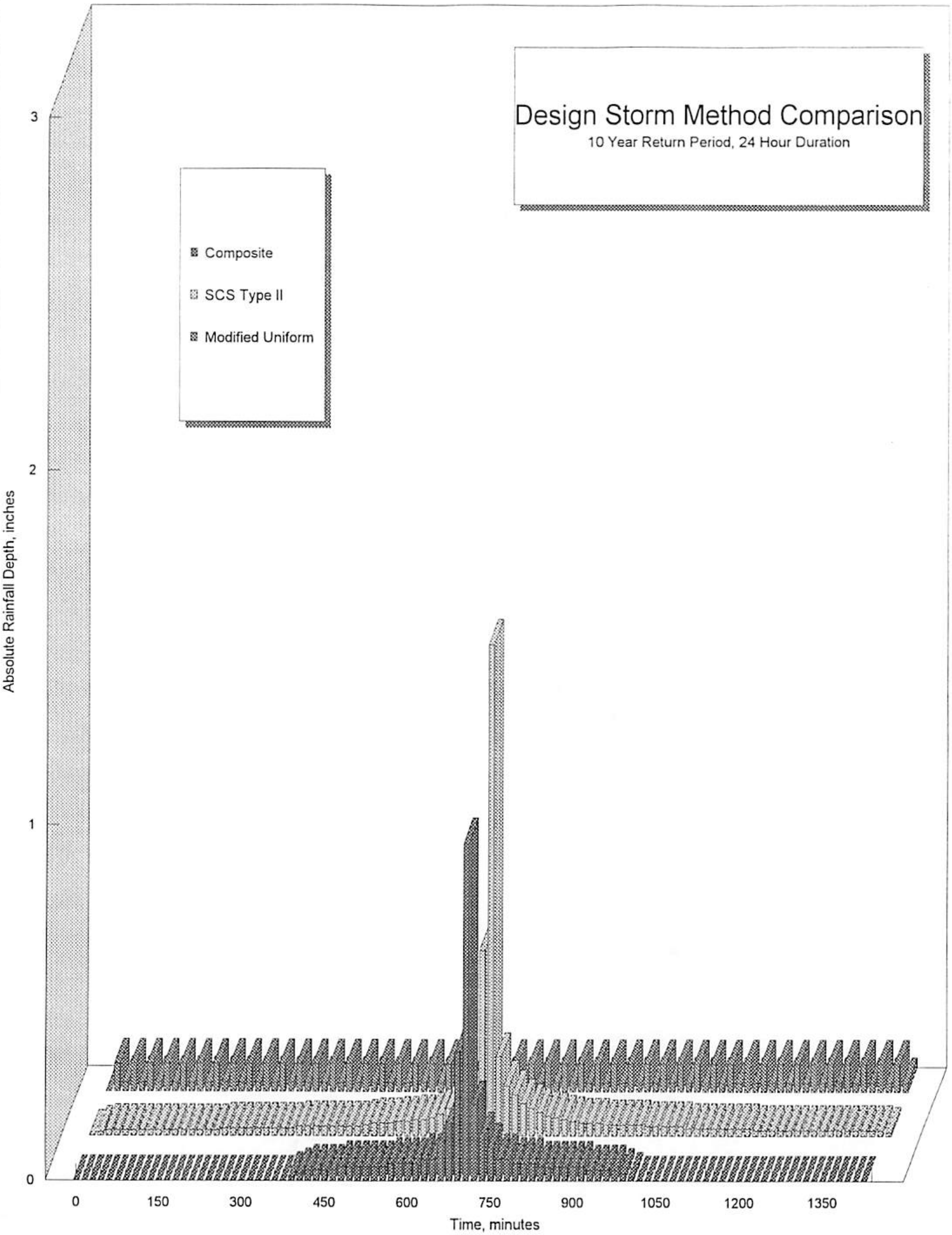

Comparison of 10-year Rainfall Intensity Values
Leavenworth, Kansas
Intensity, in/hr
0
2
4
6
8
Time, minutes
0
10
20
30
40
50
60
70
80
90
100
110
120
KDOT
B&V 1967

Figure VI-4



Design Storm Method Comparison
10 Year Return Period, 24 Hour Duration
Composite
SCS Type II
Modified Uniform
Absolute Rainfall Depth, inches
0
1
2
3
0
150
300
450
600
750
900
1050
1200
1350
Time, minutes

Figure VI-5

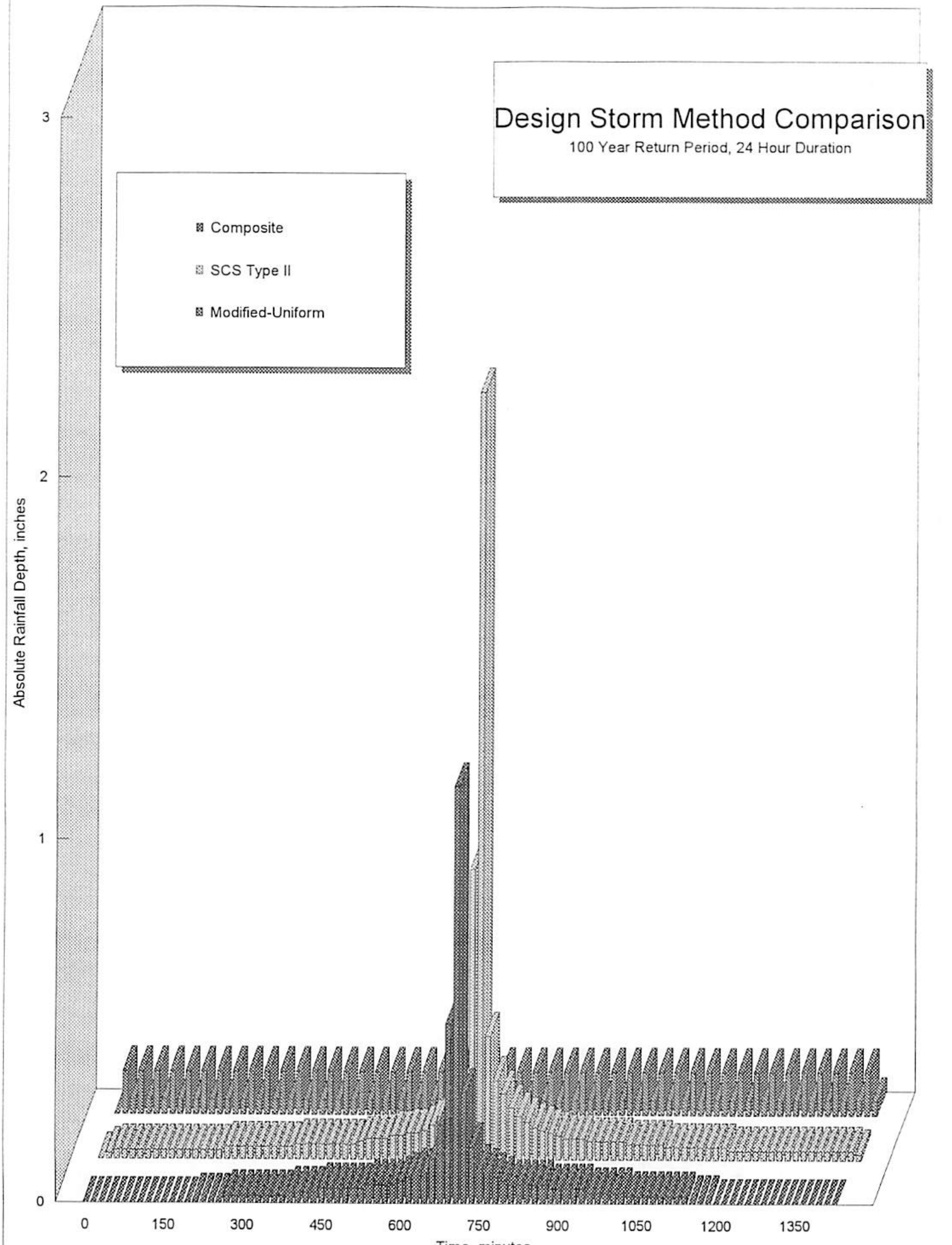
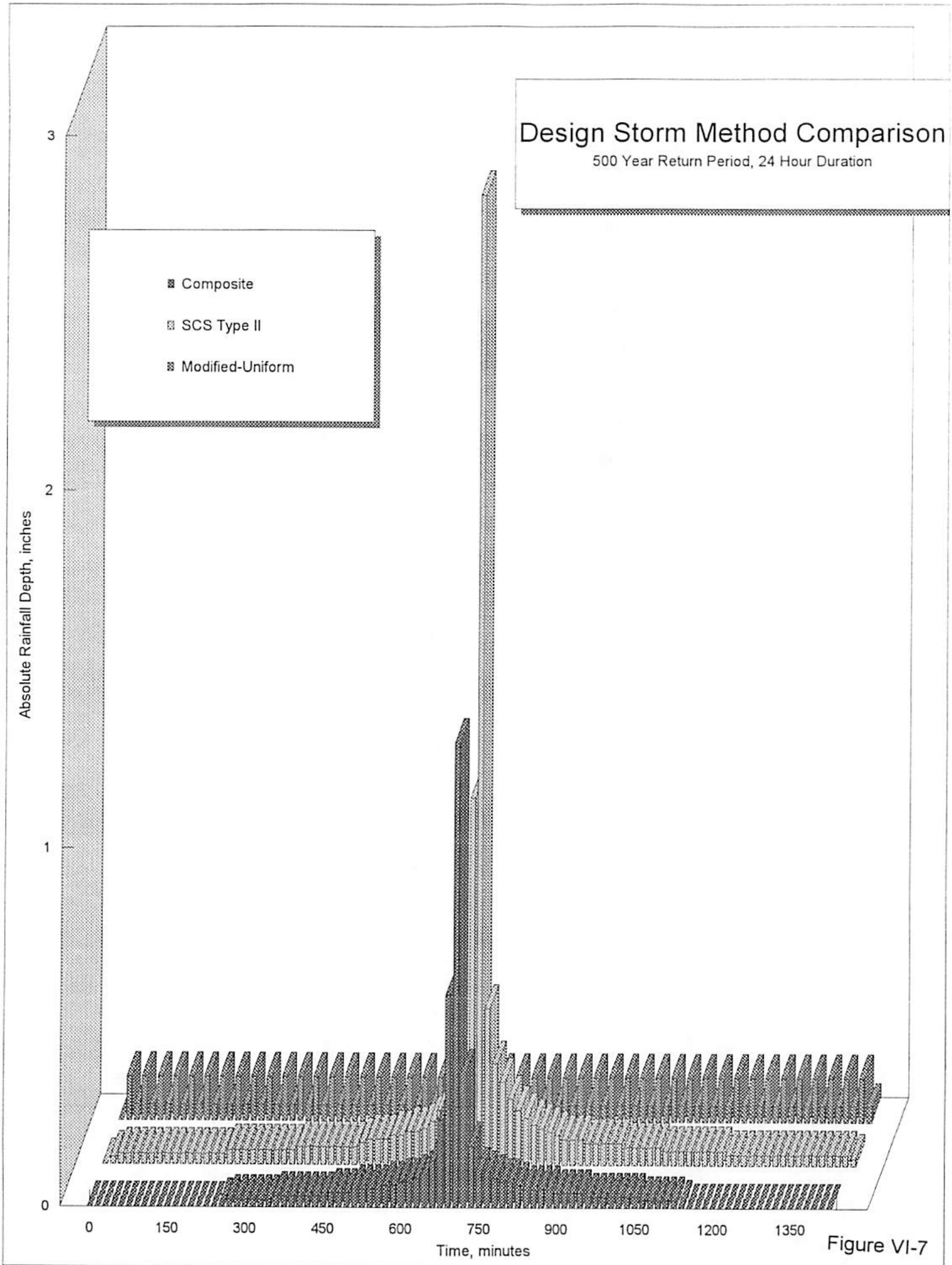

Design Storm Method Comparison
100 Year Return Period, 24 Hour Duration
Composite
SCS Type II
Modified-Uniform
Absolute Rainfall Depth, inches
0
1
2
3
0
150
300
450
600
750
900
1050
1200
1350
Time, minutes

Figure VI-6

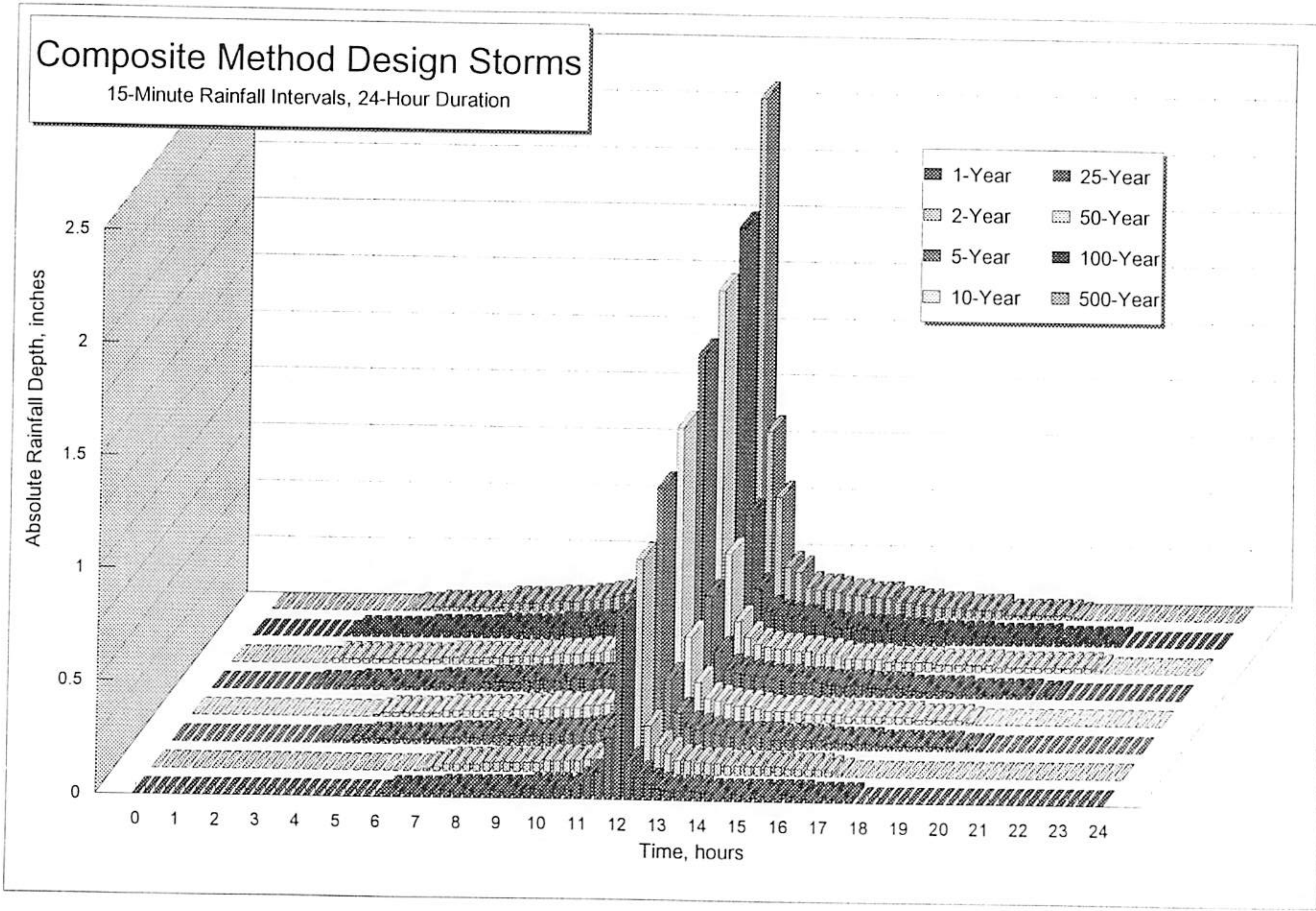

Design Storm Method Comparison
500 Year Return Period, 24 Hour Duration
Composite
SCS Type II
Modified-Uniform
Absolute Rainfall Depth, inches
3
2
1
0
0
150
300
450
600
750
900
1050
1200
1350
Time, minutes
Figure VI-7

storms in other parts of the country (SCS Type 2). In the modified-uniform design storm. developed for the Kansas Department of Transportation by Dr. Bruce M. McEnroe and Ke Zhao, rainfall is distributed in a uniform temporal pattern with a periodic step function. The rainfall intensity is constant over the long term, but over the short term, it fluctuates between 50 and 150 percent of the average intensity. According to Dr. McEnroe's study, the period of the fluctuations is unimportant as long as it is much shorter than the watershed's time of concentration. In this study, the period of the fluctuations was about 2 percent of the storm duration. Calculations for the three design storm methods are presented in Appendix H.

Flood studies are typically conducted using a peaked, fixed-shape hyetograph. Because of the lack of a storm peak, the modified-uniform method was eliminated. The shapes of the design storms generated by the composite and SCS Type 2 methods were similar. The peak of the SCS Type 2 storm, however, was higher than that for the composite storm, and would probably have resulted in higher peak runoff. Since this could lead to overly-conservative design of improvements, the SCS Type 2 storm was eliminated. Therefore, the composite design storm method was selected. Rainfall distributions for the 1-, 2-, 5-, 10-, 25-, 50-, 100-, and 500-year return period storms were prepared as indicated on Figure VI-8. The total rainfall depths, in inches, were computed as indicated in Table VI-3. The design storms were entered into the XP-SWMM models.

Table VI-3
Total Rainfall Depths

Design Storm Return Period in Years	24-Hour Duration Rainfall Depth in Inches
1	2.88
2	3.36
5	4.56
10	5.04
25	6.24
50	6.96
100	7.68
500	9.84



Composite Method Design Storms
15-Minute Rainfall Intervals, 24-Hour Duration
Absolute Rainfall Depth, inches
0
0.5
1
1.5
2
2.5
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time, hours
1-Year
2-Year
5-Year
10-Year
25-Year
50-Year
100-Year
500-Year

Figure VI-8

4. Land Use

Two land use scenarios were considered for the modeling--present conditions and ultimate conditions. Data for present conditions was obtained from the City Planning Department's existing land use map, and information for the ultimate conditions, from the future land use map, as indicated on Figures VI-1 and VI-2. From a modeling standpoint, the difference between the present and ultimate conditions is the percent imperviousness in each subarea. This is important, since an increase in percent impervious area increases both peak runoff flow and total runoff volume. The present land use conditions were modeled first to estimate peak flows and total runoff volumes and to identify inadequate structures. Verification consisted of comparing these values to those computed by another method. In addition, the existing inadequate conduits were plotted on a map, with the historical flooding locations and questionnaire responses superimposed, for the 5-year and 10-year events, as described in Section G of this chapter.

The purpose of modeling the ultimate land use condition was to estimate the future peak flows that can be expected when Leavenworth has reached full development. Additionally, total runoff volumes were determined and structures that may become inadequate in the future as the land uses change were identified. Therefore, improvements were sized based on future land use conditions. Land use planning and zoning can be effective flood plain management tools. Altering land use plans to require more open spaces and detention storage can limit runoff and lower the magnitude of required improvements. Also, preventing development in flood prone areas prevents flood damages from occurring.

5. Assumptions

The following assumptions were made to simplify the hydrologic modeling and to provide the accuracy necessary for planning level analyses.

- In general, small detention ponds throughout the City have no storage capacity.
- Manning's roughness coefficients for pervious and impervious areas are constant and of areal extent.
- Pervious and impervious depression storage values are constant and of areal extent.
- The average slopes, widths, Manning's coefficients, depression storage values, infiltration parameters, and rainfall hyetographs are the same for present and future conditions.

- The main structures on Five Mile Creek, Three Mile Creek, and Three Mile Creek South Branch were evaluated based on the frequency mixing concept in the Texas Department of Highways Hydraulic manual. The 100-year flood event was simulated over the watershed with tailwater at the outlet due to the 2-year event on the Missouri River. In addition, the 2-year flood event was applied to the watershed, and combined with the 100-year Missouri River flood backwater.
- Not all of the nodes in the models had contributing drainage areas. Of the nodes with contributing drainage areas, some had more than one subcatchment area draining to it. Lists of the drainage nodes and their contributing subcatchments for the Three Mile and Five Mile Creek basin models are provided in Appendix H.
- The processes of snowfall/snowmelt, erosion, groundwater movement, and pollutant buildup/washoff were not simulated.
- Duration of rainfall simulation time was 24 hours for all conditions and models. Computational time step was 5 minutes during rainfall and 15 minutes during the wet-dry transition.

E. Hydraulics

1. Introduction

The hydraulic modeling was performed using the Extran block of XP-SWMM. The Extran block performs hydraulic analyses, including accounting for backwater effects, in calculating water surface profiles. The purpose of the hydraulic modeling is to analyze the major culverts, bridges, channels, and enclosed stormwater conveyance system components for present and future conditions; locate system deficiencies and inadequacies; and recommend practical and cost-effective improvements to alleviate flooding.

The Three Mile and Five Mile Creek models each included the following conveyance system elements: the local storm sewer subsystems consisting of underground conduits, cross-road culverts, and small open channels; and the major conveyance system consisting of 36 inch and larger (or equivalent) enclosed system conduits, large open channels, culverts, and bridges.

Because of the unmanageably large number of conveyance system elements in the first-cut aerial mapping data received, it was decided to model only 24 inch and larger (or equivalent) conduits, unless there were smaller pipes in areas of known flooding or locations of questionnaire responses/complaints. If an underground system contained 15-24 inch pipes between larger pipes, the smaller pipes were retained.

The Three Mile and Five Mile Creek models were used to identify flooding locations throughout the tributaries and to evaluate the performance of the main channel structures. After improvements of the main channel bridges and culverts were sized for the 100-year design storm, the 10-year and 50-year storms were applied to the system to determine the two design tailwater elevations at the outlets of all the tributary storm sewer subsystems on the main channel. Following establishment of the 10-year and 50-year tailwater elevations, individual subsystem models were created by extracting these tributaries from the main models. The subsystem names and descriptions for the Three Mile and Five Mile Creek watersheds are listed in Tables VI-4 and VI-5 and the locations are shown on Figure II-1. The subsystem models were used to evaluate the local tributary systems; and improvements were sized for the 10-year storm, for underground pipes and open channels and culverts; and for the 50-year storm, for structures under collectors and major arterial streets.

2. Data Requirements

Data used in the hydraulic modeling were collected for the local and major conveyance systems. Data on the open channels, the enclosed system, and most culverts were obtained from the City's Stormwater Sewer Maps, and have been incorporated into the City's GIS. A copy of the data will be presented to the City in the format requested.

Data on culverts and bridges on Three Mile and Five Mile Creeks and Three Mile Creek South Branch were obtained from the KDOT bridge assessment disk, the FEMA Flood Insurance Study, the Bucher Willis 1993 Bridge Inspection Report, and numerous construction drawings and maps provided by the City. Where flowline elevations in these documents conflicted, elevations from the Stormwater Sewer Maps were used.

Table VI-4
Three-Mile Creek Watershed
Storm Sewer Subsystem Descriptions

Subsystem	Description	Node # on 3mc	10-Year Max Elev.	50-Year Max Elev.
1L	4th Street	92756	768.46	769.41
2L	6th Street	92197	771.52	772.65
		86197	771.59	772.73
3L	7th Street	92711	772.69	773.85
4L	Metropolitan & Broadway	92707	773.57	774.71
1R	Ohio to Spruce & Broadway	92707	773.57	774.71
5L	Broadway & 3mc	86369	775.47	776.74
		86368	776.15	777.42
2R	Ohio to Spruce & 10th Street	92702	776.7	777.97
3R	Cherokee & Sherman Avenue	92699	777.89	779.13
		92696	779.31	780.51
6L	Metropolitan & 9th Street	92618	786.92	788.7
4R	10th & Shawnee	92608	789.76	790.47
7L	Metropolitan & 11th to 12th Streets	92613	800.12	802.57
5R	15th & Osage	92305	803.59	805.42
6R	Shawnee & 20th to 18th to Osage	92303	804.51	806.92
8L	Metropolitan & 16th to 14th & Kiowa	92299	805.75	808.35
9L	Metropolitan & 18th	92018	820.72	822.89
10L	Metropolitan & 20th	86831	835.57	836.94
7R	Ottawa & 20th	86831	835.57	836.94
8R	20th & Dakota & Ottawa	92628	843.25	844.34
S1R	10th & Cherokee	92695	795.85	797.69
		92694	796.99	798.51
S1L	13th & 14th & Shawnee & Delaware	86468	807.6	808.68
S2R	14th & High	92657	808.56	809.46
S3R	15th & Spruce & Olive	92656	818.64	819.57
S2L	17th & Cherokee	92653	820.58	821.7
S3L	18th & Sherman	92654	826.1	827.03
S4R	16th & Spruce	92655	833.26	834.23
S5R	18th & 19th & Spruce	92648	844.1	847.48
		92647	844.57	847.63
S6R	West Leavenworth Tfwy to 20th & Spruce	92646	847.63	850.39
S4L	21st & Choctaw	92635	864.76	867.23
S7R	21st & Kenton	92636	864.62	867.14
S8R	22nd & Spruce	92002	870.75	871.88

Table VI-5
Five-Mile Creek Watershed
Storm Sewer Subsystem Descriptions

Subsystem	Description	Node # on 3mc	10-Year Max Elev.	50-Year Max Elev.
1L	Pennsylvania to Evergreen & 4th Streets	92251	771.66	774.72
		85855	774.52	777.09
1R	Marion Street	92250	772.51	776.45
2R	4th Street to V.A. entrance drive	92294	774.31	776.73
3R	4th Street	85855	774.52	777.09
2L	Santa Fe & 2nd Streets	92323	776.27	777.97
4R	Hughes Road & Limit Street	92328	779.61	781.56
3L	10th Avenue & Thornton	92220	781.2	783.19
		92330	782.15	785.15
5R	Hughes Road & McDonald	92507	782.39	785.28
6R	East of Shrine Park Rd to Lakeview Rd	92509	784.46	786.35
4L	West of Shrine Park Rd & Goddard Circle	92504	787.44	788.86
		84936	787.24	788.48
5L	10th Avenue & Limit Street	92505	790.18	791.62
7R	Deerfield and Garland	92502	797.09	798.96
8R	East of 10th Avenue to Parkway Drive	92496	804.56	806.22
6L	14th & Limit Street	92485	807.39	808.3
9R	West of 10th Avenue to 13th Street	92485	807.39	808.3
		92487	812.58	815.35
7L	17th Street & Vilas Street	92061	827.24	829.18
		92450	828.71	831.27
8L	Candlewood & Tudor Drive	92449	833.5	835.07
		92448	835.26	837.26
10R	West Leavenworth Tfwy & Five Mi Creek	92447	835.9	837.77
		92466	837.65	839.23
11R	County Hwy 5 & Five Mile Creek	92434	841.7	843.22
9L	Limit Street to County Hwy 5	92020	846.3	847.93
		92433	852.72	854.45
10L	Limit & 22nd Street and Vilas	92430	861	862.47
		92424	871.45	872.47
11L	Hebbelin Drive & 23rd Street	92416	877.8	879.01
		92822	891.25	892.19

The following hydraulic data were used for modeling the various elements:

Open Channels

- Channel length and slope.
- Upstream flowline elevation.
- Downstream flowline elevation.
- Manning's "n" value for channel.
- Manning's "n" value for overbank.
- Channel cross-section.
- Main channel definition.
- Contraction loss coefficient.

Enclosed system, culverts, and bridges

- Conduit length.
- Structure depth and width or diameter.
- Structure type.
- Manning's "n" value.
- Upstream flowline elevation.
- Downstream flowline elevation.
- Expansion loss coefficient.
- Number of barrels.

Manholes

- Rim, top of structure, or ground surface elevation.
- Invert elevation.
- Outfall data.

For modeling, the channels, culverts, and bridges were separated by "nodes." In a system of open channels and culverts, a node is synonymous with a manhole in an underground conveyance system. The nodes are for modeling purposes only, and do not have any physical representation. In the model, they represent locations where a channel or culvert changes size or slope; serve as an interface between the culverts and channels; and indicate where runoff from tributary areas can enter the conveyance system and can be routed downstream.

3. Assumptions

The following assumptions were made to simplify the hydraulic modeling:

- Invert elevations for open channels, bridges, and culverts were estimated from the contours on the Stormwater Sewer Maps. In general, the Three Mile Creek main channel and south branch inverts were 1-3 feet higher than the stream bed elevations indicated in the 1977 FEMA report. Since no provision was made to collect survey data, the Stormwater Sewer Map inverts are retained in the models. This situation is being investigated as part of the FEMA map update study. Also, final designs will require detailed surveying of structures and channel cross-sections to establish horizontal and vertical control.
- Manning's roughness coefficients ("n") include the following:

- Corrugated metal pipe (CMP)	0.024
- Reinforced concrete pipe (RCP)	0.015
- Horizontal elliptical concrete pipe (HERCP)	0.015
- Reinforced concrete box (RCB)	0.011
- Arch culvert, stone (A)	0.025
- Arch culvert, corrugated metal (MAC)	0.025
- Arch culvert, bolted steel plates	0.012
- Vitrified clay pipe (VCP)	0.013
- Advanced drainage system (ADS)	0.010
- Natural channel, main channel	0.030
- Natural channel, overbank	0.050

- The dimensions of culverts on the Stormwater Sewer Maps adhere to the following convention: width (feet or inches) by height (feet or inches).
- Existing lakes and detention ponds are full and, therefore, have no storage capacity or effect on hydraulics of system.
- In developed areas, the controlling high elevation for open channel cross-sections is at the ground floor flooding depth of the lowest building in the vicinity. In the downstream portions of the main channels, where Missouri River backwater for large storm events can be higher than the existing topography, cross-sections are extended to include higher ground elevations. Where there is permanent water in the main channels and where no below-water level contour lines are indicated on the Stormwater Sewer Maps, channel invert elevations were taken from the Flood Insurance Study Flood Profiles.

- Open channels conveying flow to culverts or underground pipe inlets have a contraction loss coefficient of 0.6. Culverts, bridges, or pipes daylighting to open channels have an expansion loss coefficient of 0.8.
- Flooded water does not pond at manholes, but escapes the system instead of waiting for the downstream conduit to convey the excess.
- Backwater elevations from the Missouri River at the confluences with Three Mile and Five Mile Creeks for the 10-, 50-, 100-, and 500-year floods are from the Flood Insurance Study Flood Profiles. The 1- and 2-year elevations were determined by regression analysis on the Flood Insurance Study data, as indicated on Figures VI-9 and VI-10. Calculations are provided in Appendix H. Detailed analyses of Missouri river flood elevations are beyond the scope of this study.
- HERCP, MAC, and CMAP can be modeled as circular pipes. The equivalent diameter can be calculated from the known dimensions of the non-circular conduits.
- Stone arches and bolted steel arches are equivalent to the "modified basket-handle" conduit type in XP-SWMM.
- All bridges are modeled as reinforced concrete box culverts with the clear space dimensions approximated by the culvert depth, width, and number of cells.
- All structures are modeled as though there were no obstructions due to debris, structure failure, or siltation.
- Where the lengths of bridges and culverts are not available, they are estimated from the Stormwater Sewer Maps, which is consistent with the level of detail used in master planning.
- Stormwater conveyance facilities proposed as part of the West Leavenworth Trafficway project are included in the models.

F. Model Verification

The purpose of model verification is to provide a level of accuracy in the computation consistent with the level of detail required for master planning. Model verification assures that the values obtained are reasonable for the data used and the level of detail assumed. Model calibration, on the other hand, consists of incorporating measured rainfall data into the model, and comparing the flows generated by the model with those measured in the field at stream gauges for the same event. The rainfall input would be obtained from rain gauge information obtained throughout the watershed. Once calibrated, the design events could be run to determine the appropriate design flows. Since no measured rainfall or streamflow data were available for calibration, verification

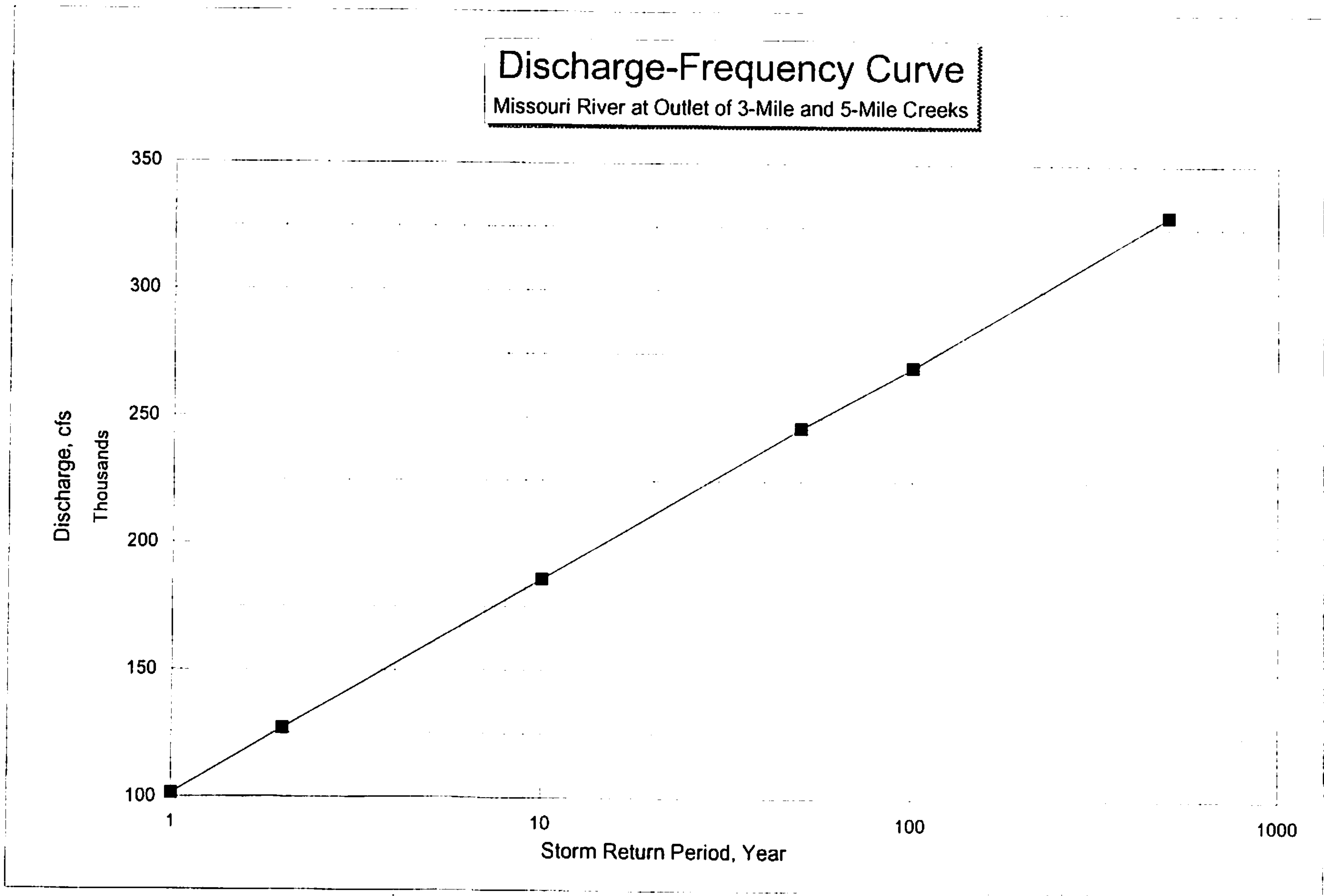

Discharge-Frequency Curve
Missouri River at Outlet of 3-Mile and 5-Mile Creeks
Discharge, cfs
Thousands
350
300
250
200
150
100
1
10
100
1000
Storm Return Period, Year

Figure VI-9

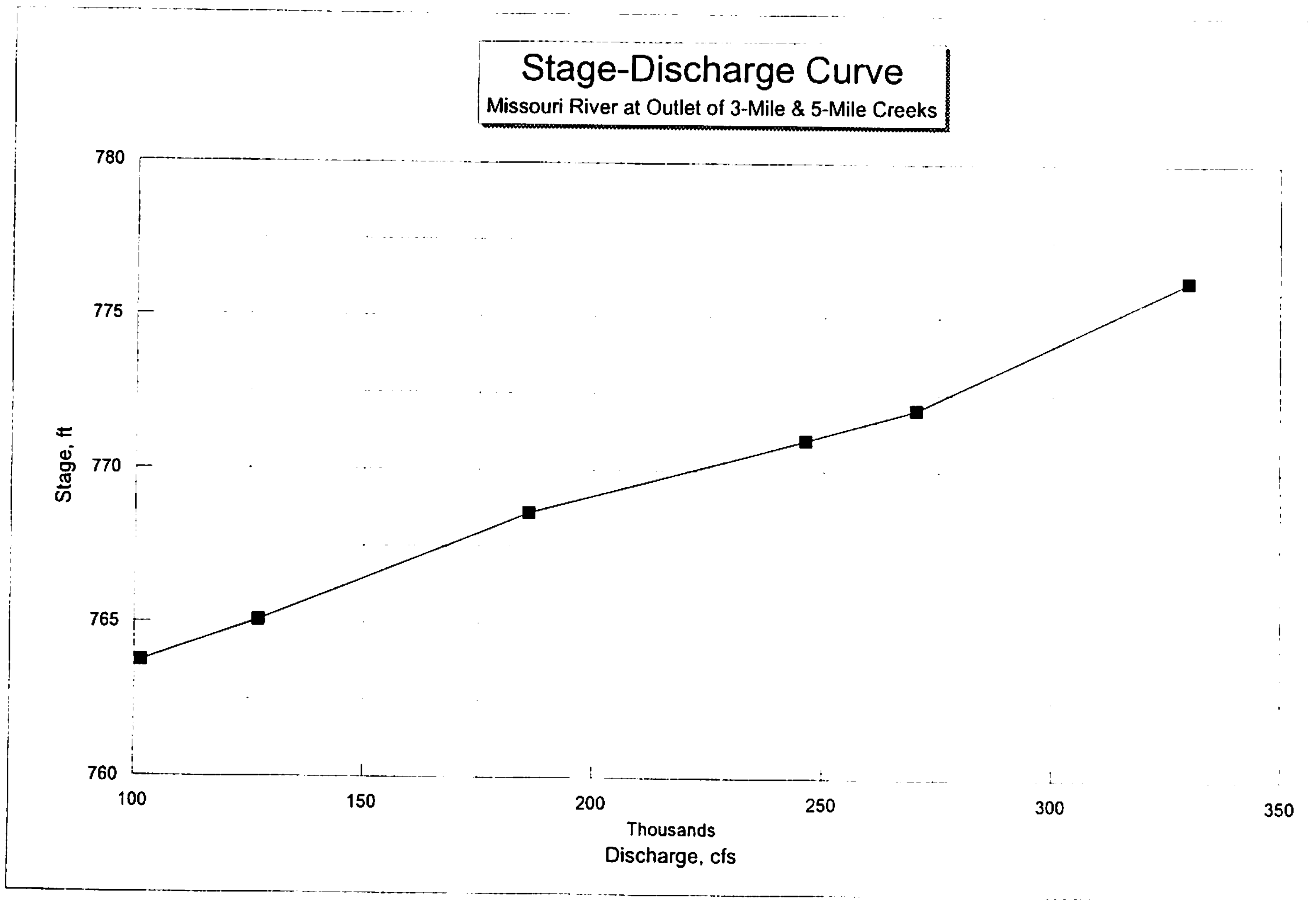

Stage-Discharge Curve
Missouri River at Outlet of 3-Mile & 5-Mile Creeks
780
775
770
765
760
Stage, ft
100
150
200
250
300
350
Thousands
Discharge, cfs

Figure VI-10

was considered the most appropriate method of checking the model. The flow verification was performed at three levels: peak runoff from each subarea; visual comparison of historical flooding areas to inadequate conduits causing flooding identified by the model; and peak discharge at basin outlet.

When resources permit, the City should implement a rainfall and stream gauge monitoring system to calibrate the models. Also, as improvements are made to the drainage system, the models should be updated. Depending on the growth in the City and the timing of implementation of the recommended improvements, the master plan should be updated every 5 to 10 years.

1. Peak Runoff

Verification of the subarea peak runoff consisted of comparing the runoff from XP-SWMM with the runoff (Q) calculated with the Rational formula, Q = C x i x A. The runoff coefficients used in the Rational formula were converted from the percent imperviousness values in the model based on an empirical formula. The runoff coefficients were calculated as follows:

$$C = (\%\ imp/100 \times 0.90) + (\%\ perv/100 \times 0.30)$$

where:

C = Rational formula runoff coefficient
% imp = percent imperviousness of the subarea
% perv = 1 - % imp/100 = percent perviousness of the subarea
0.90 = runoff coefficient for entirely impervious area
0.30 = runoff coefficient for entirely pervious area

The intensity, i, taken from the KDOT "Rainfall Intensity Tables for Counties in Kansas," was based on a duration equal to the time of concentration (T_c). The time of concentration was calculated as follows:

$$T_c > 5 \text{ minutes, and}$$
$$T_c = T_i + T_t$$

where:

$$T_i = \text{overland flow time}$$
$$= \frac{1.8 \times (1.1 - C) \times (\text{overland flow distance})^{1/2}}{(\text{subcatchment slope})^{1/3}}$$

and where:

$$T_t = \text{pipe and gutter travel time} = \frac{\text{pipe length}}{\text{pipe velocity}} + \frac{\text{gutter length}}{10^{\wedge}((\log \text{slope} + .602)/2)}$$

and:

overland flow distance ≤ 300 ft
for pipe slope <2%, pipe velocity = 7 ft/sec
for 2<slope <5%, pipe velocity = 10 ft/sec
for slope >5%, pipe velocity = 15 ft/sec

The Area (A) in the Rational formula was equal to the subcatchment area in the model.

The peak runoff verification was performed for existing and future land use conditions using the 10-year return period. Spreadsheets with the subarea peak flows for XP-SWMM and the computation of subarea peak flows using the Rational formula are provided in Appendix H. In general, there was about a 20 percent difference between the results of the two methods. The Three Mile Creek spreadsheets indicate XP-SWMM produces approximately 24 percent higher runoff values than the Rational formula. In the Five Mile Creek watershed, however, XP-SWMM produces approximately 21 percent lower values overall.

2. Historic Flooding Problem Areas

The stormwater conveyance system was modeled for typical storm events to identify inadequate conduits and quantify the magnitude of flooding. The results of the preliminary design storm simulations were plotted on maps of the watersheds. Adequate conveyance elements were shown in black line, while inadequate conduits, that is, those with flooding at their upstream manholes, were highlighted in red. The stormwater questionnaire results, color-coded to indicate major and minor problems at a given address, were superimposed on the maps. In addition, locations of known flooding problems, provided by the City, were superimposed as blue triangles. The Three Mile Creek watershed is shown on Figure VI-11, and the Five Mile Creek watershed on Figure VI-12. The City, the Citizen's Stormwater Committee, and Black & Veatch concurred that there was good correlation. However, some minor changes to the model were required to better represent the actual conveyance elements at 18th and Osage Streets; 13th, 14th, Shawnee, and Cherokee Streets; and 16th, 17th, and Vilas Streets.

3. FEMA Discharge

Peak flow verification for the Three Mile and Five Mile Creek watersheds was completed using the 1977 Flood Insurance Study (FIS). Although the study was completed nearly 20 years ago, the data were determined to be suitable for flow verification. Because of development in the watersheds, peak discharge at the basin outlet estimated with XP-SWMM for present conditions was expected to be higher than the value given in the 1977 FIS report. Table VI-6 presents the results of the basin flow comparisons for the design storm events. Overall, the peak flows for both watersheds were approximately 12 percent higher than those from the 1977 FIS report. This result is attributed to differences in hydraulic methods used in the studies.

Table VI-6
Basin Outlet Peak Discharge Comparison

Watershed	FEMA 1977 (cfs)	XP-SWMM Future (cfs)	Percent Difference %
	10-Year Event		
Three Mile Creek	3,450	5,040	46.1
South Branch	1,300	1,230	-5.4
Five Mile Creek	4,500	4,930	9.6
	50-Year Event		
Three Mile Creek	6,000	6,940	15.7
South Branch	2,300	1,870	-18.7
Five Mile Creek	8,000	8,040	0.5
	100-Year Event		
Three Mile Creek	7,500	7,770	3.6
South Branch	2,850	2,020	-29.1
Five Mile Creek	9,500	8,840	-7.0

In XP-SWMM, the flow in the channel is attenuated as a result of the timing of the peak flow and the runoff from the tributary areas downstream from the location of peak flow and storage in the conveyance system. By the time the peak flows from the upper portions reach the lower portion of the watershed, the peak runoff from the tributary areas to the lower portion of the system has already passed. As the peak flow travels downstream, it is attenuated, since the runoff contributions from tributary areas are minimal. The model is a dynamic simulation, with thousands of calculations per second extending through the hydraulic system. The system modeled is a complex dendritic network, with several hundred junction, pipe, and channel components.

The FEMA study, conversely, was based on a steady-state, step-backwater program much like HEC-2. The conveyance components consist of a single, linear system of bridges/culverts and open channel reaches. With this method, the user inputs the discharge first and the water surface profile is calculated. The FEMA discharges were determined using a synthetic unit hydrograph method for which the calculations were not available for comparison to the hydrologic parameters for this study.

The differences in peak flow rates reported in the FEMA study versus those calculated in this study are related primarily to the different models. Normally, it is expected that peak flows would increase as development occurs over a 20-year period. In general, the peak flows shown in Table VI-6 show little increase and, in some cases, decreases between the 1977 FEMA study and this master plan. The results are in large part due to different model techniques. XP-SWMM accounts for channel storage behind culverts which reduces peak flows; whereas, the models used in 1977 did not.

4. Conclusions

Three different procedures from three separate sources were used for flow verification. Although some discrepancies were identified in the comparisons of subcatchment peak flows, the verification process in general provided assurance that the flow values are reasonable and within the degree of accuracy necessary for master planning. The preferred procedure for checking flow calculations from a computer model is model calibration using measured rainfall data and streamflow field information. However, this procedure is both time-consuming and expensive, and is outside the scope of this project.