4.0 Methodology for Modeling

4.1 Methodology for Hydrologic/Hydraulic Modeling

The U.S. EPA’s Storm Water Management Model (SWMM), with a computerized graphical interface provided by XP Software (XP-SWMM), was chosen as the computer modeling package for this study. XP-SWMM uses rainfall and watershed characteristics to generate local runoff, which is routed simultaneously through complicated pipe and overland flow networks. The model can account for detention in ponding areas, backflow in pipes, surcharging of manholes, as well as tailwater conditions that may exist and affect upstream storage or pipe flows. The 1000 node version of XP-SWMM2000, Version 8.51, was used to model the storm sewer, ponding and overland flow systems within the City of Edina.

4.1.1 Hydrologic Modeling

Three major types of information are required by XP-SWMM for hydrologic modeling: (1) watershed data, (2) rainfall data, and (3) infiltration data. This data is used by XP-SWMM to generate inflow hydrographs at various points into the storm sewer, ponding, and overland flow networks. The following sections describe each of these data.

4.1.1.1 Watershed Data

The amount of runoff from a watershed depends on numerous factors, including the total watershed area, the soil types within the watershed, the percent of impervious area, the runoff path through the watershed, and the slope of the land within the watershed. ArcView geographic information systems (GIS) software was used extensively in assessing the above mentioned characteristics of each watershed within the city. The software also allowed mapping of the drainage network for the area.

4.1.1.1.1 Watershed Area

The watershed delineation was performed using 2-foot contour-interval topography, which was obtained from the City of Edina. An electronic coverage of the 2-foot topography was used in ArcView, along with the City storm sewer layout and aerial imagery, to delineated and digitize the watersheds. In certain cases, the watershed divides were field verified. A total of 1386 separate watersheds were delineated for this plan.

4.1.1.1.2 Land Use Data

The percent of impervious area within each watershed was estimated using land use data provided by the City of Edina. An electronic land use coverage was obtained from the City and used in ArcView. For areas outside of the Edina city limits that were included in the model, such as small portions of Eden Prairie, Bloomington, Hopkins, St. Louis Park, Minneapolis, and Richfield, land use data based on the 1997 Metropolitan Council aerial photographs was used. Land use within the study area was divided into the following categories: commercial, natural/open/park, golf course, highway, industrial/office, institutional, residential, wetlands, and open water. The land use information provided by the City categorized residential land use as single-family residential or multiple-family residential. For modeling purposes, these residential categories were further broken down based on the density of housing units within the area. The City's electronic land use coverage and aerial imagery was used in ArcView to determine the density of the residential areas. The single-family residential areas were further categorized as very low density residential (<1 unit/acre) or low density residential (1-4 units/acre). The areas categorized as multiple-family residential by the City were broken down into the following categories: low density residential (1-4 units/acre), medium density residential (4-8 units/acre), and high density residential (>8 units/acre).

The land use categories were used to estimate the total and "directly-connected" impervious fractions for each subwatershed within the study area. The total impervious fraction of a watershed represents the portion of the watershed that is covered by an impervious surface. The "directly-connected" impervious fraction represents the impervious surfaces that are hydraulically connected to a stormwater conveyance system. For example, if a rooftop drains onto an adjacent pervious area such as a yard, it is not a "directly-connected" impervious area. However, if a rooftop drains onto a driveway, which drains to the street and thence to a stormwater catchbasin, the rooftop would be a "directly-connected" impervious area.

To determine the impervious fractions within each watershed, assumptions for the total impervious fraction and "directly-connected" impervious fraction were made for each land use. The land use categories and the impervious fraction assumptions used in the analysis are listed in Table 4.1. The imperviousness assumptions used for the City of Edina are based on a calibrated XP-SWMM model for the *Nine Mile Creek Watershed District Bloomington Use Attainability Analysis*, Barr Engineering, 2001.

Table 4.1 Land Use Impervious Fraction Assumptions for Hydrologic Modeling

Land Use Designation	Total Impervious %	Directly-Connected Impervious %
Commercial	90%	80%
Golf Course	5%	2%
Highway	50%	50%
Industrial/Office	90%	80%
Institutional	40%	20%
Institutional- High Imperviousness	70%	50%
Natural/Park/Open	2%	0%
Open Water	100%	100%
Residential- Very Low Density	12%	8%
Residential- Low Density	40%	20%
Residential- Medium Density	55%	30%
Residential- High Density	70%	40%
Wetlands	100%	100%

4.1.1.1.3 Watershed Width and Slope

The SWMM Runoff Non-linear Reservoir Method was used as the hydrograph generation technique for this project. This method computes outflow as the product of velocity, depth and a watershed width factor. The watershed "width" in XP-SWMM is defined as twice the length of the main drainage channel, with adjustments made for watersheds that are skewed (i.e., the areas on both sides of the main drainage channel are not equal). This factor is a key parameter in determining the shape of the hydrograph for each watershed and is often used as a calibration parameter. To determine the width parameter, the main drainage channel for each watershed was digitized in ArcView and a customized ArcView script was used to calculate the width based on the skew of the drainage path within the subwatershed.

The average slope (ft/ft) for each watershed was calculated in ArcView using the electronic topographic data provided by the City of Edina. The topographic data was converted into a grid format in ArcView. The slope was then calculated by measuring the differences in elevation between each grid cell within each individual watershed.

4.1.1.2 Rainfall Data

Storm events for several return periods were analyzed in this study. Typically, the 100-year and 10-year storm events were modeled. However, for the Morningside watershed in northeast Edina, the 100-year and 5-year storm events were modeled. For the 100-year return period, the Soil Conservation Service (SCS) Type II rainfall distribution was applied to a total rainfall of 6 inches over a 24-hour duration. The SCS distribution, developed from the Weather Bureau's Rainfall

Frequency Atlases, represents a continuous “stacked” event, including the runoff peaks from a variety of different storm durations. For the 5-year and 10-year return period, a 30 minute duration storm event was used. The Huff Second Quartile rainfall distribution was used for the 5-year and 10-year 30-minute events. The 5-year analysis was based on 1.5 inches of rainfall over 30 minutes and the 10-year analysis was based on 1.65 inches of rain throughout a 30-minute storm. The precipitation totals for the design storms were taken from NOAA Technical Memorandum NWS HYDRO for storms with durations of 1 hour or less or Technical Paper 40 published by the U.S. Weather Bureau for the Twin Cities metropolitan area.

4.1.1.3 Infiltration Data

4.1.1.3.1 Soils

Soils data for the City of Edina was obtained through the Hennepin County Soils GIS database, which was imported into ArcView. The database included the soil names and the hydrologic soil group (HSG) designation for most of the soil types. The hydrologic soil group designation classifies soils into groups (A, B, C, and D) based on the infiltration capacity of the soil (well drained, sandy soils are classified as “A” soils; poorly drained, clayey soils are classified as “D” soils). When a hydrologic soil group designation was not included in the soils database, the soil description was used to estimate the HSG. If a soil description was unavailable, the most dominant soil group in the vicinity was assumed. Although all soil types are represented in the city, the predominant soil type in the city is Type B (sandy loam).

4.1.1.3.2 Horton Infiltration

Infiltration was simulated in the XP-SWMM models using the Horton Infiltration equation. This equation is used to represent the exponential decay of infiltration capacity of the soil that occurs during heavy storm events. The soil infiltration capacity is a function of the following variables: F_c (minimum or ultimate value of infiltration capacity), F_o (maximum or initial value of infiltration capacity), k (decay coefficient), and time.

The actual values of F_c, F_o, and k are dependent upon soil, vegetation, and initial moisture conditions prior to a rainfall event. Because it was not feasible to obtain this detailed information for each subwatershed through field samples, it was necessary to make assumptions based on the various soil types throughout the city. Table 4.2 summarizes the Horton infiltration values used for each Hydrologic Soil Group to calculate composite infiltration parameters for each subwatershed. The values shown in the table are based on suggested values in the *Storm Water Management Model, Version 4: User’s Manual*, U.S. EPA, 1988. Composite F_c and F_o values were calculated for each subwatershed based on the fraction of each soil type within the subwatershed. Global databases containing the infiltration parameters for each subwatershed were developed and imported into the XP-SWMM models.

Table 4.2 Horton Infiltration Parameters

Hydrologic Soil Group	F_o (in/hr)	F_c (in/hr)	k (1/sec)
A	5	0.38	0.00115
B	3	0.23	0.00115
C	2	0.1	0.00115
D	1	0.03	0.00115

4.1.1.4 Depression Storage Data

Depression storage represents the volume (in inches) that must be filled with rainfall prior to the occurrence of runoff in XP-SWMM. It characterizes the loss or "initial abstraction" caused by such phenomena as surface ponding, surface wetting, interception and evaporation. Separate depression storage input values are required in XP-SWMM for pervious and impervious areas.

The depression storage assumptions used for the models were based on the values used in the XP-SWMM model developed for the *Nine Mile Creek Watershed District Bloomington Use Attainability Analysis*, Barr Engineering, 2001. For this model, the depression storage was estimated by plotting total precipitation for several measured rainfall events at a Bloomington continuous recording precipitation gage versus runoff from several Bloomington monitoring sites. A regression of the data yielded a y-intercept that was assumed to be the depression storage (in inches). Based on this analysis, the assumed impervious depression storage was 0.06 inches and the pervious depression storage was 0.17 inches. XP-SWMM also uses a “Zero Detention Storage” parameter to account for areas that generate immediate runoff (i.e., water surface areas). This parameter was estimated for each subwatershed by dividing the water surface area by the directly connected impervious surface area.

4.1.2 Hydraulic Modeling

4.1.2.1 Storm Sewer Network

Data detailing the storm sewer network within the City of Edina was provided by the City. An electronic AutoCAD file provided detailed information on the storm sewer system, including the type of pipe (material of construction), invert elevations, pipe sizes, pipe lengths, and manhole rim elevations. All elevations entered into the model are in Mean Sea Level (MSL). Where this data was incomplete, additional information was obtained from other sources such as construction plans or field surveys.

4.1.2.1.1 Assumptions

A variety of pipe types are used throughout the City. The assumptions used for the roughness coefficient (Manning’s “n”) for each pipe type are listed in Table 4.3.

Table 4.3 Roughness Coefficient Assumptions

Pipe Type	Abbreviation	Assumed Roughness Coefficient
Corrugated Metal Pipe	CMP	0.024
Clay	-	0.015
Steel	-	0.015
Ductile Iron Pipe	DIP	0.014
Reinforced Concrete Pipe	RCP	0.013
Poly Vinyl Chloride	PVC	0.01
High Density Polyethylene	HDPE	0.008

Outlets from ponding areas that may be inlet controlled were modeled in XP-SWMM assuming a groove end projecting concrete pipe inlet condition. This allowed XP-SWMM to determine the controlling flow condition in the outlet pipe (i.e., is the flow in the pipe controlled by the inlet size, barrel capacity, or tailwater conditions) and accurately estimate the pond's water surface elevation.

4.1.2.1.2 Tailwater Effects

For the portion of the city that drains to Nine Mile Creek, the XP-SWMM model incorporated the creek system. Therefore, the reported modeling results take into account tailwater impacts from the creek.

For the portion of the city that drains to Minnehaha Creek, the XP-SWMM model does not incorporate the creek system. For these major drainage areas, the 10-year and 100-year creek flood elevations from the Federal Emergency Management Agency (FEMA) Federal Insurance Administration Flood Insurance Study for the City of Edina (FEMA, 1979) were evaluated in comparison with model results to determine if tailwater conditions would affect the storm sewer systems discharging to the creek. Where the predicted creek flood elevation was higher than the results from XP-SWMM, the creek flood elevation was reported in the results table(s).

4.1.2.2 Overland Flow Network

Overland flow networks were entered into the XP-SWMM models because preliminary modeling results indicated that water was being routed out of the systems and lost (i.e., manholes and ponding areas would surcharge and the model assumed the water disappeared once it exceeded the respective spill crest elevation). An iterative process was used by adding storage and overland flow network data until all of the stormwater had been accounted for by XP-SWMM. Data for the overland flow network were taken from storm sewer information from the City, electronic 2-foot topographic data, and site visits. The following additions were made to the models to account for existing storage and develop the overland flow networks. The storage and overland flow paths were added to the models at various locations in a stepwise manner until the water that was otherwise lost from the system was "captured". Therefore, varying levels of the following steps were iteratively implemented to "capture" the water at any one given location.

Storage was added to XP-SWMM nodes based on the 2-foot topographic information. Initially, storage was added only to the XP-SWMM nodes representing ponds or backyard depression areas. The storage added to the model to "capture" the stormwater typically represents low areas in the streets or other depression areas.

Overland flow paths were added with the following characteristics:

- Overland flow along streets
- Trapezoidal channels with
- Bottom width = 16 feet (approx. ½ street width)
- Side slopes = 1H:1V
- Manning's "n" for the surface flow channels was set equal to 0.014 for flow down paved streets
- Channel depth = 1 foot
- Natural overland flow paths
- Trapezoidal channels with
- Bottom width = variable based on topographic information. Typically and estimate of 10 feet was used.
- Side slopes = variable based on topographic information. Typically 5H:1V was used.
- Manning's "n" = 0.03 where overland flow was clearly over vegetated areas or onto boulevards.
- Channel depth = 1 foot.
- Street overland flow channel width increased to 32 feet.
- Overland flow depth increased to 2 feet, if consistent with the topographic information.
- Raise the spill crest elevation if a nearby pond's water surface exceeds the node spill crest elevation and the storage was accounted for at the storage node (pond).
- Route the water out of the system if so indicated on the 2-foot topographic information (i.e., a possible out of district overflow location).

4.2 Methodology for Water Quality Modeling

P8 (Program for Predicting Polluting Particle Passage through Pits, Puddles and Ponds, IEP, Inc., 1990) is a computer model used for predicting the generation and transport of stormwater runoff pollutants in urban watersheds. The P8 model was used in this study to simulate the hydrology and phosphorus loads introduced from the watershed of each pond and the transport of phosphorus throughout the stormwater system. P8 is a useful diagnostic tool for evaluating and designing watershed improvements and best management practices (BMPs). The model requires user input on watershed characteristics, pond attributes, local precipitation and temperature, and other parameters relating to water quality and pond removal performances.

4.2.1 Watershed Characteristics

Examination of the watershed characteristics for each pond being modeled involved assessment of soil type, land use and residential density, and the impervious fraction of the land in the watershed. Arcview GIS software was used extensively in assessing the watershed characteristics. The software also allowed mapping of the drainage network for the area.

In P8, pervious and impervious areas are modeled separately. Runoff volumes from pervious areas are computed using the SCS Curve Number method. Runoff from impervious areas begins once the cumulative storm rainfall exceeds the specified depression storage, with the runoff rate equal to the rainfall intensity.

4.2.1.1 Impervious Fraction

Because P8 calculates runoff separately from pervious and impervious areas, it was necessary to determine the impervious fraction of each watershed. For the P8 model, the impervious fraction included only the directly-connected impervious area, the impervious surfaces that are “connected” directly to a stormwater conveyance system, where stormwater does not cross over pervious areas. The directly-connected impervious fraction was calculated for each watershed based on the land use(s) within the watershed and impervious fraction assumptions for each land use. The assumptions made for the total impervious fraction and directly-connected impervious fraction for each land use for the water quality modeling are listed in Table 4.4.

Table 4.4 Land Use Impervious Fraction Assumptions for Water Quality Modeling

Land Use Designation	Total Impervious %	Directly-Connected Impervious %
Commercial	90%	80%
Golf Course	5%	2%
Highway	50%	50%
Industrial/Office	90%	80%
Institutional	40%	20%
Institutional- High Imperviousness	70%	50%
Natural/Park/Open	2%	0%
Open Water	100%	0%
Residential- Very Low Density	12%	8%
Residential- Low Density	40%	20%
Residential- Medium Density	55%	30%
Residential- High Density	70%	40%
Wetlands	0%	0%

4.2.1.2 Pervious Curve Number

Watershed runoff volumes from pervious areas are computed in P8 using the SCS Curve Number method. Thus, it was necessary to determine a pervious curve number for each watershed. The soil type(s) within each watershed were determined and a pervious curve number was selected for the watershed based on the soil type, land use, and hydrologic conditions (e.g., if watershed soils are Type B and pervious areas are comprised of grassed areas with >75 percent cover, then a curve number of 61 would be selected). The pervious curve number was then weighted with the indirect (i.e., unconnected) impervious area in each subwatershed as follows:

$$CN_{wt} = \frac{[(\text{Indirect Impervious Area})*(98)] + [(\text{Pervious Area})*(\text{Pervious Curve Number})]}{[(\text{Indirect Impervious Area})+(\text{Pervious Area})]}$$

4.2.1.3 Other P8 Watershed Input Parameters

Outflow Device Number: The Device Number of the device receiving runoff from the watersheds was selected to match the pond or manhole node ID used for the hydrologic/hydraulic modeling.

Swept/Not Swept: An “Unswept” assumption was made for the entire impervious watershed area. A Sweeping Frequency of 0 was selected. Selected parameters were placed in the “Unswept” column since a sweeping frequency of 0 was selected.

Depression Storage = 0.03 (P8 default value)

Impervious Runoff Coefficient = 0.94 (P8 default value)

4.2.2 Treatment Device Characteristics

The treatment devices in P8 provide collection, storage, and/or treatment of watershed discharges. A variety of treatment devices can be modeled in P8, including detention ponds (wet or dry), infiltration basins, swales and buffers, aquifers, and pipe/manholes. For this study, nearly all ponds were modeled as detention basins. The user-defined characteristics of these ponds are described in the following sections.

4.2.2.1 Dead Storage

Detailed information pertaining to the permanent pool storage volume (dead storage) was only available for a small number of the ponds that were modeled. Pond depth data for the ponds in the Mirror Lake watershed was available as a result of pond surveys being performed for the Mirror Lake Use Attainability Analysis. Pond depth information for Indianhead Lake was available from the Minnesota Department of Natural Resources (MDNR). Where detailed information on pond depths was not available, it was necessary to make assumptions. The surface area of each pond was determined from the 2-foot topographic information provided by the City. Where detailed information was not available, pond depths were estimated based on the type of wetland, which was determined in the wetland inventory process. An average depth of 4 feet was typically assumed for Type 5 wetlands; 2 feet for Type 3 and Type 4 wetlands; 0.5 feet for Type 1, 2, 6, and 7 wetlands.

4.2.2.2 Live Storage

The flood pool storage volume (live storage) for each pond was calculated in ArcView using the electronic topographic data provided by the City. The live storage represents the storage volume between the normal water elevation and the flood elevation. The overflow elevation from each pond was determined from the 2-foot topographic data. The live storage volume was then calculated in ArcView based on the slope of the flood pool.

4.2.2.3 Other P8 Treatment Device Input Characteristics

Infiltration Rate (in/hr): An infiltration rate was entered only for land-locked detention ponds. The rates applied were dependent upon the type of soil surrounding each pond. The infiltration rates used for each soil type are listed in Table 4.5.

Table 4.5 Infiltration Assumptions for Water Quality Modeling

Hydrologic Soil Group	Infiltration Rate Assumption for Dead Storage Areas [in/hr]	Infiltration Rate Assumption for Live Storage Areas [in/hr]
A	0.02	0.06
B	0.015	0.05
C	0.015	0.02
D	0.005	0.01

- **Orifice Diameter and Weir Length:** The orifice diameter or weir length of the pond outlet was determined from storm sewer system data provided by the City of Edina. For landlocked basins, the overflow was represented as a weir, with the weir length estimated using ArcView and available topographic information.
- **Particle Removal Scale Factor:** 0.3 for ponds less than 2 feet deep and 1.0 for all ponds 3 feet deep or greater. For ponds with normal water depths between two and 3 feet, a particle removal factor of 0.6 was selected. These factors were selected based on development of a similar P8 model for the *Round Lake Use Attainability Analysis,* Barr Engineering, March 1999.
- **Pipe/Manhole— Time of Concentration:** The time of concentration for each pipe/manhole device was determined and entered here. Time of concentration was determined in accordance with Kirpich's method (Schwab et al., 1993).

4.2.3 Precipitation and Temperature Data

The P8 model requires hourly precipitation and daily temperature data; long-term data can be used so that watersheds and BMPs can be evaluated for varying hydrologic conditions. Hourly precipitation data was obtained from the Minneapolis-St. Paul International Airport for October 1994 through September 1995 (1995 water year, which represents average yearly precipitation). Average daily temperature data was obtained from the NWS site at the Minneapolis-St. Paul International Airport.

4.2.4 Selection of Other P8 Model Parameters

4.2.4.1 Time Step, Snowmelt, and Runoff Parameters

- **Time Steps Per Hour (Integer) = varied.** This parameter varied between each P8 model. Selection was based upon the number of time steps required to eliminate continuity errors greater than two percent.
- **Minimum Inter-Event Time (Hours) = 10.** During 1999 frequent storms were noted during the summer, particularly during July. The selection of this parameter was based upon an evaluation of storm hydrographs to determine which storms should be combined and which storms should be separated to accurately depict runoff from the lake's watershed.

- **Snowmelt Factors—Melt Coef (Inches/Day-Deg-F) = 0.03.** The P8 model predicts snowmelt runoff beginning and ending earlier than observed snowmelt. The lowest coefficient of the recommended range was selected to minimize the disparity between observed and predicted snowmelt (i.e., the coefficient minimizes the number of inches of snow melted per day and maximizes the number of snowmelt runoff days).
- **Snowmelt Factors— Scale Factor For Max Abstraction = 1**. This factor controls the quantity of snowmelt runoff (i.e., controls losses due to infiltration). Selection of this factor was based upon other calibrated P8 models developed for lakes within the metropolitan area (Reference Glen Lake, Smetana Lake).
- **Growing Season AMC-II = .05 and AMC-III = 100**. Selection of this factor was based upon calibration efforts for the P8 model developed for the *Glen Lake Use Attainability Analysis*, Barr Engineering Company, 1999. In development of this calibrated model, it was observed that the model accurately predicted runoff water volumes from monitored watersheds when the Antecedent Moisture Condition II was selected (i.e., curve numbers selected by the model are based upon antecedent moisture conditions). Modeled water volumes were less than observed volumes when Antecedent Moisture Condition I was selected, and modeled water volumes exceeded observed volumes when Antecedent Moisture Condition III was selected. The selected parameters direct the model to only use Antecedent Moisture Condition I when less than 0.05 inches of rainfall occur during the five days prior to a rainfall event and to only use Antecedent Moisture Condition III if more than 100 inches of rainfall occur within five days prior to a rainfall event, thus causing the model to simulate Antecedent Moisture Condition II throughout the majority of the simulation period.

4.2.4.2 Particle File Selection

The NURP50.PAR file was selected for the P8 models. The NURP 50 particle file represents typical concentrations and the distribution of particle settling velocities for a number of stormwater pollutants. The component concentrations in the NURP 50 file were calibrated to the 50th percentile (median) values compiled in the EPA’s Nationwide Urban Runoff Program (NURP).

4.2.4.3 Passes through the Storm File

The number of passes through the storm file was determined after the model had been set up and a preliminary run completed. The selection of the number of passes through the storm file was based upon the number required to achieve model stability. Multiple passes through the storm file were required because the model assumes that dead storage waters contain no pollutants. Consequently, the first pass through the storm file results in lower pollutant loading than occurs with subsequent passes. Stability occurs when subsequent passes do not result in a change in pollutant concentration in the pond waters. To determine the number of passes to select, the model was run with five passes and ten passes. A comparison of pollutant predictions for all devices was evaluated to determine whether changes occurred between the two scenarios. If there is no difference between five and ten passes, five passes is sufficient to achieve model stability. This parameter was determined for all of the P8 model areas and no differences were noted between five and ten passes. Therefore, it was determined that five (5) passes through the storm file resulted in model stability for these models.