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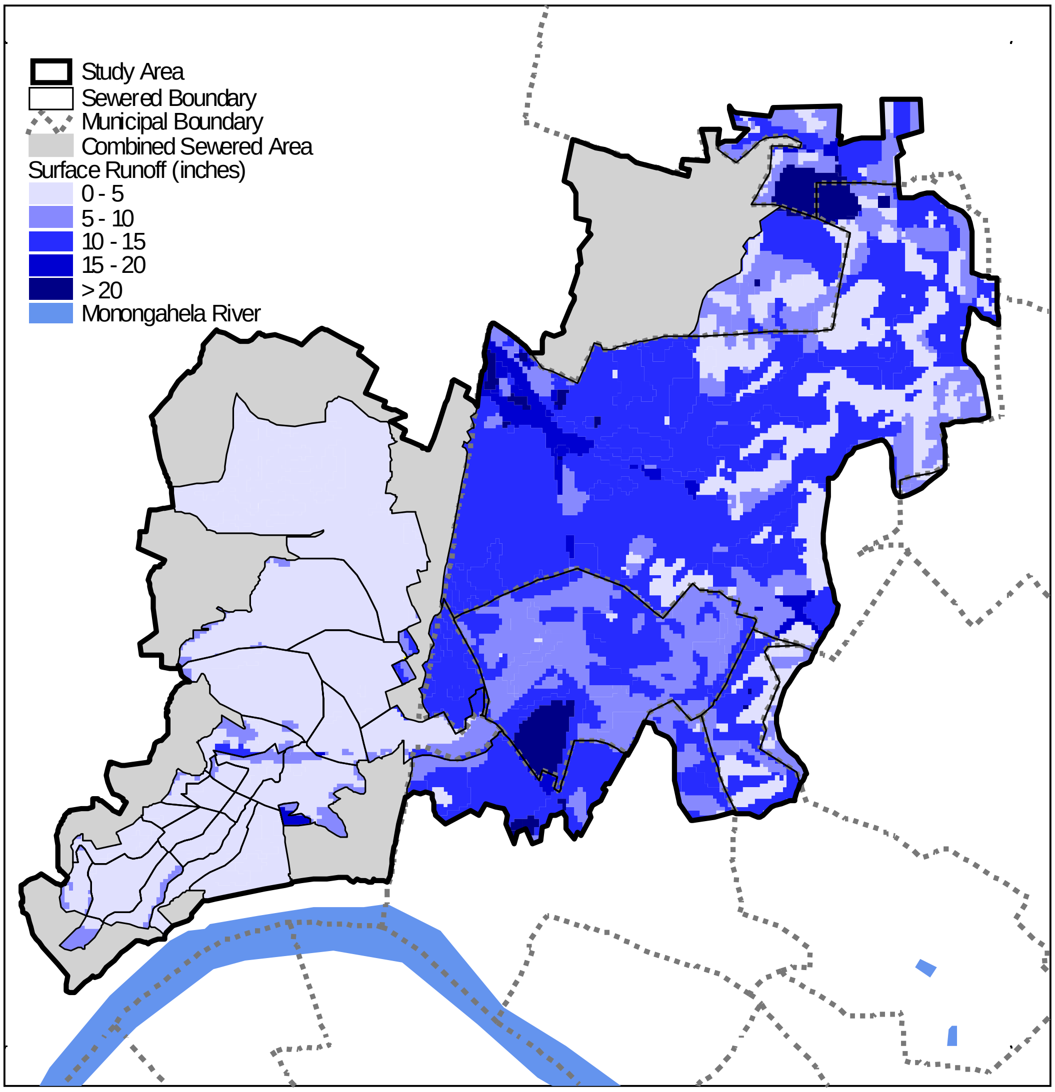
Assessment of Point and Runoff Sources of Water Quality Constituents in the Nine Mile Run Watershed

July 2001



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Appendix Section 1
Introduction

The Nine Mile Run watershed, shown in Figure 1.1, drains approximately 4300 acres in the greater Pittsburgh area, including portions of the City of Pittsburgh, Edgewood Borough, Swissvale Borough, and Wilkinsburg Borough. Water quality in Nine Mile Run is affected by runoff from urbanized land uses and by sewer overflows in wet weather. In the Nine Mile Run Aquatic Ecosystem Restoration Project Report (USACE, 2000), the U.S. Army Corps of Engineers characterized instream water quality for Nine Mile Run based on data collected in both dry and wet weather. The City of Pittsburgh Department of City Planning conducted a further statistical analysis of the data and identified instances where water quality criteria were exceeded (City of Pittsburgh, 2000). Water quality standards exceeded included those for fecal coliform, iron, and pH. Concentrations of several species of metals exceeded applicable water quality standards under wet weather conditions, including copper, lead, and zinc. The objective of the current study is to identify and begin to quantify sources of water quality constituents in the watershed that may affect instream water quality.

A computer simulation of system hydrology and potential contaminant sources, a watershed loading model, is a useful tool to help relate instream conditions to the surrounding land area and sewer system. The loading model provides information on the relative contributions of different sources, including surface runoff from different land use types, inputs from wet weather sewer overflows, and concentrations in base flow. Model results also are used to compare inputs from different geographical areas. This information can help identify potential solutions, such as storm water best management practices in specific areas or requirements for reductions in wet weather sewer overflows. Within a range of uncertainty, the model quantifies potential load reductions that are achievable through these measures. The model is not intended to provide a direct relationship between loads and instream concentrations of water quality constituents.

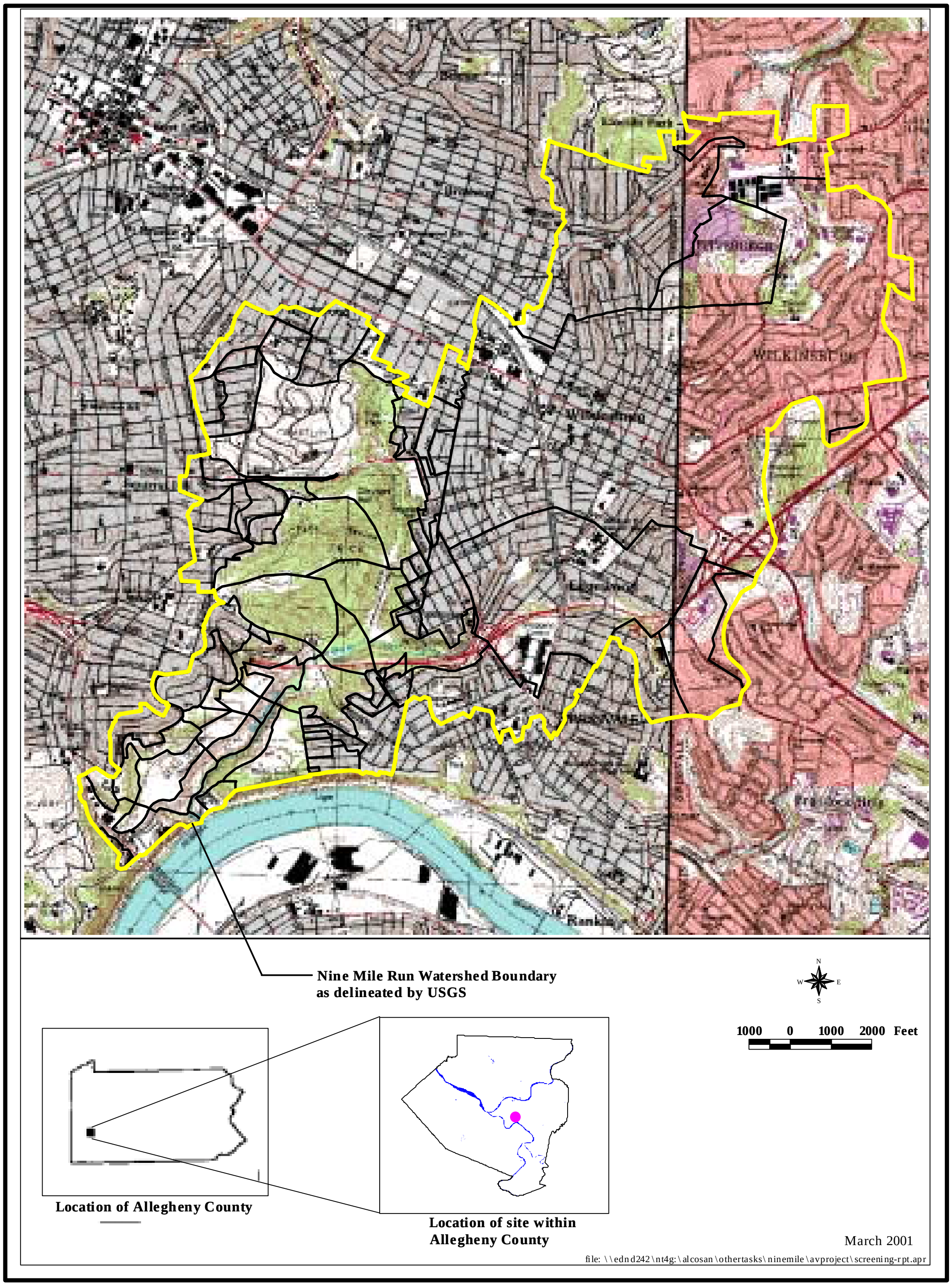


Figure 1.1 Study Area for the Nine Mile Run Watershed

Appendix Section 2
Model Structure and Theory

The current model is an updated version of a simulation framework previously developed for the EPA, the Watershed Management Model, or WMM. WMM is a simple but appropriate framework for use at the screening level to complement the existing body of water quality data, evaluate the relative magnitudes of potential pollutant sources, and identify possible solutions in mixed urban and suburban watersheds. The model framework is capable of accounting for point sources, combined and sanitary sewer overflows, septic system loadings, atmospheric loads, baseflow loads, and storm water loads. The original WMM model computes storm water runoff using the rational method, a simple, empirical method most applicable to urban systems. Storm water loads are determined by combining estimates of storm water runoff from various land uses with typical concentrations of water quality constituents in urban runoff, either provided by the user from locally collected sources or taken from literature values. Thus, modeled storm water loads are driven by both land use and hydrology as they are in the physical system.

The formulation of the WMM framework used for this study implements the same basic structure as the original WMM but reduces uncertainty in the model output by simulating system hydrology and hydraulics at a greater level of detail. Where other versions of the WMM framework employ the rational method to calculate surface runoff, this version employs the hydrology engine (RUNOFF) from the USEPA Storm Water Management Model, SWMM Version 4.4. An existing model of the Nine Mile Run sewer system employing the EXTRAN and TRANSPORT modules of SWMM is used to provide more accurate estimates of wet weather sewer overflows.

Figures 2.1 and 2.2 display the structure of the watershed loading model. Storm water runoff and wet weather sewer overflows are the two main sources of loads to the surface water system. Storm water runoff can be a significant source of water pollutants in highly urbanized, impervious catchments. Substances most frequently associated with storm water include sediment, nutrients, bacteria, oxygen demanding substances, oil and grease, heavy metals, other toxic chemicals, and floatables. The primary sources of these substances include automobiles, roadways (pavement, bridges), housekeeping and landscaping practices, industrial activities, construction, non-storm connections to drainage systems, accidental spills, and illegal dumping. Combined sewer overflows in wet weather introduce contaminated storm water mixed with sanitary wastewater constituents such as additional oxygen-demanding material, nutrients, and pathogens. Similarly, sanitary sewer overflows in wet weather typically introduce sanitary wastewater constituents such as additional oxygen-demanding material, nutrients, and pathogens, diluted either by groundwater or by rainwater. The loading model relies on detailed and accurate simulation of hydrologic processes within the watershed and hydraulic processes leading to wet weather overflows.

The long-term rainfall record at the Pittsburgh International Airport is used to drive the hydrology of the system. Using a long-term record represents a wide range of hydrologic conditions that occur in a given climate. Using a long-term record on a continuous basis accounts for antecedent moisture conditions and more accurately represents initial conditions at the beginnings of wet weather events. The use of long term, continuous simulation techniques for small basins such as Nine Mile Run eliminates concerns regarding the use of regional (i.e., not local) rainfall records.

Areas within the Nine Mile Run watershed are served by two types of sewer systems. In areas with separate sanitary and storm sewer systems, the storm sewer system conveys most surface runoff directly to a receiving stream. In areas served by combined sanitary and storm sewers, the sewer system conveys flows to an interceptor sewer and later to a wastewater treatment plant under dry weather conditions. During larger wet weather events, a combined flow regulator structure diverts a portion of the flow to a receiving stream. In the Nine Mile Run system, a significant portion of the precipitation flows directly overland to the receiving stream even in areas served by combined sewers. This flow will be referred to as direct surface runoff or combined area surface runoff (CASR).

For both types of areas, the portion of flow reaching the sewershed or subwatershed outlet is simulated by the RUNOFF module of SWMM. The amount and timing of surface runoff from a given sewershed depends on several factors, including the proportion of impervious surfaces, the slopes of pervious and impervious areas, depression storage, evaporation, and infiltration into soil in pervious areas. These parameters are determined from the regional Geographic Information System (GIS) maintained by the Allegheny County Sanitary Authority (ALCOSAN) and adjusted according to the modeler’s judgment. In separate sanitary sewered areas, a portion of the flow infiltrates the sanitary sewer and does not reach the receiving stream unless that system becomes overloaded. Snowfall and snowmelt affect the quantity and timing of surface runoff during the winter months but can be neglected in long-term continuous simulation.

The mass load of a particular constituent (dissolved, particulate, or microbial) reaching the receiving stream is a function of the volume of surface runoff and the concentration of that constituent in the runoff. Therefore, the uncertainty in estimation of this mass load is a function of the uncertainty in measurement or simulation of sewershed hydrology and uncertainty in knowledge of the runoff concentration. Detailed, accurate simulation of system hydrology minimizes the uncertainty due to the runoff estimate. Researchers and modelers have attempted a number of methods of estimating runoff concentrations, including empirical equations, statistical methods, and event mean concentrations (James, 1999). Due to the large uncertainties involved, it is extremely difficult to simulate time-varying runoff concentrations with any degree of accuracy. Today, the use of typical concentrations of water quality constituents in urban runoff (event mean concentrations or EMCs), when based on large amounts of information from national data sets, provide the most accurate estimates of long-term loading rates (Smullen, Shallcross, and Cave, 1999). An EMC is the total mass load of a chemical parameter yielded from a site during a storm divided by the total runoff water volume discharged during the storm. EMCs are functions of the constituent of interest and the land use type.

For any sewershed, the surface runoff from a particular land use predicted by SWMM RUNOFF, in units of volume per time, is multiplied by the EMC for that land use type, in units of mass per volume, to yield a loading rate, in units of mass per time. For separate sanitary sewered sewersheds, this loading rate is conveyed directly to the receiving stream network. For combined sewered sewersheds, the modeling scheme is necessarily more complicated (Figure 2.2). Regulator structures receive both surface runoff and sanitary sewage. Sanitary sewage contains much greater concentrations of many pollutants than does surface runoff. The portion of flow that is conveyed through the connector pipe to the interceptor sewer in wet weather is termed the treatment rate. Some method of determining the treatment rate, as either an approximate constant rate or a dynamic rate that changes with conditions in the structure and in the interceptor sewer, is needed. The dynamic treatment rate, computed by simulation models, is a more realistic representation but requires more time and labor to determine.

While the scope of the present study did not warrant development of a detailed interceptor hydraulic model, an existing SWMM EXTRAN model of the system was modified to estimate these treatment rates. The EXTRAN module is the most widely used and accepted model for interceptor and CSO modeling (Roesner et al., 1988). It accurately simulates complex hydraulic conditions that occur in combined sewer interceptors, including unsteady flow, surcharging, branched and looped pipe networks, pumps, orifices, and weirs.

The existing EXTRAN model of the Nine Mile Run sewer system was simplified and run continuously for 50 years. The computed inflows and outflows to the regulator structures and their interceptor connection points were saved for each time step in the 50-year period of the simulation. These estimated flows include surface runoff and dry weather sanitary flow entering the regulator structure, captured flow leaving the regulator structure and entering the interceptor system at the connection node, overflow leaving the regulator structure and entering the receiving stream, and upstream and downstream interceptor flows at the connection point.

In this implementation of the WMM framework, the regulator structures and sewer system then are represented in the TRANSPORT module of SWMM. The known flows taken from the continuous EXTRAN simulation are input to the TRANSPORT network. A high level of detail is desirable for two reasons. First, when surcharge conditions occur in the interceptor, flow in the connector pipe can reverse, adding additional combined flow to the overflow at that structure. Second, the completely mixed TRANSPORT nodes allow surface runoff, sanitary sewage, and mixed flow to combine at the proper concentrations. This mixing creates overflow concentrations that are as realistic as possible.

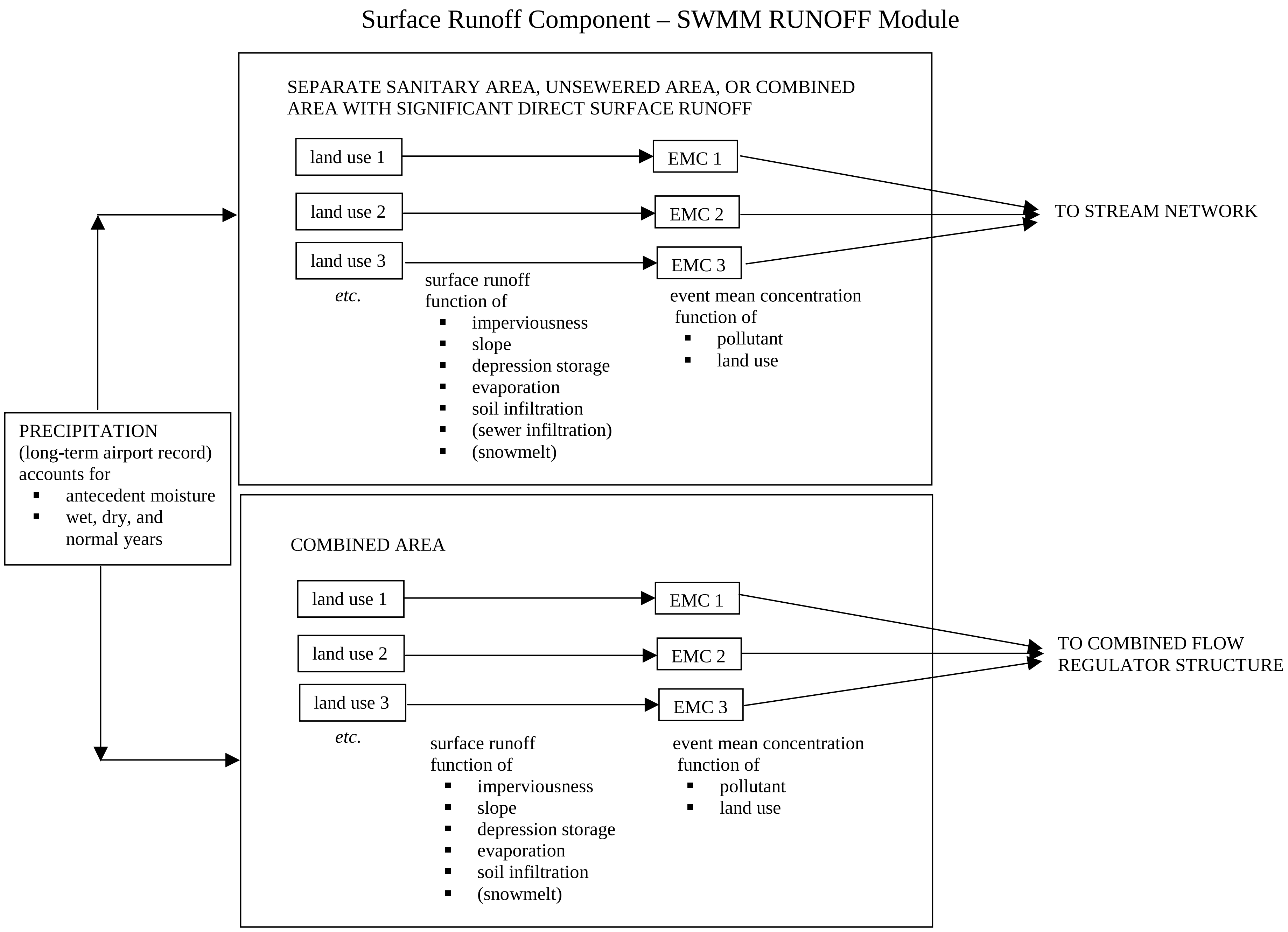
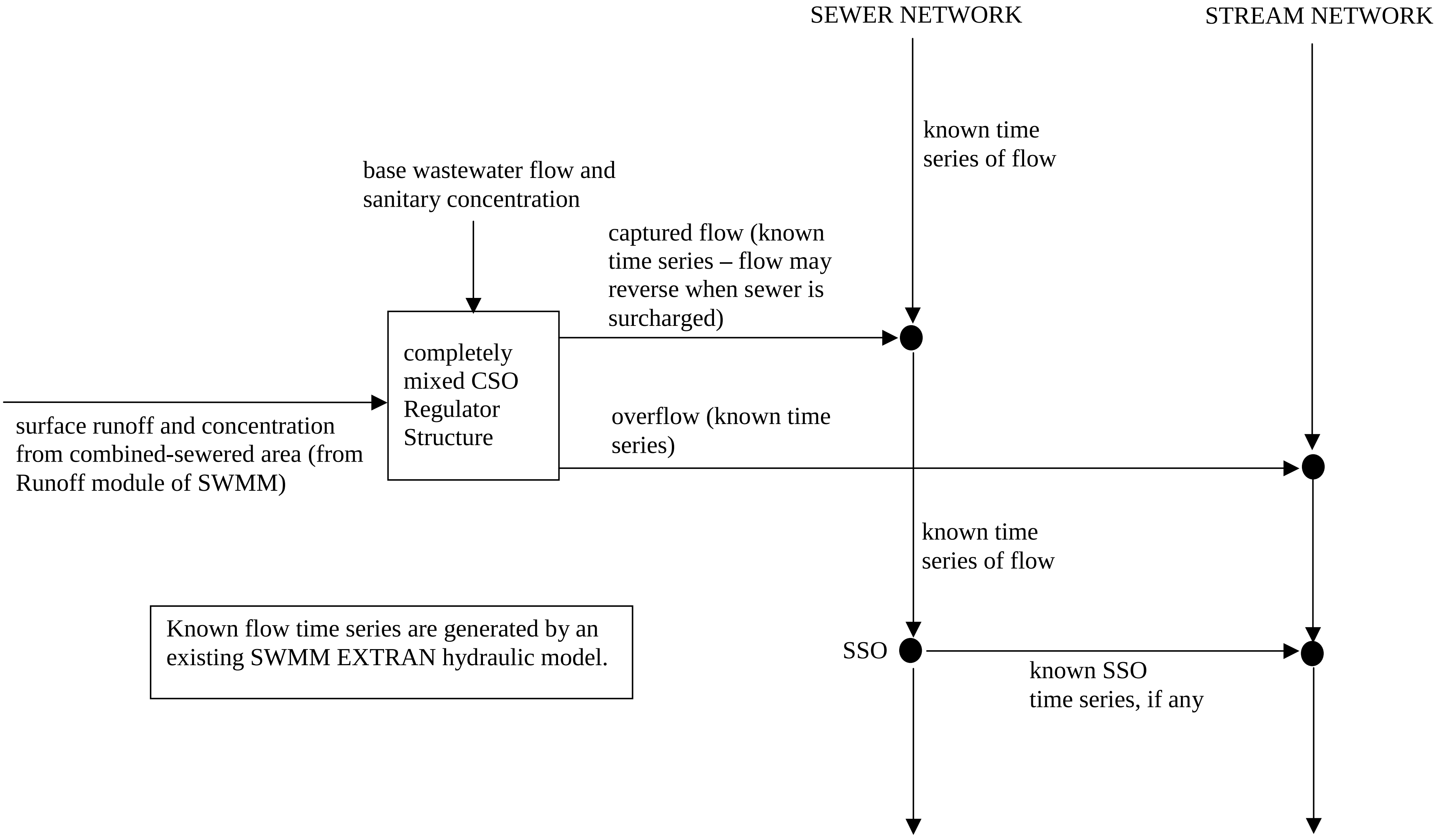


Figure 2.1 Watershed Loading Model Schematic Diagram

Combined Sewer Overflow Component – SWMM TRANSPORT Module



Known flow time series are generated by an existing SWMM EXTRAN hydraulic model.

Figure 2.2 Watershed Loading Model Schematic Diagram

Appendix Section 3
Data Needs and Sources

3.1 Sewershed Delineation

The first step in preparing the hydrologic model is to subdivide the study area into smaller sub-watersheds and sewersheds. These areas are shown on Figures 3.1, 3.2, and 3.3. The Nine Mile Run study area delineation is based on the topographic watershed boundary provided by U.S. Geological Survey's Water Resources of Pennsylvania and the sewershed delineation completed for the Pittsburgh Water and Sewer Authority Nine Mile Run Aquatic Ecosystem Restoration Project. The study area initially was broken up into combined, separate, and non-sewered areas based on the type of contribution to the sewer system. The City of Pittsburgh portion of the watershed mostly is served by combined sewers with a small area in the northeastern part of the watershed served by separate sewers. The communities of Wilkinsburg, Edgewood, Penn Hills, Braddock and Swissvale have separate sewers. There are very small areas from Churchill and Forest Hills Boroughs within the study area. Because the separate sewered areas eventually contribute to the Nine Mile Run culvert, these areas were subdivided based on municipal boundaries. The separate sewered area is broken into 13 sewersheds.

An area classified as un-sewered or "non-contributing" is typically an area of open space such as a park that contributes no flow to the sewer system; however, an un-sewered area may contribute runoff to the surface water system during larger storms. The un-sewered area in the Nine Mile Run watershed is within the Homewood Cemetery and Frick Park. The un-sewered areas are subdivided based on natural drainage. The Fern Hollow drainage area is broken into three sub-watersheds while Nine Mile Run is broken into 20 sub-watersheds. The lower portion of Nine Mile Run was delineated to reflect the phased construction of the Summerset at Frick Park development. This is the area currently dominated by the slag pile. Since storm water from separate and un-sewered areas is routed to Nine Mile Run, these two types of drainage areas are functionally identical for storm water modeling purposes. Areas classified as separate or un-sewered may be referred to as either sewersheds or sub-watersheds.

For input to the model, the separate and unsewered sub-watersheds were further divided by land use. The GIS intersect of sub-watershed and land use creates the smallest area simulated for generation of loads. After the intersect with land use, there are 355 unique combinations of sub-watershed/sewershed and land use.

The combined sewered area was further subdivided into smaller sewersheds based on point of contribution to the sewer network, where the point of contribution is the downstream outlet of the sewershed through which storm water runoff enters the sewer system. The combined sewered areas first were subdivided based upon points of contribution to the main Nine Mile Run interceptor, and subsequently further subdivided at points of contribution to other smaller sewers as necessary in order to reach an appropriate level of model definition. The areas classified as combined are broken into 52 sewersheds.

3.2 Land Use

Land uses for areas in Allegheny County were available in the ALCOSAN GIS. This land use information originally was obtained from the Allegheny County Planning Department. Figure 3.1 is the circa 1990 land use map for the Nine Mile Run watershed. Inside the City, much of the area is occupied by open space, including a large park and a large cemetery. There is an area of steel mill slag, classified as Strip Mine in the Allegheny County Planning Department land use information, deposited near the outlet of the system, just north of the Monongahela River. The slag is a byproduct of steel production and consists primarily of silica with smaller fractions of aluminum, calcium, and other minerals. Slag piles have been shown to influence water quality, including wet weather pH, alkalinity, and concentrations of some metals (USACE, 1989). Outside the City, land uses are primarily residential, with some commercial areas and some open space.

3.3 Land Surface Impervious Cover

The proportion of impervious surface in a watershed is an important factor affecting the quantity of surface runoff. Figure 3.2 is a graphic representation of impervious cover based on the planimetric digital vector land-base map developed from low altitude photography. The digital vector mapping is a GIS coverage of the map features, including building footprints, parking lots, and roads and allowing for a direct estimate of impervious area. For this study we used data available in the ALCOSAN GIS. This information originally was obtained from the residual digital records of the Allegheny County Planning Department by the Allegheny County Health Department. To determine the impervious cover of a sub-watershed, the buildings, parking lots, and roads are extracted, summed as the total impervious cover, and then divided by the total area of the sub-watershed.

This method does not determine whether impervious surfaces are directly connected to the drainage system (directly connected impervious area, or DCIA). However, it is believed to be more accurate than simply assigning DCIA based on land use type (Angell, Clement, and Smullen, 1998). Runoff from impervious surfaces also is affected by slope, depression storage, and evaporation.

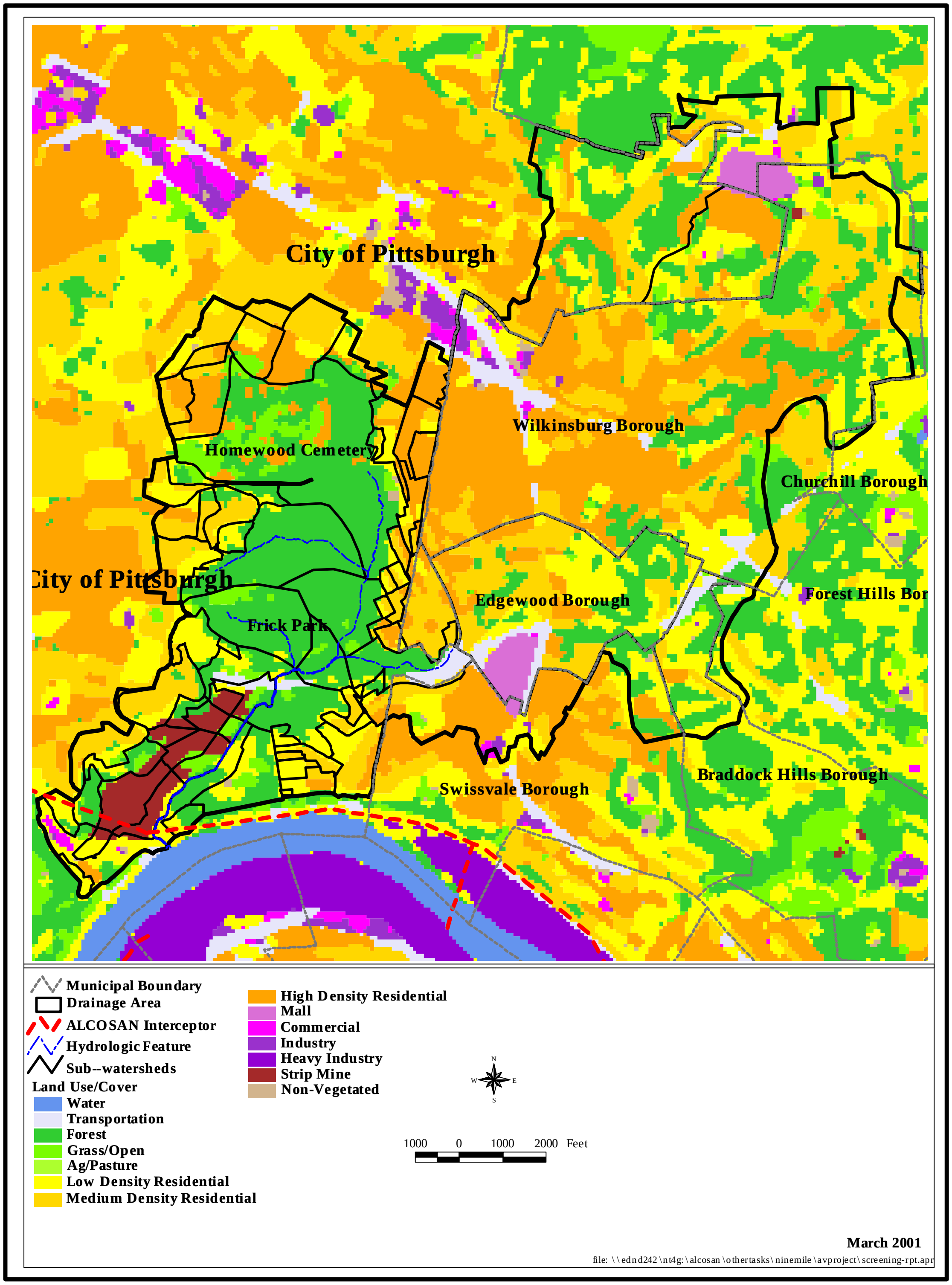


Figure 3.1 Land Use Map

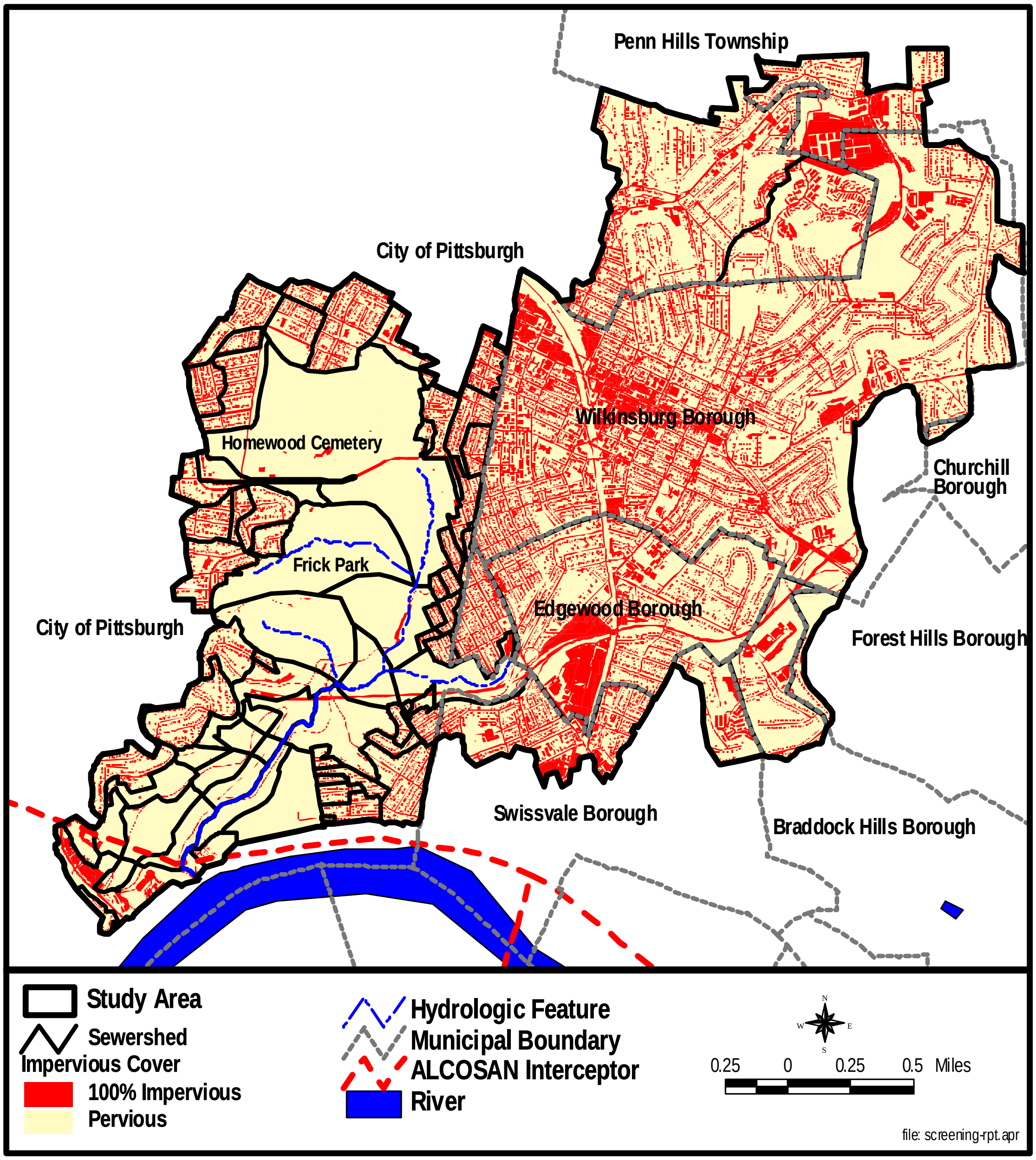


Figure 3.2 Imperviousness

For pervious areas, the portion of precipitation that runs off is affected by slope, depression storage, infiltration, vegetative cover and evapotranspiration. Infiltration is determined by the type of soil type. The SWMM RUNOFF model simulates infiltration using the Green-Ampt theory for both saturated and unsaturated soils. Parameters that must be input for each sub-watershed include saturated hydraulic conductivity, the height of capillary rise, and the maximum soil moisture deficit under dry conditions. For the Nine Mile Run model, these parameters were assigned by area-weighting the proportion of USGS soil types in each sub-watershed and applying textbook values of the three parameters based on soil type. These values are summarized in Table 3.1 below.

Table 3.1 Soil Parameters (James, 1999)

Type	Brief Description	K (inches/hour)	Suction (inches)	IMD
A	sand, sandy loam	0.38	4	0.34
B	loam, silty loam	0.23	8	0.33
C	clay loam	0.1	10	0.24
D	clay	0.03	7	0.21

K = saturated hydraulic conductivity
suction = height of capillary rise
IMD = inter-event maximum soil moisture deficit

3.4 Event Mean Concentrations (EMCs)

Event Mean Concentrations (EMCs) are defined as the total mass load of a chemical parameter yielded from a site during a storm divided by the total runoff water volume discharged during the storm. The EMC is widely used as the primary estimator of runoff water quality for storm water loading assessments.

3.4.1 Use of EMCs in Loading Analyses

Runoff pollutant loading analyses typically apply land use-specific storm water pollution loading factors to watersheds under study. Loading rates of urban storm water constituents (nutrients, metals, BOD, fecal coliform) are determined by the quantity of runoff from the land surface. Thus, they are closely related to the imperviousness of the land use type. Applying EMCs to calculated runoff volumes provides reasonable estimates of runoff pollutant loadings, especially for urban areas.

Runoff volumes are computed for each land use category based on percent imperviousness of the land use and annual rainfall. These runoff volumes are multiplied by the land use-specific EMC load factor (mg/L) to obtain runoff pollutant loads by land use category. This analysis can be performed on a sub-area or watershed-wide basis, and the results can be used to perform load allocation studies, to evaluate pollution control alternatives, or as an input into a receiving water quality model.

This WMM framework estimates pollutant mass loads that vary by land use and the percent imperviousness associated with each land use. The pollutant mass load estimate M_L is computed for each land use L within each model sub-basin by the following equation:

$$M_L = EMC_L * R_L * K$$

where:

M_L = pollutant mass load for land use L in a sub-basin (lb/acre/year)

EMC_L = event mean concentration of runoff from land use L (mg/L); EMCs may vary by land use and pollutant

R_L = surface runoff from land use L in a sub-basin (in/yr); and

K = 0.2266, a unit conversion constant.

By multiplying the pollutant loading factor by the area of a land use within a sub-basin and summing for all land uses, the total annual pollution load from a sewershed can be computed. The EMC coverage typically is not constant for the land uses within a given study watershed.

3.4.2 Sources of EMC Information

Once point source discharges from treatment plants and industrial facilities were addressed in the 1970's and 1980's, more attention was focused on storm water runoff as a source of water quality degradation. As pollutants in storm water runoff came under investigation, studies focused on the types of pollutants and methods to reduce them. Unfortunately, these investigations did not consider the achievable level of improvement of receiving water bodies with the mitigation of storm water pollution. In addition, many research studies concluded that additional and more comprehensive information was needed to make such assessments. This need led to the development of the Nationwide Urban Runoff Program (NURP).

The goals of NURP were to develop and provide information to local decision makers, the states, EPA, and other parties for use in assessing the impacts of storm water and urban runoff on water quality. The information collected also was intended to aid in the development of water quality management plans and provide a foundation for local, State and Federal policy decision making about water quality issues.

The NURP studies investigated urban runoff for 10 water quality constituents. As a result of data collected through the NURP program, EMCs for these and other pollutants were developed from over 2,300 station-storms at more than 81 urban sites located in 28 different metropolitan areas. These studies greatly increased the knowledge of the characteristics of urban runoff, its effects upon the designated uses of receiving water bodies, and the performance efficiencies of various control measures. Important conclusions of the NURP studies include:

- The variance of EMCs, when data from sites are grouped by land use type or geographic region, is so great that differences in measures of central tendency among those groups are not statistically significant.

- Statistically, the entire sample of EMCs and the medians of all EMCs among sites are log-normally distributed.

EMCs often are used in screening models. The pollutant loads (L_i) are estimated as the product of the area of urban land (A_U), the rainfall-runoff depth as estimated by a modified rational formula approach (d_r), and a constant pollutant concentration (C_i), usually estimated from the EMCs reported by NURP (i.e., $L_i = C_i A_u d_r$).

Since the conclusion of the NURP Program in the 1980's, additional urban runoff quality monitoring data has been collected. One large effort conducted by the United States Geological Survey resulted in the collection of urban runoff data for over 1,100 station-storms at 97 urban sites in 21 metropolitan areas. Additionally, EPA required many major cities to collect urban runoff quality data as part of the application requirements for storm water discharge permits under the National Pollutant Discharge Elimination System (NPDES). The USGS urban runoff data and data for 800 station-storms from 30 of the storm water NPDES city programs have been gathered, incorporated into a database with the NURP data, and new, updated urban runoff EMCs estimated (Smullen, Shallcross and Cave, 1999). While the resulting EMCs from the new combined data sets did not indicate statistical differences in water quality among land uses, the pooled EMCs were significantly different than the NURP EMCs for several parameters (e.g., TSS, Cu, and Pb) and would produce different loading rates for urban areas. These results are included in this study. Table 3.2 indicates the EMCs used in the Nine Mile Run study and the source of each EMC value.

Table 3.2 Event Mean Concentrations (EMCs)

Land Use	BOD		TSS		TP		TKN		NO2+NO3	
	EMC	Source	EMC	Source	EMC	Source	EMC	Source	EMC	Source
Water (Atmos.)	0	NA	0	NA	0.064	2 (161)	1.022	2 (161)	0.571	2 (161)
Transportation	24	3	141	3	0.43	3	1.82	3	0.83	3
Forest	2	4 (19)	218	4 (19)	0.188	4 (19)	0.62	4 (19)	1.23	4(19)
Grass/Open	2	4 (19)	218	4 (19)	0.188	4 (19)	0.62	4 (19)	1.23	4(19)
Low Density Res.	14.1	1 (14)	78.4	1 (14)	0.315	1 (14)	1.73	1 (14)	0.658	1 (14)
Med Density Res.	14.1	1 (14)	78.4	1 (14)	0.315	1 (14)	1.73	1 (14)	0.658	1 (14)
Hi Density Res.	14.1	1 (14)	78.4	1 (14)	0.315	1 (14)	1.73	1 (14)	0.658	1 (14)
Malls	14.1	1 (14)	78.4	1 (14)	0.315	1 (14)	1.73	1 (14)	0.658	1 (14)
Commercial	14.1	1 (14)	78.4	1 (14)	0.315	1 (14)	1.73	1 (14)	0.658	1 (14)
Industrial	14.1	1 (14)	78.4	1 (14)	0.315	1 (14)	1.73	1 (14)	0.658	1 (14)
Slag (Strip Mine)	14.1	1 (14)	78.4	1 (14)	0.315	1 (14)	1.73	1 (14)	0.658	1 (14)
Non-Vegetated	14.1	1 (14)	78.4	1 (14)	0.315	1 (14)	1.73	1 (14)	0.658	1 (14)

Table 3.2 Event Mean Concentrations (EMCs) continued

Land Use	Pb		Cu		Zn		Fecal Coliform	
	EMC	Source	EMC	Source	EMC	Source	EMC	Source
Water (Atmos.)	0.00266	2 (280)	0.0022	2 (280)	0.0652	2 (280)	0	NA
Transportation	0.572	3	0.052	3	0.367	3	30000	4 (19)
Forest	0.0728	4 (19)	0.0197	4 (19)	0.1037	4 (19)	30000	4 (19)
Grass/Open	0.0728	4 (19)	0.0197	4 (19)	0.1037	4 (19)	30000	4 (19)
Lo Density Res.	0.0675	1 (14)	0.0135	1 (14)	0.162	1 (14)	30000	4 (19)
Med Density Res.	0.0675	1 (14)	0.0135	1 (14)	0.162	1 (14)	30000	4 (19)
Hi Density Res.	0.0675	1 (14)	0.0135	1 (14)	0.162	1 (14)	30000	4 (19)
Malls	0.0675	1 (14)	0.0135	1 (14)	0.162	1 (14)	30000	4 (19)
Commercial	0.0675	1 (14)	0.0135	1 (14)	0.162	1 (14)	30000	4 (19)
Industrial	0.0675	1 (14)	0.0135	1 (14)	0.162	1 (14)	30000	4 (19)
Slag (Strip Mine)	0.0675	1 (14)	0.0135	1 (14)	0.162	1 (14)	30000	4 (19)
Non-Vegetated	0.0675	1 (14)	0.0135	1 (14)	0.162	1 (14)	30000	4 (19)

Sources

1	Smullen, Shallcross, and Cave (1999)
2	EPA (1982)
3	Federal Highway Administration (1999)
4	NOAA (1987)
NA	EMC not available

Notes

- ♦ Source column contains source number, then page number in parentheses
- ♦ All units in mg/L except fecal coliform in count/100 mL

3.5 Stream Baseflow

Perennial streams exhibit baseflow due to groundwater discharge. To account for baseflow discharges as part of the average annual flow volume discharged from a watershed, an estimate of baseflow rate and quality is included in the model. Total stream baseflow was taken from the hydrologic and hydraulic model prepared for the Nine Mile Run Aquatic Ecosystem Restoration Project (USACOE, 2000). Stream baseflow concentrations were derived from data collected by USACOE (USACOE, 2000). Arithmetic mean dry weather baseflow concentrations, collected at 16 sites on 5 different dates, were input to the model. The value chosen for fecal coliform is the geometric mean of dry weather samples. These concentrations are listed in Table 3.3. Any inputs originating from dry weather sources other than groundwater, such as illegal connection discharges or sanitary sewer exfiltration, are reflected in these values. The total load contributed by stream baseflow may be obtained by multiplying each concentration by the total stream baseflow.

Table 3.3 Stream Baseflow Concentrations

Parameter	Concentration	Units
BOD_5	3.78	mg/L
TSS	4.08	mg/L
Total Phosphorus	0.08	mg/L
Total Kjeldahl Nitrogen	0.59	mg/L
Nitrate and Nitrite	2.64	mg/L
Pb	7.05	mg/L
Cu	7.91	mg/L
Zn	21.33	mg/L
Fecal Coliform	2,114	/100 mL

3.6 Combined Sewer Overflows (CSOs)

In many cities throughout the United States, storm water runoff and sanitary wastewater are collected in the same sewer (a combined sewer). In dry-weather conditions, all flows are conveyed to a wastewater treatment plant. In wet-weather, often the capacity of the combined sewer system is exceeded and discharges of mixed sanitary and storm water can occur to receiving waters. CSO discharges typically exhibit elevated concentrations of fecal coliform and other substances associated with sanitary sewage and storm water. Within watersheds such as the Nine Mile Run basin, CSOs can be a significant pollutant source contributing to degraded water quality within a stream system. The 13 CSO structures located along Nine Mile Run and its tributaries are represented in the model.

Concentrations of substances found in sanitary sewage under dry weather conditions were determined from local data when possible and literature sources when no data were available. Table 3.3 lists these concentrations and their sources. Values for

BOD,TSS, and TKN are the mean of daily dry weather measurements of ALCOSAN wastewater treatment influent between January and December 2000. Dry weather days were defined as days on which no more than 0.01 inches of rain were measured at the plant. Phosphorus concentrations in the plant influent are not monitored; based on the relative magnitude of measured and literature-based nitrogen values, literature values for weak-strength wastewater were used in the model for phosphorus. Values for lead, copper, and zinc are averages of twelve monthly composite samples taken in 2000. These data include dry and wet weather effects but are the best data available.

Fecal coliform counts in the treatment plant influent are available for two periods: as monthly averages in both dry and wet weather for the years 1962 to 1970, and during a seven day period in January 1998 of which three days meet the definition of dry weather. Fecal coliform measurements should be thought of as representing an order of magnitude rather than an exact count. The geometric mean of monthly values recorded during the 1960's period was 6.5×10^6 /100 mL. Because these measurements were taken under all weather conditions, they may tend to underestimate concentrations during dry weather periods. The geometric mean of the three dry weather measurements taken in 1998 is 2.0×10^6 /100 mL. The number of samples taken in 1998 is too small to compare directly to the earlier measurements. However, the order of magnitude suggests that there has been no discernable change in concentrations over time. The value 5×10^6 /100 mL is included in the model as a conservative estimate of typical bacteria counts.

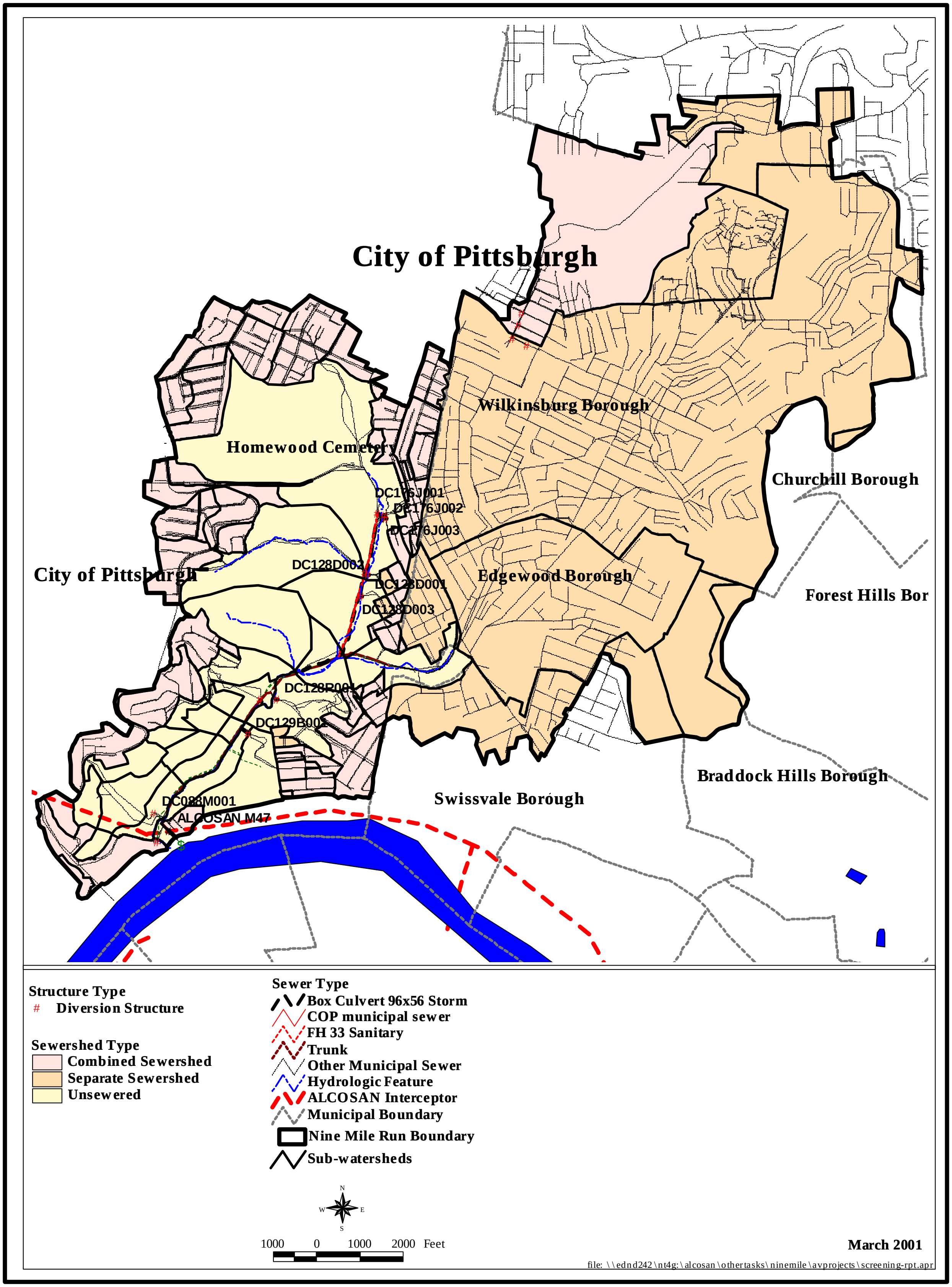
Table 3.4 Dry Weather Sanitary Sewage Concentrations

Parameter	Concentration	Units	Source
BOD_5	99.5	mg/L	ALCOSAN primary influent data January-December 2000
TSS	158.2	mg/L	ALCOSAN primary influent data January-December 2000
Total Phosphorus	5	mg/L	Metcalf and Eddy, 1991
Total Kjeldahl N	12.5	mg/L	ALCOSAN primary influent data January-December 2000
Nitrate and Nitrite	0	mg/L	Metcalf and Eddy, 1991
Total Nitrogen	12.5	mg/L	sum of TKN and inorganic nitrogen
Pb	0.039	mg/L	ALCOSAN primary influent data January-December 2000
Cu	0.087	mg/L	ALCOSAN primary influent data January-December 2000
Zn	0.210	mg/L	ALCOSAN primary influent data January-December 2000
Fecal Coliform	5×10^6	/100 mL	ALCOSAN primary influent data 1962-1970, January 1998

Approximately 23% of the Nine Mile Run watershed is served by combined sewers. The portions of combined flow that are captured and discharged to the streams are controlled by the 13 regulator structures as listed in Table 3.5 and shown in Figure 3.3.

Table 3.5 Combined Flow Regulator Structures

Regulator Node	Over Flow Conduit	Over Flow Node	Captured Flow D/S Conduit	Downstream Node	Notes
ADC129NM47	PW	ACS129NM47	orifice	ADC_MHOF47	Mon interceptor tie-in
DC088M001	O2	CSO088M001	PS2	10641	
DC088S001	O1	CSO088S001	PS1	MH129J006	
DC129B001	O3	CSO129B001	PS3	MH129B001	
DC128P001	O4	CSO128P001	PS4	MH128P009	
DC128R001	O5	CSO128R001	PS5	MH128R002	
DC128D001	1851	MH128D003	1848	MH128D002	overflows to Fern Hollow culvert
DC128D002	1847	MH128D003	1843	10680	overflows to Fern Hollow culvert
DC128D003	1837	10678	1840	10679	overflows to Fern Hollow culvert
DC176J001	1859/1860	MH176J012	1856	10682	double-barrel OF pipe overflows to Fern Hollow culvert
DC176J002	720	MH176J012	718	10233	overflows to Fern Hollow culvert
DC176J003	704	MH176J012	705	10233	overflows to Fern Hollow culvert
DC175G002	1772	MH127D003	1774	10667	PITTS175 combined area - "leaping weir"



City of Pittsburgh
Wilkinsburg Borough
Homewood Cemetery
Churchill Borough
DC176J001
DC176J002
DC176J003
City of Pittsburgh
DC128D002
DC128D001
Edgewood Borough
Forest Hills Bor
DC128D003
DC128P001
DC129B002
Braddock Hills Borough
Swissvale Borough
DC088M001
ALCOSAN M47
Structure Type
Diversion Structure
Sewershed Type
Combined Sewershed
Separate Sewershed
Unsewered
Sewer Type
Box Culvert 96x56 Storm
COP municipal sewer
FH 33 Sanitary
Trunk
Other Municipal Sewer
Hydrologic Feature
ALCOSAN Interceptor
Municipal Boundary
Nine Mile Run Boundary
Sub-watersheds
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3.7 Sanitary Sewer Overflows (SSOs)

SSOs result in discharges of untreated wastewater that can affect stream quality and occasionally flood basements and city streets. The USEPA has found that SSOs represent a significant health and environmental threat in areas where they occur frequently. Frequent SSOs may indicate that the capacity of the collection system is insufficient to convey the flows introduced or that the system is in need of maintenance or repair. Potential causes of excess flow include infiltration and inflow, illegal connections, population growth, and under-design. Problems requiring maintenance or repair may include broken or cracked pipes, tree roots, poor connections, and settling. Proper maintenance can help prevent problems or identify them before they become extremely costly to repair (USEPA, 2000). While SSOs are a probable source of bacterial and other pollution to the Nine Mile Run watershed, pollutant loads from SSO discharges were not explicitly included in the current loading model because there was insufficient information available to characterize them.

3.8 Atmospheric Sources

Pollutants from atmospheric deposition on land surfaces are considered to be included in the calculations for the storm water runoff. Direct deposition on water surfaces also is included in these calculations by the use of a water surface land use type. Specifically, precipitation falling on the water surface land use was assigned EMCs of nutrients and metals derived from rainfall data. For this study, the water surface EMCs were taken from the Chesapeake Bay Program literature (EPA, 1982). Atmospheric contributions are included in the Nine Mile Run analysis for completeness; however, they are not likely to be significant because the land use information for Nine Mile Run includes very little area classified as open water or wetlands.

Appendix Section 4
Results and Discussion

4.1 Average Annual Runoff Load Estimates for Separate Sewered and Un-Sewered Areas

Figures 4.1 through 4.9 show the estimated average annual aerial loading from surface runoff for sub-basins in Nine Mile Run that are served by separate storm sewers or are un-sewered. For each parameter, the range of loading intensity is divided into five levels; darker colors denote greater intensities. Gray-shaded areas denote combined sewered areas and are analyzed separately. The loading rates are estimates of the total annual input to the stream system. As expected, the pollutant loadings, degree of impervious cover, and runoff volume all follow the same general trends.

The modeled runoff depth is a function of several parameters, including slope, infiltration, and evaporation, but is most strongly affected by the amount impervious cover. In general, the areas with the highest impervious cover yield the greatest runoff volume. Figure 4.1 shows three areas with the highest average annual runoff; these areas are dominated by shopping centers, densely populated residential areas, the fringes of some industrial areas, and roadways. One of the highest runoff values, approximately 23 inches, comes from the area surrounding the intersection of Braddock Avenue and Edgewood Avenue near the boundary of Swissvale and Edgewood Borough. The other two areas have runoff values of approximately 21 and 17 inches. The first is located just south of the intersection of Robinson Boulevard and Rt. 380 Frankstown Rd., and the other is at the intersection of Penn Avenue and a Conrail corridor near Columbia Hospital.

Many of the areas with the least annual runoff, less than 1 inch, are located in open areas of Homewood Cemetery and Frick Park. Other areas with runoff values from 1-5 inches are scattered throughout the eastern side of the study area. These areas are made up mostly of open fields of schools and parks, cemeteries, and less densely populated residential areas.

Figures 4.2 through 4.9 show the estimated average annual mass loading for biochemical oxygen demand (BOD_5), total suspended solids (TSS), total phosphorus, total nitrogen, lead, copper, zinc, and fecal coliform (cell loading). These graphics depict the per-area values at the sub-basin and land use level. The mass loading rates are a function of both the runoff volume and the land use. Because they prinicipally are a function of the surface runoff volume, they display trends similar to the runoff shown in Figure 4.1. The runoff volume is determined by all the components of the surface water balance, including evaporation and infiltration, and is most sensitive to the percentage of impervious land cover (e.g., roadways, parking lots, and buildings).

Because the loadings are also a function of land use (Figure 3.1), they follow trends related to their assigned event mean concentrations.

There are three easily distinguishable areas, including large shopping centers and major transportation corridors, that fall within the highest loading category for all parameters. These areas all are highly impervious, and some are assigned higher EMCs due to land use designations. There are two large areas designated as the Mall land use, a 30-acre area in the southern portion of Edgewood Borough and a 34-acre area in northern Wikinsburg Borough and Penn Hills Borough. These areas are modeled as approximately 80% impervious and assigned urban EMCs. Consequently, modeled loads in this area fall into the highest loading intensity category for each pollutant. The third significant area falling into the highest intensity category is the area around the intersection of Penn Avenue and the rail corridor. This area is coded mainly Transportation, with some commercial and industrial areas. EMCs for areas coded as Transportation are somewhat higher than other EMCs due to buildup of solids and potential pollutants associated with those solids in urban transportation corridors.

The large area in Pittsburgh that falls within the lowest runoff and pollutant categories includes Frick Park and Homewood Cemetery. These areas are coded Grass / Open or Forest and produce only small amounts of runoff.

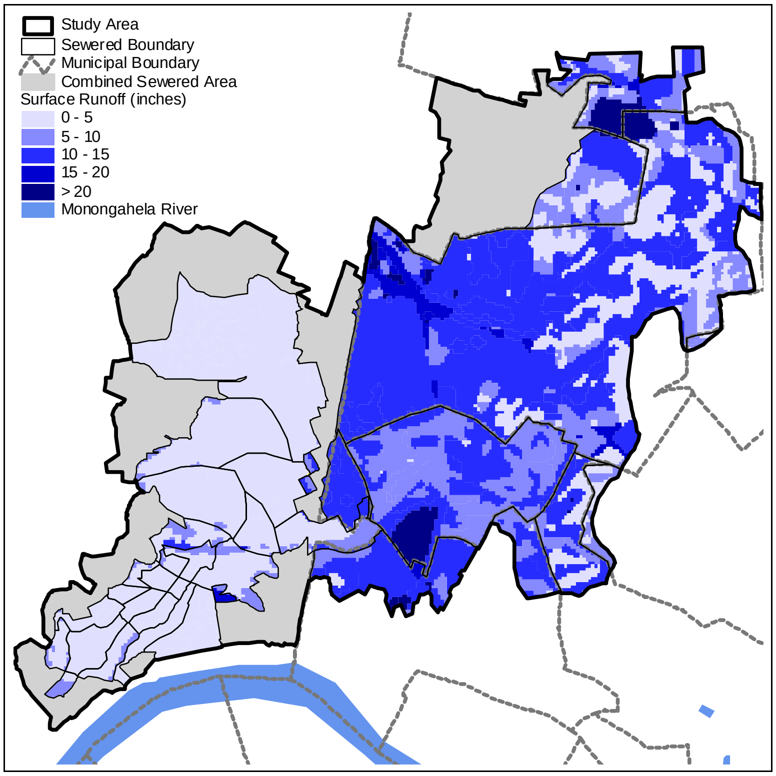


Figure 4.1 Estimated Annual Runoff Depth

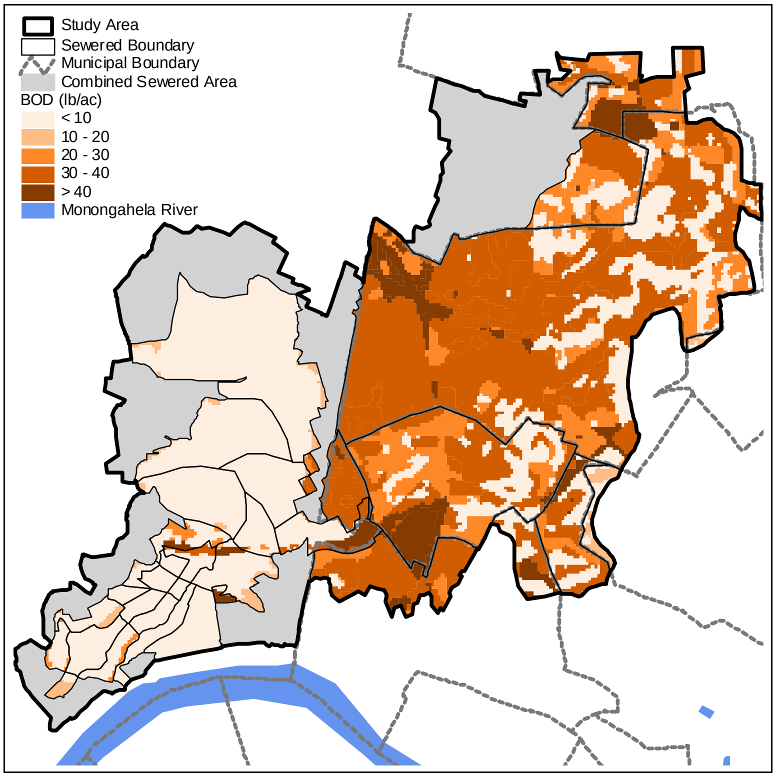


Figure 4.2 Estimated Annual BOD Loading Contributed by Surface Runoff

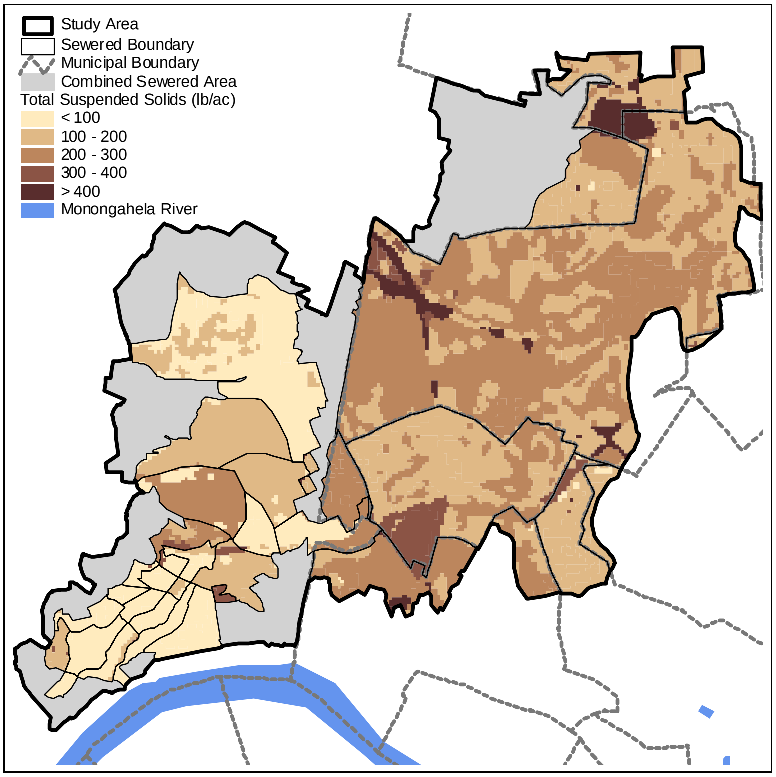


Figure 4.3 Estimated Annual TSS Loading Contributed by Surface Runoff

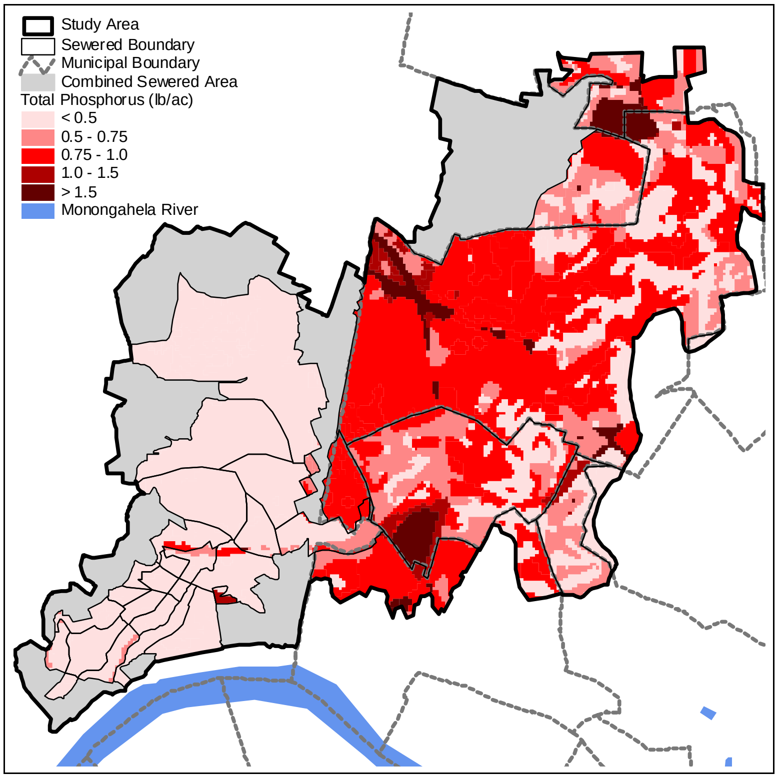


Figure 4.4 Estimated Annual Total Phosphorus Loading Contributed by Surface Runoff

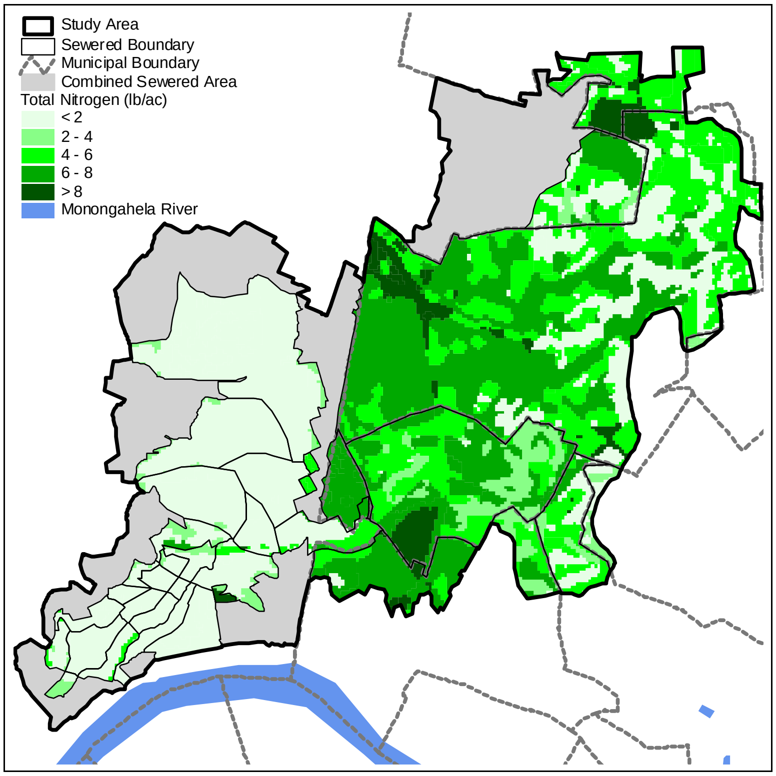


Figure 4.5 Estimated Annual Total Nitrogen Loading Contributed by Surface Runoff

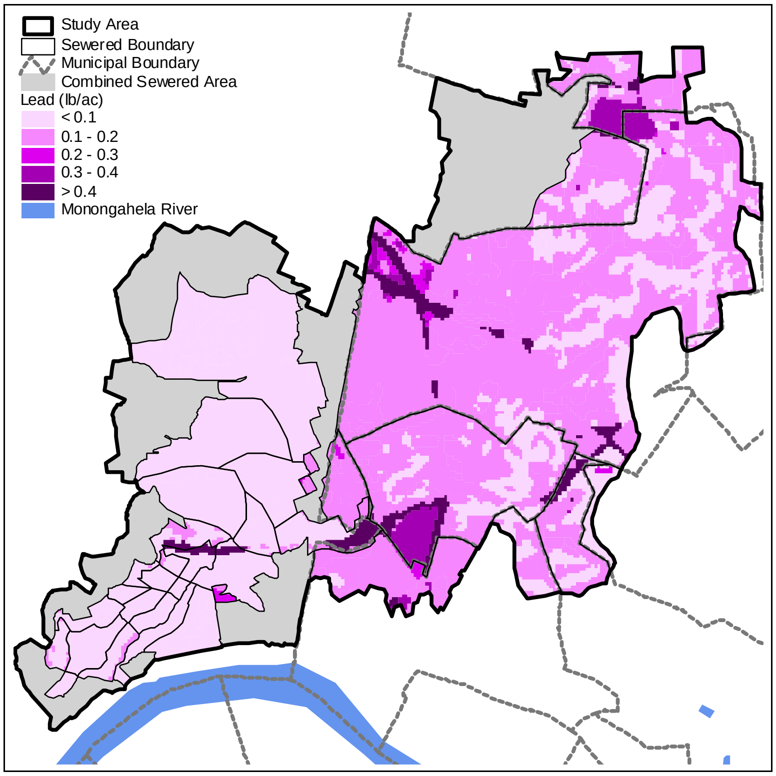


Figure 4.6 Estimated Annual Lead Loading Contributed by Surface Runoff

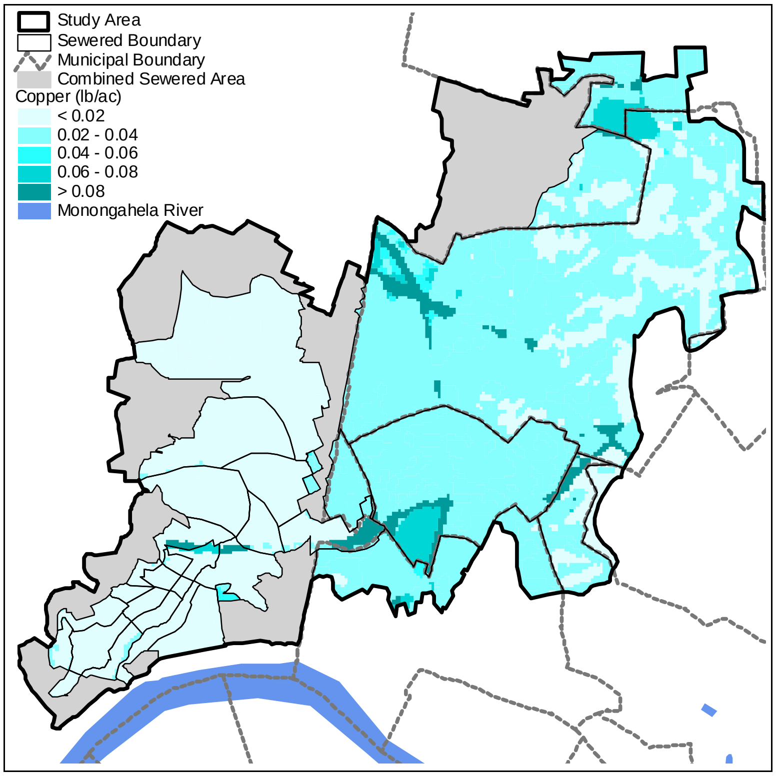


Figure 4.7 Estimated Annual Copper Loading Contributed by Surface Runoff

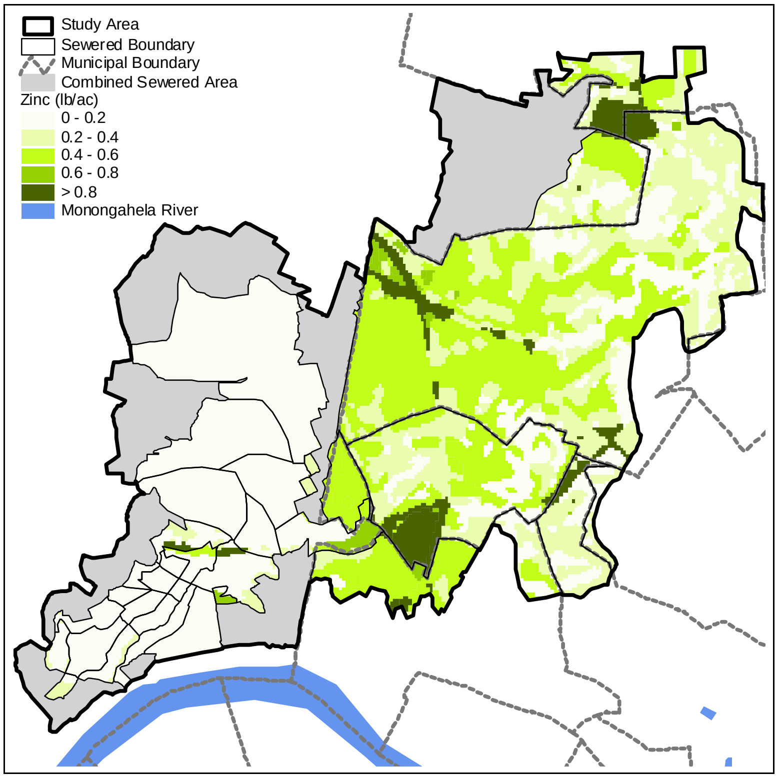


Figure 4.8 Estimated Annual Total Zinc Loading Contributed by Surface Runoff

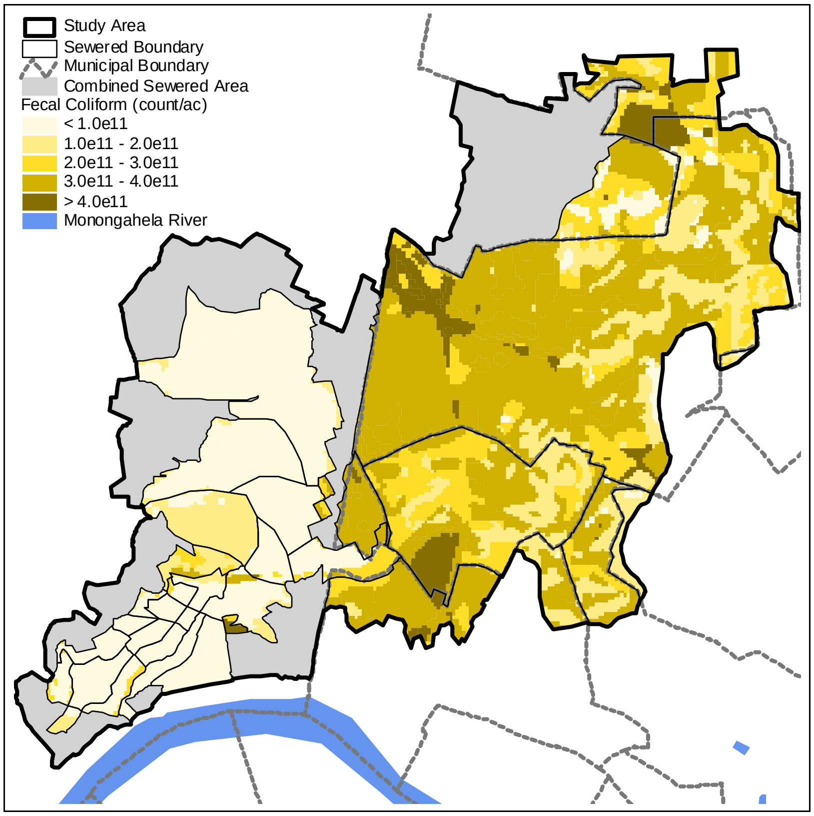


Figure 4.9 Estimated Annual Fecal Coliform Total Cell Loading Contributed by Surface Runoff

4.2 Combined Sewer Overflow Load Estimates

Table 4.1 lists the model-estimated CSO loads by pollutant and by structure. The flows and loads are a function of sewershed size, regulator configuration, and interceptor capacity. These values are explained further in Section 4.3, where they are expressed on a per-area basis and compared to loads from other sources.

Table 4.1 Estimated Annual Average Loads from CSO Sub-Basins

Regulator	Area (acres)	Outfall	Flow (MG)	BOD_5 (lb)	TSS (lb)	TP (lb)	TKN (lb)	NO2+3\ (lb)	TN (lb)	Pb (lb)	Cu (lb)	Zn (lb)	Fecal Coliform
ADC129NM47		PW	8.45E+01										
DC088M001	31.3	O2	7.85E-01	7.64E+01	5.16E+02	1.98E+00	9.61E+00	3.89E+00	1.35E+01	3.71E-01	8.28E-02	8.59E-01	2.33E+12
DC088S001	58.8	O1	9.84E-01	6.72E+01	5.25E+02	1.68E+00	8.54E+00	3.91E+00	1.24E+01	3.61E-01	7.79E-02	8.13E-01	1.24E+12
DC129B001	23.6	O3	1.16E+00	4.87E+01	3.02E+02	1.11E+00	6.03E+00	2.44E+00	8.47E+00	2.43E-01	4.93E-02	5.71E-01	4.87E+11
DC128P001	65.5	O4	4.46E+00	3.69E+02	2.97E+03	1.06E+01	4.75E+01	2.09E+01	6.84E+01	1.87E+00	4.47E-01	4.17E+00	1.63E+13
DC128R001	62.6	O5	7.89E+00	6.91E+02	3.89E+03	1.76E+01	8.56E+01	3.08E+01	1.16E+02	3.10E+00	6.84E-01	7.41E+00	2.22E+13
DC128D001	42.6	1851	1.19E+01	9.50E+02	7.61E+03	2.57E+01	1.22E+02	5.48E+01	1.77E+02	4.96E+00	1.13E+00	1.11E+01	3.12E+13
DC128D002	7.44	1847	3.05E-02	3.63E+00	2.03E+01	8.12E-02	4.46E-01	1.70E-01	6.16E-01	1.74E-02	3.49E-03	4.18E-02	3.51E+10
DC128D003	9.35	1837	3.99E-01	3.07E+01	1.71E+02	6.86E-01	3.77E+00	1.43E+00	5.20E+00	1.47E-01	2.94E-02	3.53E-01	2.96E+11
DC176J001	279	1859 / 1860	3.35E+00	5.37E+02	4.81E+03	1.50E+01	7.49E+01	3.40E+01	1.09E+02	3.28E+00	6.82E-01	6.60E+00	1.61E+13
DC176J002	90.2	720	8.96E+00	8.31E+02	4.27E+03	2.35E+01	1.03E+02	3.26E+01	1.36E+02	3.42E+00	8.15E-01	8.11E+00	4.50E+13
DC176J003	6.41	704	2.00E-02	2.18E+00	1.39E+01	5.00E-02	2.71E-01	1.12E-01	3.83E-01	1.10E-02	2.24E-03	2.58E-02	2.21E+10
DC175G002	326	MH127D004	6.30E+01	1.26E+04	6.72E+04	6.90E+02	3.47E+03	4.04E+02	3.88E+03	4.23E+01	8.58E+00	8.09E+01	2.06E+15
TOTAL	1003		103.0	1.62E+04	9.23E+04	7.88E+02	3.94E+03	5.89E+02	4.52E+03	6.00E+01	1.26E+01	1.21E+02	2.20E+15
Direct Runoff	451	stream	1.29E+02	1.29E+04	1.03E+05	2.93E+02	1.58E+03	7.90E+02	2.37E+03	1.04E+02	1.75E+01	1.75E+02	1.35E+14

4.3 Average Annual Loading Contribution by Source

Figure 4.10 presents the approximate relative contribution from each source of the total potential loading to Nine Mile Run from the watershed area. The sources include storm water runoff from separate sanitary areas, CSOs, direct surface runoff from combined sewered areas, and dry weather base flows.

As often found in urbanized settings, storm water runoff from separate sewered areas is the largest source for most pollutant types. Baseflow contributes a significant amount of total nitrogen. Separate sanitary overflows (SSOs) may be a significant source of pollutants, but information concerning these sources was insufficient to include in the screening-level analysis.

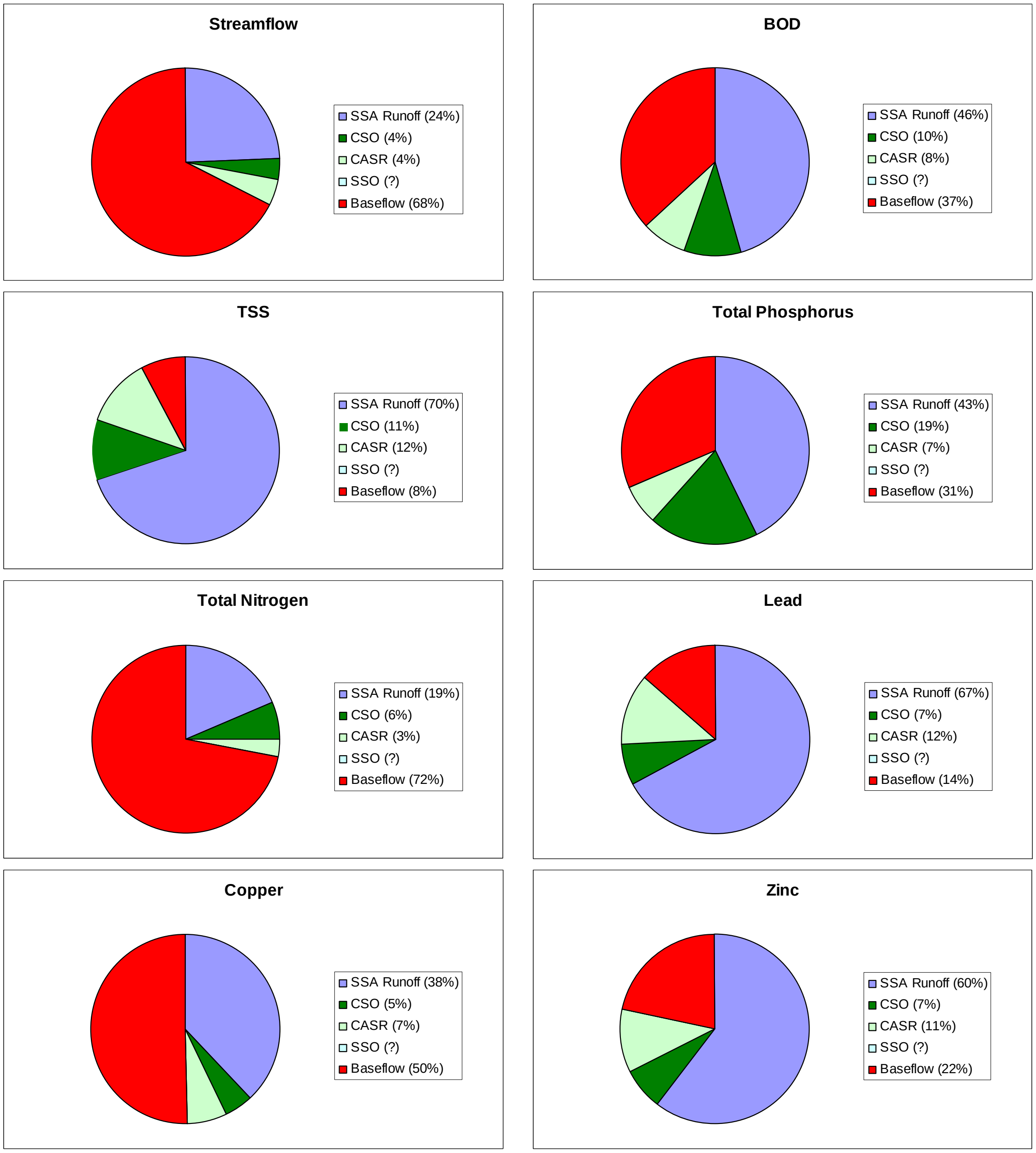
The CSOs in the watershed are estimated to contribute only about 5% of the total annual discharge entering Nine Mile Run. There are three factors contributing to this surprisingly low number. First, the combined sewer system in the basin has a very large capture and transport capacity relative to the actual amount of combined sewage generated. Second, and closely related, a significant portion of excess precipitation flows overland and reaches the receiving stream directly. This storm water runoff bypasses the sewer system in the combined sewered areas and never commingles with sanitary sewage. Therefore, the effective combined area is smaller than the stated 23%. Third, much of the wet weather overflow that does occur discharges directly to the Monongahela River rather than Nine Mile Run. CSOs contribute a large proportion of the total load for parameters associated with sanitary sewage, including phosphorus and fecal coliform.

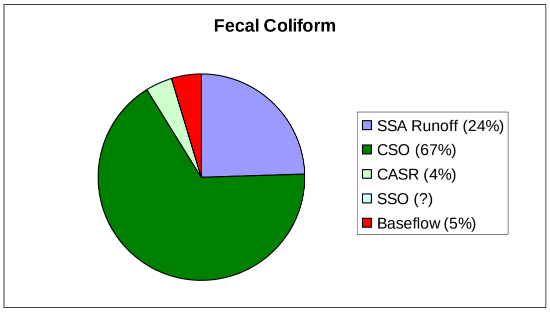
Table 4.2 presents the average areal loads contributed by runoff from separate and combined sewered areas. Areal loads show the intensity of loading rather than total loads. Loads for surface runoff from separate sewered (including un-sewered) are similar to loads from direct storm water runoff in combined areas. CSO loads are grater than surface runoff loads for parameters associated closely with sanitary sewage, including phosphorus and fecal coliform. CSO loads for many other parameters, including metals, are comparable or slightly lower due to the portion of flow that is captured.

Table 4.2 Estimated Annual Areal Loads by Source

	Separate Sewered Areas Storm water	Combined Sewer Overflows	Combined Sewer Area Direct Storm water
Effective Area (ac)	3312	552	451
Flow (in)	7.88	6.88	10.5
BOD_5 (lb / ac)	23.0	29.3	28.6
TSS (lb / ac)	182	167	229
TP (lb / ac)	0.541	1.43	0.65
TKN (lb / ac)	2.81	7.13	3.49
NO2+NO3 (lb / ac)	1.34	1.07	1.75
TN (lb / ac)	3.21	8.20	5.24
Pb (lb / ac)	0.171	0.109	0.230
Cu (lb / ac)	0.029	0.023	0.039
Zn (lb / ac)	0.294	0.219	0.389
Fecal Coliform (/ ac)	2.43E+11	3.99E+12	3.00E+11

Figure 4.10 Annual Contribution by Source Type





Notes:

- SSA = separate sanitary area runoff
- CASR = combined area surface runoff
- Sanitary sewer overflows (SSOs) were not explicitly included in this analysis.
- The model indicates that direct atmospheric loads to surface water were found to contribute less than 0.1% of the load for any parameter studied. This result is due mainly to the fact that very little area is classified as water or wetlands.

4.4 Model Sensitivity

Model uncertainty can be characterized by observing the change in model response to changes in input parameters. While the model produces discrete output, the load estimates presented above should be considered as lying somewhere within a range of possible values. Simulation of watershed hydrology and sewer system hydraulics at a high level of complexity and physical realism minimizes this uncertainty; the remaining error is due mainly to uncertainty in the event mean concentrations and sanitary sewer flow concentrations. Because surface runoff rates are multiplied by constant EMCs, the WMM framework-based storm water runoff load estimates respond linearly to changes in the EMCs.

Concentrations of pollutants in CSO discharges depend on the concentrations in surface runoff, sanitary baseflow, and sometimes upstream wet weather sewer flows. These concentrations depend on physical factors such as type of storm, initial conditions, and the presence or absence of surcharge conditions in the sewer. These physical processes are simulated at a high level of complexity and physical realism to minimize error. Because combined sewer overflows include surface runoff, the same uncertainties that affect separate sewered areas affect these discharges. However, the effect is not linear, and in fact, should be regarded as highly nonlinear. The modeling framework provides a linear, or first order approximation of these processes.

Appendix Section 5
Conclusions

- The total potential source load to surface water, the surface runoff load per unit area, and the proportional contribution of different land use types were completed for BOD_5, TSS, total phosphorous, total nitrogen, lead, copper, zinc, and fecal coliform. These results are intended to complement instream water quality data by characterizing existing sources of water quality constituents in the watershed that may affect surface water quality. The model may be used in the future to identify geographic areas and source types where cost-effective load reductions can be accomplished. The model does not provide a direct link between pollutant loads and instream water quality.

- As in many urbanized systems, wet weather surface runoff is the most significant source of many water quality constituents that reach the receiving stream on an annual basis. In Nine Mile Run, a significant amount of surface runoff in areas served by combined sewers bypasses the sewer system and reaches the receiving stream directly. Constituent loads in this runoff are considered to be contaminated to the EMC levels as for runoff in areas served by storm sewers.

- Discharges from combined sewers contribute only about 5% of the total flow in Nine Mile Run. The hydraulic model indicates that much of the wet weather sewer flows that occur take place near the system outlet and affect the Monongahela River rather than Nine Mile Run. CSO discharges are a proportionally large source of pollutants that have elevated levels in sanitary sewage, and are a comparable source of other pollutants associated more strongly with storm water..

- The model output should be interpreted within a range of uncertainty. Because detailed simulation of the physical processes governing watershed hydrology and sewer hydraulics minimize error, much of the remaining error is due to uncertainty in runoff concentrations and sanitary baseflow concentrations. The most useful way to interpret the model output is to examine the relative contributions of different sources and areas to identify possible approaches to improving water quality conditions.

Section 6
References

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Section 7
Appendix Supplements

Tertiary Extran, Runoff, Regionally Integrated (TERRI) Hydrology, Hydraulics and Water Quality SWMM Input and Output NMR Files

Appendix Supplement A: Simulation Methods used in this Model

Appendix Supplement B: NMR Runoff layer input file

Appendix Supplement C: NMR Runoff layer output file

Appendix Supplement D: NMR Extran layer input file

Appendix Supplement E: NMR Extran layer output file

Appendix Supplement F: NMR Transport Water Quality layer input file

Appendix Supplement G: NMR Transport Water Quality layer output file

Appendix Supplement H: NMR Transport Combine layer input file

Appendix Supplement I: NMR Transport Combine output file

Purpose of these Appendix Supplements: The NMR file appendices show the basic input and reduced output files for the NMR Runoff layer model, Combine Transport layer model, Extran hydraulics model and the Transport Water Quality layer model. The NMR model consists of all the major layers of the SWMM: Hydrology (Runoff), Hydraulics (Extran) and Water Quality Routing (Transport). The GIS input and output transfer tables and the overall flow and water quality constituent continuity errors are presented in these Appendices along with the hydrologic, water quality and hydraulics data used to characterize the NMR system.

Note: Appendix Supplements A through I are provided in the hard-copy versions of the NMR Watershed Management Plan. The CD versions of the plan include only Appendix Supplement A.

Appendix Supplement A: Simulation Methods used in this Model

The Nine Mile Run (NMR) stormwater, combined and sanitary networks are simulated using the Stormwater Management Model (SWMM) analysis system. The NMR model consists of all the major layers of the SWMM: Hydrology (Runoff), Hydraulics (Extran) and Water Quality Routing (Transport). It starts with a Hydrologic Runoff Layer model that has watersheds with both pervious and impervious characteristics. These pervious and impervious areas use the watershed characteristics generated in Arc View and exported to SWMM using an ASCII text file. The Arc View or GIS watershed information included: the watershed area, average watershed slope, the pervious area, the impervious area, an estimate of the pervious and impervious depression storage based on the average slope, an estimate of the important watershed width parameter which is used to generate the peak surface runoff rates, land use information, and soil type information to determine the Green-Ampt infiltration parameters.

The runoff layer generates surface runoff, subsurface runoff, water quality estimates, snow melt and snow fall, pipe infiltration, simulates infiltration losses from the ground and subsurface areas of the watershed, and evaporation. The driving force of the Runoff layer is the precipitation, which may be a continuous record, a design storm, or a measured storm event. The storm may be simulated as moving through the watershed or stationary over the watershed. In the NMR model the 53 year precipitation record of the Pittsburgh Airport is used as the wet weather driving force.

The NMR model next uses the Transport layer of SWMM to combine the flows and loads of the continuous Runoff interface file so that they are organized and flow to the load points of the Extran layer of SWMM. Another important purpose of the Transport layer is to simulate the leaping weir at Pitt through the mechanism of a flow splitter. The dry weather flows does not contribute flow and load to the NMR model at Pit. The flow splitter sends the low flow offsite and the wet weather flow to a loading point (node MH127J001) of the NMR model.

The transport layer is used to route water quality through the conveyance system to a pond or other BMP or network outfall. It will simulate scour and deposition using Shield’s diagram. Transport can be used to simulate the infiltration in pipes and the dry weather base flow for a sanitary or combined sewer area. Transport simulates the flow in conduits as a series of cascading conduits. It uses a modified kinematic wave equation in the solution of an upstream and downstream conduit flow. The limitations of the Transport layer are its treatment of surcharge flow, lack of boundary conditions and only allowing downhill flow. In the NMR model these limitations are superseded because the superior hydraulic routing of the Extran layer is substituted.

Transport makes a combined interface that supplies the surface runoff flows to the Extran hydraulics layer of SWMM. Extran will use the real hydraulic characteristics of the network to route dry weather flow input and wet weather flow. The flow splitting at the regulators is determined by the modeled water surface elevations and the upstream conduit elevations of the bypass and outfall conduits.

Extran will use the flow generated by either the Runoff layer, Transport layer, or its own independent dry weather flow or user inflow time series to route the flow hydraulically through the storm, sanitary, combined or river system. Extran handles many different boundary conditions, interconnected ponds, outfall structures, pumps, open and closed conduits, culverts, regulators, bridges, and specialized types of flow conveyance systems.

SWMM is used to model the full hydrologic cycle, including stormwater and wastewater quality, EMC washoff of chemical constituents, the routing of stormwater and sanitary sewer flows, and the hydraulic analysis of bypass and flows and overflows. The following steps were followed in the construction of the NMR integrated SWMM model.

Water Quality Analysis Roadmap

- Gather Sanitary Network Data
    1. Previous Models
    2. GIS Import
    3. Spreadsheet Data
    4. As-Built Drawings
    5. Survey of the Network Elements
    6. USGS Quad Maps

- Determine the Reach Variables of Interest
    1. Substrate
    2. Form of the Land-water interface
    3. Habitat heterogeneity
    4. Water chemistry
    5. Sanitary network chemical constituent loading concentration

- Determine the Watershed Variables of Interest
    1. Habitat fragmentation
    2. Land use characterization
    3. Cumulative effects of peak flows
    4. Watershed geology
    5. Watershed size/morphology
    6. EMC loading estimates for each chemical constituent and land use

- Define the Sewershed Areas
    1. Use the Watershed Delineation tools in Arc View
    2. Calculate the overland flow path length, area and average slope of the watershed and estimate the surface roughness.
    3. Use the physical data to estimate the watershed parameters.

- Define or obtain the Rainfall Data
    1. Historical or Continuous Rainfall Databases
    2. Synthetic, statistically representative annual wet, dry and average year rainfall records
    3. Characterize the frequency distributions of the storm volume, inter-event dry periods and storm durations for the design of on-site detention systems.

- Define the Objectives of the Sanitary Model
    - Sewershed Master Plan
    - Retro-Fit of Existing Sanitary System

- Define the level of detail of the sanitary network
    1. State the simplifying assumptions (pipe size, major interceptors)
    2. Use a lumped parameter approach and combine the sanitary network elements

3. Decide whether to model wet weather flow and dry weather flow
4. Select the hydrology method of choice if you are modeling wet weather flow
5. Determine the parameters for the hydrology method of choice
6. Select the Infiltration Loss Method
7. Determine the parameters of the Infiltration Loss Method
8. Estimate the evaporation
9. Select the routing method for the sanitary network
10. Determine the additional data you will need based on the selected routing method (e.g. channel slopes versus channel elevations)

- Edit data
    - Check the network data for data consistency
    - Conduit Elevations above node invert
    - Conduit Crowns not above the ground elevation
    - Correct Stage-Storage data entered for ponds and lakes
    - Conduits flow in the right direction (e.g. the downstream node is really the downstream node and not the upstream node).

- Inflow data
    - Estimate the mean dry weather flow at each modeled manhole
    - Estimate the diurnal and weekly flow variations for different parts of the city
    - Estimate the wet weather inflow during the storm event

- Import and download from/to data collectors
    1. Import measured stages or flows for model calibration and verification
    2. Change the format if necessary for direct model predicted and measured result comparison

- Calibrate the model
    1. Compare the model results to measured data or “ballpark” estimates of peak flows per area
    2. Change the model parameters if necessary to match measured data or “ballpark” estimates of peak flows per area

- Verify the model
    1. Run the model under different conditions to test the sensitivity of the model assumptions (e.g. small storms, medium storms and large storm events)
    2. Perform a sensitivity analysis on the model parameters for a selected variety of storm events.

Hydrology Information

The Runoff layer used soil information from Arc View coverage’s to estimate the parameters of the Green-Ampt soil infiltration method. The excess rainfall once evaporation, infiltration and depression storage is accounted for is generated using the non-linear surface runoff algorithm. The watershed surface runoff and chemical constituent loading at each time step is saved to an interface file for routing in the Extran and Transport layers of SWMM. Each of the watersheds in the Nine Mile Run system has its flows and loads saved to an interface file. This interface file is then combined using the first pass Transport file to create an interface file for Extran and then Transport.

Non-Linear Runoff Routing.

Non-linear reservoir routing using Manning's equation and other pervious and impervious area parameters is used to generate overland flow hydrographs. This deterministic hydrology allows accurate simulation of hydrologic processes. Urban, suburban, and rural areas of any size may be simulated using non-linear routing by altering the overland flow patch or subcatchment width parameters.

An important calibration parameter that was added for this for this nine Mile run model was the proportion of Impervious flow that ended up in the streams and in not overland to the combined or storm water network. This was modeled as a 45% transfer of flow from the impervious portion of the watershed directly to the node Stream, which represented the open channels draining directly to Nine Mile run.

Infiltration

Infiltration is computed using the Horton, Green-Ampt, Initial/Continuing Loss, Proportional Loss or the SCS method with optional sub-surface routing. If groundwater is simulated then the unsaturated zone interacts with the infiltration coming from the watershed surface. It the shallow water aquifer becomes saturated the infiltration will be zero and the surface runoff will increase. Between storm events, there will be exponential recovery of infiltration capacity for Horton infiltration and adjustment of the soil moisture deficit using Green-Ampt infiltration. The NMR infiltration method is Green-Ampt.

Rainfall

The surface runoff of each of the Watersheds was generated using one-hour precipitation data from the Pittsburgh airport for the years 1948-2000. The Runoff layer integrated the hourly data using 15-minute time steps when it rains and one-hour time steps when it has stopped raining but has surface storage of runoff. During the dry periods the model will use the time step one day or 86,400 seconds 86400 seconds. An important contribution to the overall water balance was an estimate of the Pan Evaporation Coefficient in Lake Evaporation and Lake Evaporation that was used to simulate evaporation loss from both the pervious and impervious surfaces of the Watersheds.

EMC

By using the Event Mean Concentration (EMC) method, no build-up or washoff calculations are necessary. The particular pollutant distribution is defined by specifying the mean and standard deviation of a lognormal statistical distribution for the EMC. At the beginning of each storm event a value is chosen from the distribution of the pollutant and used until the end of the rainfall event. In the NMR model the coefficient of variation was 0.0 of EMC.

Chemical Constituents and Land Use

Any number of pollutants and land uses may be stored in the SWMM Global Database with up to 20 or more pollutants and 10 ore more land uses selected for analysis during any one simulation. Each watershed in the system may be assigned up to 10 land uses, with up to 5 watersheds defined at each node.

The water quality of the storm water and was estimated using the results of the 50 year runoff simulation described above and Event Mean Concentration for 9 pollutants and 15 land uses. Thus, each of the storm loads is calculated automatically by the model from the surface runoff of a storm event and one of the pollutant concentrations. These runoff flows and loads were saved to a GIS ASCII output table and a SWMM interface file.

In Conduits

Quality routing is performed by advection and mixing in conduits. Each constituent may be subjected to first order decay during the routing process. The decay of one constituent has no effect on other constituents. The integrated form of the complete mixed conduit volume in the Transport layer of SWMM performs the routing of quality parameters in NMR. The routing becomes closer to pure advection (plug flow) as the number of conduits is increased.

Dry Weather Flow

A new option new dry weather flow option that bypasses most of the Filth routine in Transport was added to SWMM. This option is enacted by using the command # TRANSPORT_DWF in the input data file. At the same time we added the same facility to the Extran layer of SWMM. To make this work we had to redo the day of the week calculations. This was the old variable Kday in Transport. Kday in this new version of Transport and Extran is the actual day of the week starting with a value of one for Sunday. You can now run Transport and Extran dry weather flow and get the same answers in both programs. This facility can be added on top of what you are now changing.

```
*  diurnal flow variation
BW  1
*M - Hour of day variation (factors from agerage DWF-I/I from
metered data)
*  1    2    3    4    5    6    7    8    9    10   11   12
BX 0.92 0.82 0.76 0.75 0.74 0.78 0.90 1.11 1.17 1.17 1.16 1.12
1.11 1.08 1.04 1.01 1.00 1.03 1.04 1.05 1.07 1.09 1.07 1.01
*  Day of week DWF variation
*  S    M    T    W    T    F    S
BY 0.97 1.03 1.02 1.07 0.98 0.95 0.99
```

We also added a new regulator to transport that will read Chuck's B9 output of Extran use the Extran flows instead of the Transport flows downstream of the regular. Another change was to make a GIS summary table of the loads and flows in transport.

I had to modify the way Runoff and Transport read the scratch files because of the slowness of the old method. Rewinding the scratch file for each location would take days on a fast machine if you had more than five humdred watersheds that you want to print to the GIS output table. I changed it to read the scratch files only one time but this caused an increase in memory storage to contain the intermediate information. A scratch file for a large watershed model run for 50 years can be almost 10 GB in size.

GIS ASCII Output Table

The GIS ASCII output table was normalized in units of inches per Watershed area in units of inches of Runoff per year for each Watershed and Pounds per acre per year for each of the loadings. This allows us to compare the nine Mile run Loadings and flow to those of other Watersheds.

The Transport layers of SWMM will collate and combine the 358 Separate and Runoff locations for the whole 50-year continuous simulation. The results and the end result is a 50-year Transport interface file for Extran's 50-year continuous simulation. One of the functions of this Transport Layer MODEL besides the collation and combination of inlet locations is the modeling of the weeping Weir at that spans the Pitt Watershed. The leaping Weir at Penn's will send the low flow dry weather flow offsite from the NMR Watershed Model. The leaping weir will let the wet weather flow drain to the to the nine Mile run Watershed Model and NMR.

The combined 50-year interface file will be used both for Transport and Extran models. The purpose of the Extran model is to take this 50 year interface file and predict the Overflows and Bypass Flow downstream using the full dynamic wave equation in Extran. The Overflows and Bypass Flows are saved to a file using the B9 option of the Extran layer of SWMM. The Transport layer of SWMM reads these flows and substitutes these flows for the calculated Transport flows.

The sequence of the NMR models is:

- ☐ 50 year continuous Runoff Model
- ☐ 50 year continuous Transport collate and combine model
- ☐ 50-year continuous Extran model
- ☐ 50 year continuous Transport Water Quality Model

At each of these steps a normalized GIS table is generated with the flows in units of inches per year and loads in units of pounds per acre per year. Two other tables are created in the Runoff layer and the Transport layer: an average flow weighted concentration table and a total load table for each regulator and watershed.

The Runoff EMC or event mean Concentration estimates are passed through each of these interface falls files. Load in the Runoff Interface File is solely a function of Surface Runoff and EMC concentration. Loading in the 50 year Transport Model is a combination of the Dry Weather Flow Loading and the surface flow Loading. The number of chemical constituents is the same in the Runoff and Transport layers of SWMM.

The rainfall time step was 15 minutes in the Runoff layer of SWMM; 10 seconds in the Extran layer and 300 seconds in the Transport layer of SWMM.

The Transport and Extran dry weather flow parameters are the same. The dry weather flow parameters include the mean base flow, the diurnal flow variation and the daily flow variation. It is very important to the overall validity of the CSTR water quality routing mechanism that the two input time series to the Extran and Transport models be the same. The wet weather input time series is the same since both layers use the same interface file. The SWMM program was modified so that the same dry weather time series is generated in the Extran and Transport layers.

Extran generates a separate SAV file that contains the flows at five-minute intervals. The flow locations are designated on the B9 line of Extran. The flow at the regulator, the flow in the outfall, and the downstream flow or all saved to the B9 SAV file. The B9 SAV file from Extran is read by the Transport layer model by using the special flow diversion Type 30 in Transport. Inflow Diversion Type 30 will substitute the flows from the Extran B9 SAV file for the calculated flows in transport. The Transport layer of SWMM has a limited amount of flow dividing capability. The enhanced ability of the Extran layer of SWMM is used to divide the flows based on the hydraulic characteristics of the network and the predicted water surface elevations. Ay elements of this link EXTRA and in Transport Model is to make sure that the time steps saved to t9 line 99 is the same time step that is used inside of the Transport Model. Additional feature that is very important is to make sure that the dry weather flow inside the Transport and Extran layers has the same mean, the same diurnal pattern and the sane daily flow pattern.

The input interface file for both the Transport Model and the Extran layer is the same combined interface file generated by Transport. This interface file contains all of surface runoff and loadings for a 50-year simulation.

Continuously Stirred Tank Reactor (CSTR) Calculations

The Extran model uses the one-dimensional St. Venant Equation to calculate the overflows based on the hydraulic characteristics of the NMR network. Extran does not provide water quality estimates. The Transport layer of SWMM will read the Extran B9 SAV ASCII File to get the overflow flows and bypass flows and use these flows to route the water quality constituents. At each time step the Transport Layer is reading the same combined interface file used by Extran with the pollutant loadings from surface runoff and mix it with the dry weather flow generated sanitary loadings.

The concentrations in the overflow conduits and in the bypass conduits are based solely on the Continuously Stirred Tank Reactor calculations. The upstream load, manhole input load and surface runoff load is mixed with the existing load in the conduit. The CSTR equations are used to calculate the new concentrations based on the flow rate through the conduit, the change in volume and the total upstream load. The CSTR equations resulted in a continuity error in water quality of less than 0.5% over the 50 years. A GIS ready table is used to estimate the flow and loadings at the regulator Structures.

Transport layer Combine Model

The purpose of the Transport layer combine model is to collect the surface runoff from the combined watersheds and combine the flows and loads that should drain to the appropriate loading point of the NMR model.

Foe example combined watersheds '10A.1EastA-C-7' '10A.1EastA-C-8' '10A.1EastB-C-3' '10A.1EastB-C-6' '10A.1EastB-C-7' '10A.1EastB-C-8' '10A.1EastC-C-3' '10A.1EastC-C-4' '10A.1EastC-C-6' '10A.1EastC-C-7' '10A.1EastC-C-8' '10A.1North-C-3' '10A.1North-C-6' '10A.1North-C-7' '10A.1North-C-8' '10A.1North-C-14' '10A.1Wes.N-C-4' '10A.1Wes.N-C-6' '10A.1Wes.N-C-7' '10A.1Wes.N-C-8' '10A.1Wes.S-C-7' '10A.1Wes.S-C-8' '10A.2East-C-3' '10A.2East-C-4' '10A.2East-C-6' '10A.2East-C-7' '10A.2East-C-8' '10A.2West-C-3' '10A.2West-C-4' all drain to the collection manhole 'DC176J001'. The Transport layer combine model adds up all of the flows and loads and saves the time series to manhole 'DC176J001' for subsequent usage by the Extran layer hydraulic model and the Transport layer water quality model.

Another purpose of the Transport layer combine model is to organize the flows and loads from those stormwater watersheds that do not drain directly to the NMR streams. For example, The PENN hills node collects the flow from watersheds 'PENN175G-S-2' 'PENN175G-S-3' 'PENN175G-S-4' 'PENN175G-S-6' 'PENN175G-S-7' 'PENN175G-S-8' 'PENN175G-S-9' 'PENN175G-S-10' 'PENN175G-S-14'.

Leaping Weir Description

The Pitts leaping weir called ‘leaping’ collects the flow from the combined areas 'PITTS175G-C-2' 'PITTS175G-C-3' 'PITTS175G-C-4' 'PITTS175G-C-6' 'PITTS175G-C-7' 'PITTS175G-C-8' 'PITTS175G-C-9' The node leaping has a mean Dry Weather Flow of 0.93 cfs. The flow splitter 'flow_split' sends the flow and loads less than 0.93 cfs to element ‘leaping_out’ and sends the flow and loads over 0.93 cfs to ‘leaping_in’, which has a one-to-one connection with manhole 'MH127D004'. The total loads from the Pitts combined sewer watersheds is listed as the flows and loads at node ‘leaping_in’; and the exported loads that never reach nine Mile run are listed as the flows and loads at node ‘leaping_out’.