Appendix D. Chagrin River Model Setup

CHAGRIN RIVER WATERSHED MODEL SETUP

The following sections describe the process used to set up the Chagrin River Loading Simulation in C++ Program (LSPC) model. LSPC is a version of the Hydrologic Simulation Program Fortran (HSPF) model that has been ported to the C++ programming language to improve efficiency and flexibility. LSPC integrates a geographical information system (GIS), comprehensive data storage and management capabilities, the original HSPF algorithms, and a data analysis/post-processing system into a convenient PC-based windows interface. LSPC's algorithms are identical to a subset of those in the HSPF model. LSPC is currently maintained by the EPA Office of Research and Development in Athens, Georgia. A detailed discussion of HSPF simulated processes and model parameters is available in the HSPF User's Manual (Bicknell et al. 1996).

For the Chagrin River TMDL project, LSPC was employed only in a "screening-level" mode. A streamlined setup of the model was done using easily available data while certain watershed characteristics (e.g., in-stream dams, lakes) and some sources (e.g., combined sewer overflows, sanitary sewer overflows, small package treatment plants) were not addressed in detail. The model was based primarily on existing land use, soils, topographic, and surface hydrology data and only a preliminary hydrologic calibration was performed. The resulting model is able to provide reliable information about the likely watershed-wide impacts of land use change and adoption of BMPs, but is not suitable for evaluating certain site-specific hydrologic or water quality issues.

1.1. Watershed Delineation

LSPC was configured to simulate the Chagrin River watershed as a series of hydrologically connected subwatersheds. The spatial subdivision of the watersheds allowed for a more refined representation and description of hydrologic factors. Subwatershed delineation was primarily based on Ohio 14 digit subwatersheds and topography (30 meter Digital Elevation Maps). Output from LSPC is for the most downstream point of each subwatershed (sometimes referred to as the "pour point"). Subwatersheds were therefore delineated to obtain modeling output at the USGS gage and certain monitoring locations. The Chagrin River LSPC model resulted in 38 delineated subwatersheds. The final delineated subwatersheds and primary streams for the Chagrin River models are shown in Figure D-1.

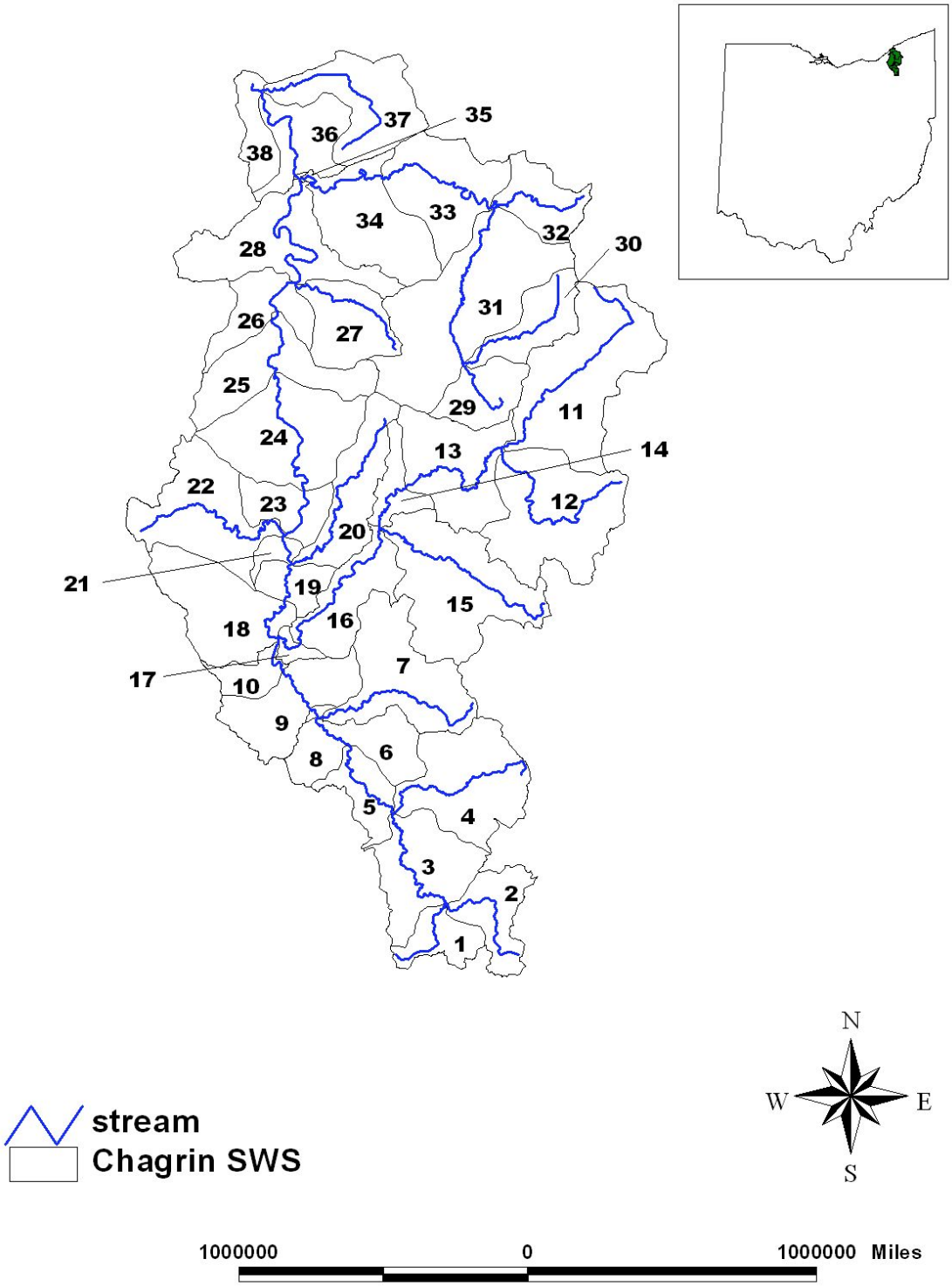


Figure D-1. Chagrin River Watershed

1.2. Waterbody Representation

Each delineated subwatershed in LSPC was represented with a single stream assumed to be a completely mixed, one-dimensional segment with a trapezoidal cross-section. Input parameters for the reaches include initial depth, length, depth, width, slope, Manning's roughness coefficient, and coefficients to describe the shape and of the stream channel. Physical characteristics of each stream were determined by Rosgen's method (Rosgen, 1996). This method takes into account a watershed's size and location to estimate the depth and the width of a stream. Parameters used for LSPC were IDEPTH (Reach Initial Water Depth), LENGTH (Reach Length), DEPTH (Reach Bankfull Depth), WIDTH (Reach Bankfull Width), SLOPE (Reach Slope), MANN (Manning's Roughness Coefficient for the Stream Channel),R1 (Reach ratio of Bottom Width to Bankfull Width), R2 (Reach Side Slope of Floodplain) and W1 (Reach Floodplain Width Factor) as shown Figure D-2.

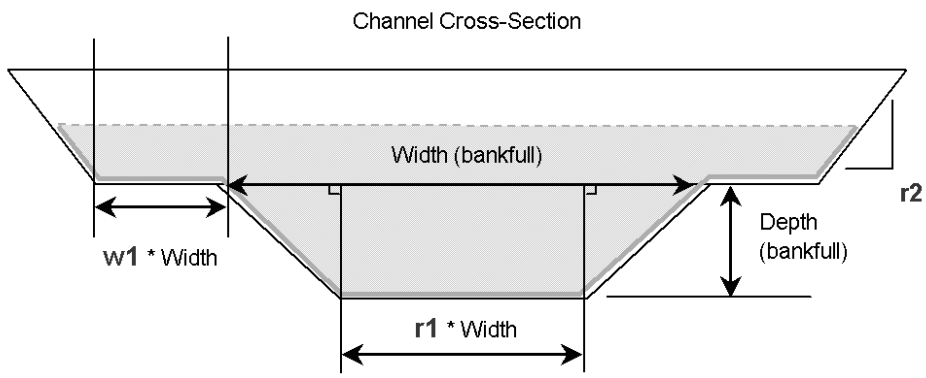


Figure D-2.Stream channel representation in the LSPC model.

1.3. Weather Data

The LSPC model is driven by precipitation and other climatologic data (e.g., temperature, cloud cover, wind speed). As a result, meteorological data are a critical component of the watershed modeling effort. Appropriate representation of precipitation, wind movement, solar radiation, potential evapotranspiration, cloud cover, temperature, and dew point are required to develop a valid model.

Daily climatologic data from the National Climatic Data Center (NCDC) during the period of 1998 to 2004 was accessed. The length of the selected period was determined based on the most recent available data and LSPC model requirements. The stations selected for this study were Chardon (weather station ID number 331458) and Hiram (weather station ID 33780) (Figure D-3). These two stations were selected for proximity and a completeness of the available data. Daily records obtained from these two stations were disaggregated to hourly data to meet LSPC model requirement and assignments of each weather gage to subwatersheds was determined during the hydrologic calibration process. Table D- 1 describes the final assignment of each weather station to subwatersheds. At the time of the model setup, weather data were only available through 2004.

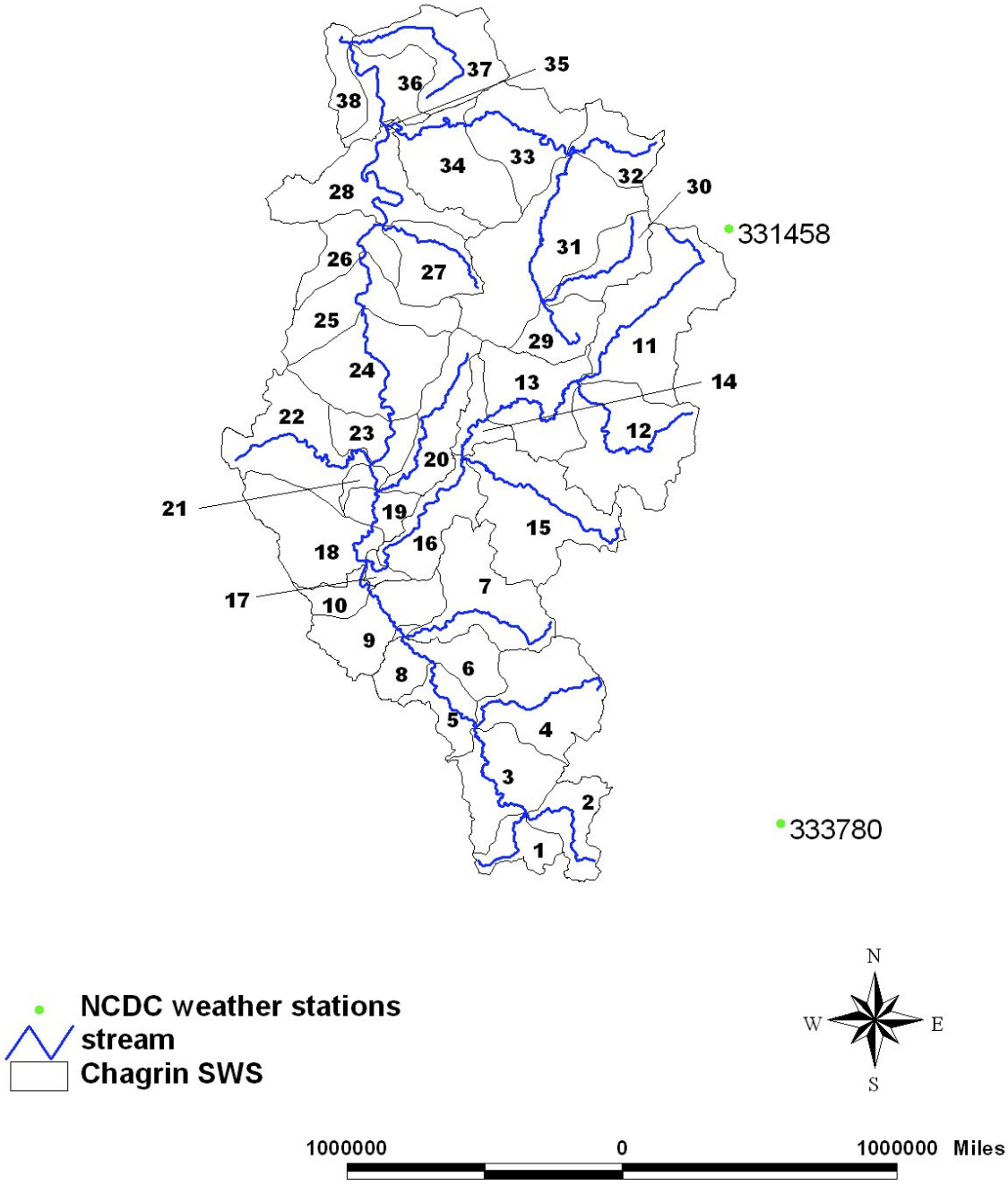


Figure D-3. The locations of NCDC weather stations

Table D-1. The assignment of weather stations to each subwatershed

subwatershed ID	weather station ID	subwatershed ID	weather station ID
1	333780	20	333780
2	333780	21	333780
3	333780	22	333780
4	333780	23	333780
5	333780	24	333780
6	333780	25	333780
7	333780	26	333780
8	333780	27	333780
9	333780	28	333780
10	333780	29	333780
11	333780	30	331458
12	333780	31	331458
13	333780	32	331458
14	333780	33	331458
15	333780	34	331458
16	333780	35	331458
17	333780	36	331458
18	333780	37	331458
19	333780	38	331458

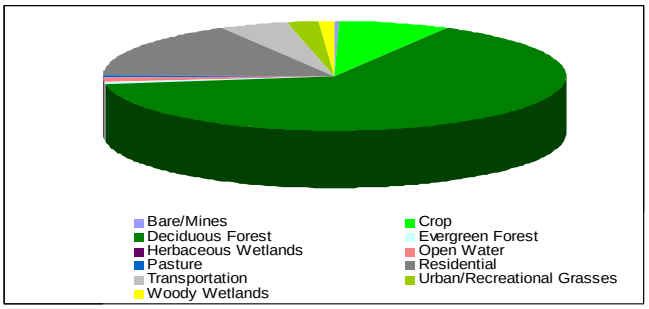
1.4. Land Cover Representation

LSPC requires a basis for distributing hydrologic parameters. This is necessary to appropriately represent hydrologic variability throughout each watershed, which is influenced by land surface and subsurface characteristics.

Land cover data were obtained from the Ohio Statewide Land Cover Level-II Classification map (1999 - 2003) based on Landsat-7 analysis. Land uses identified in the coverage are shown in Table D-2 with a corresponding pie chart based on the landuses percentages. Figure D-4 shows the land use distribution coverage within Chagrin River watershed.

Table D-2. Landuses distributions within Chagrin River Watershed

land description	acre	mi^2	percentage
Bare/Mines	473.9	0.7	0.28
Crop	13001	20.3	7.68
Deciduous Forest	109259.7	170.7	64.51
Evergreen Forest	1438.2	2.2	0.85
Herbaceous Wetlands	210.8	0.3	0.12
Open Water	1830.5	2.9	1.08
Pasture	1328.8	2.1	0.78
Residential	28122.7	43.9	16.6
Transportation	7879.9	12.3	4.65
Urban/Recreational Grasses	3997.1	6.2	2.36
Woody Wetlands	1825.2	2.9	1.08



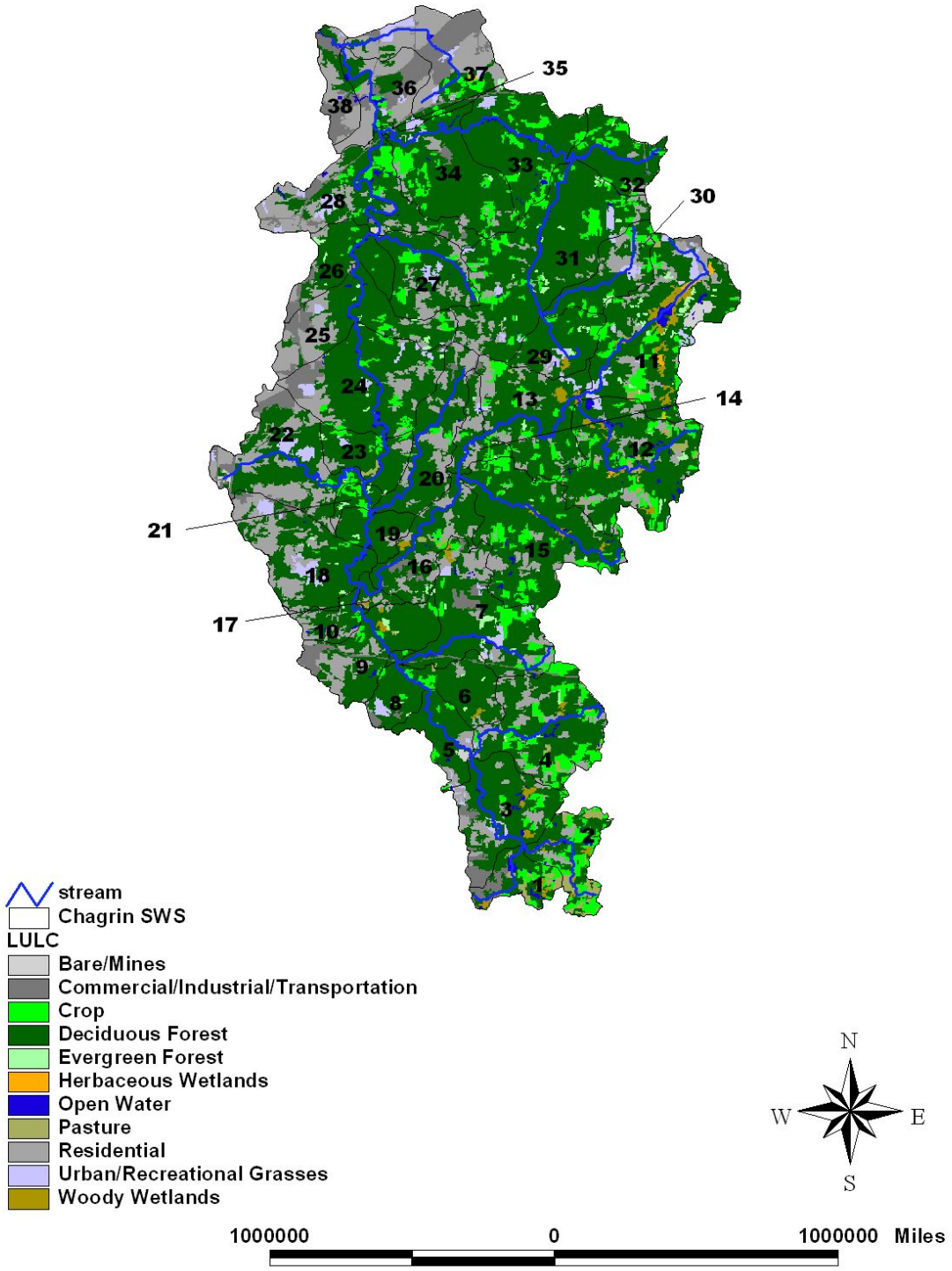


Figure D-4. Chagrin River Watershed Landuses

As part of the hydrology calibration process, it was important to evaluate the effects of impervious and pervious percentage of residential and commercial/industrial/transportation land uses. These percentages

are not explicitly identified in the land use data. LSPC requires that land cover categories be divided into separate pervious and impervious land units for modeling. Separate model algorithms are then used to simulate major hydrologic and pollutant loading processes for both land units – PERLND and IMPLND (respectively). For modeling purposes, it was assumed that 50 percent of residential and 80 percent of commercial/industrial/transportation were covered by impervious surfaces. All other land uses were assumed to be 100 percent pervious surfaces. The original land uses were grouped by similar characteristics to simplify the LSPC model and improve model run time. The LSPC land use groups, associated original land use classes, and percentages of pervious/imperviousness are shown in Table D-4.

Table D-4. LSPC land use groups, associated original land use classes with percentages of pervious/imperviousness

Modeled Land Use	Original Land Use Description	Percent Imperviousness
Forest	Deciduous Forest	0
	Evergreen Forest	0
Pasture	Pasture	0
Crop	Crop	0
Water	Open Water	0
Bare/Mines	Bare/Mines	0
Wetland	Herbaceous Wetlands	0
	Woody Wetlands	0
Urban Pervious	Residential	50
	Transportation	80
	Urban/Recreational Grasses	0
Urban Impervious	Residential	50
	Transportation	80

Watershed Grouping

The LSPC model allows for variation of input parameters by land use. Input parameters can also be varied by watershed groups. A watershed group is defined as a subset of modeling subwatersheds that have similar soils and geology. The basis for watershed groups in LSPC was defined by the available soils data. Watershed groups and their assigned subwatersheds are presented in Table D-5.

Table D-5. Watershed groups and their assigned subwatersheds

Modeling Group	Corresponding Hydrologic Soil Group	Subwatershed Ids
1	A (low runoff potential)	24,25,26,28,30,31,32,33,34,35,36,37,38
2	B (moderate runoff potential)	11,13,27,29
3	C (moderate to high runoff potential)	1,2,3,4,5,6,7,8,9,10,12,14,15,16,17,18,19,20,21,22,23

Hydrologic Calibration

Hydrologic calibration was performed after the initial model setup. Calibration refers to the adjustment or fine-tuning of modeling parameters to reproduce observations. For LSPC, calibration is an iterative procedure of parameter evaluation and refinement as a result of comparing simulated and observed values at a specified location in the watershed. Calibration is required for parameters that cannot be deterministically and uniquely evaluated from topographic, climatic, physical characteristics of the

watershed and compounds of interest. Calibration generally covers more than a few years to capture a variety of climactic conditions. In the Chagrin River watershed, USGS gages 04209000 (Chagrin River near Willoughby) was used to compare simulated modeled flows to observed flows (Figure D-5).

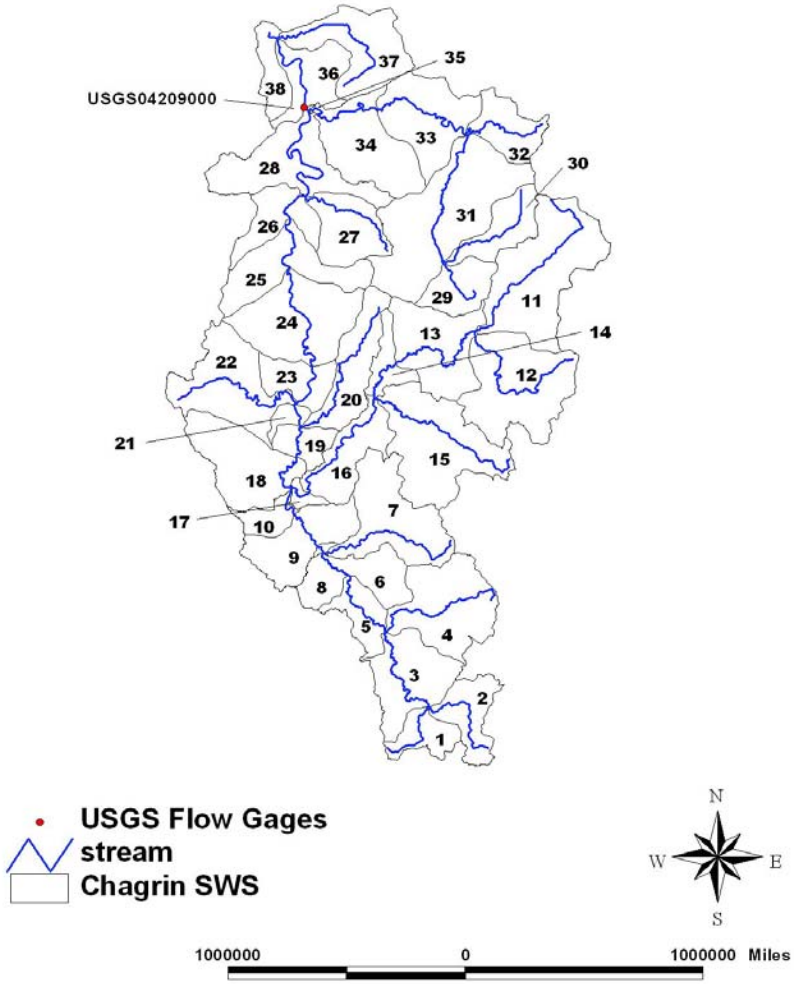


Figure D-5. The location of USGS gage 04209000.

The hydrologic calibration process involved a comparison of observed data to modeled in-stream flow and an adjustment of key parameters. Modeling parameters were varied within generally accepted bounds and in accordance with observed temporal trends and soil and land cover characteristics. An attempt was made to remain within the guidelines for parameter values set out in BASINS Technical Note 6 (USEPA, 2000). The selected calibration time period was from 2001 to 2004 during the period that USGS continuous daily flow data is available at USGS 2040900.

Model parameters were adjusted after model iterations to improve model performance. The parameters that were adjusted include those that account for the partitioning of surface versus subsurface flow, infiltration rate, surface and subsurface storage, evapotranspiration, and surface runoff and snow.

The hydrology calibration results are shown below. Figure D-6 shows daily simulation comparison between model and observed flow. The regression line in Figure D-7 shows how well the model predicts monthly flows against the observed flows. Figure D-8 shows the monthly model results and observed data. Table D-6 shows statistically shows the model results with observed data.

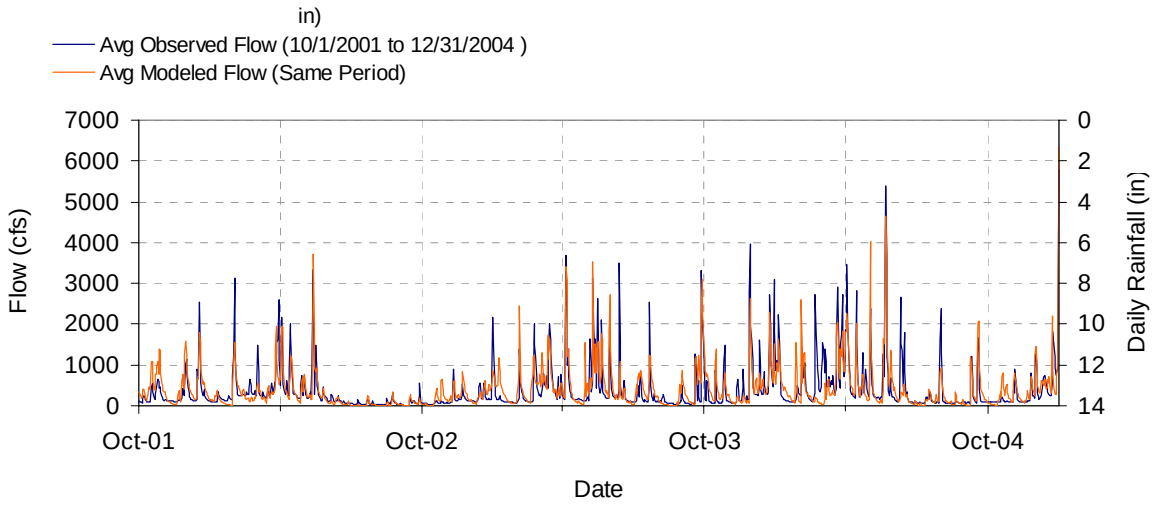


Figure D-6. Daily model and observed flow

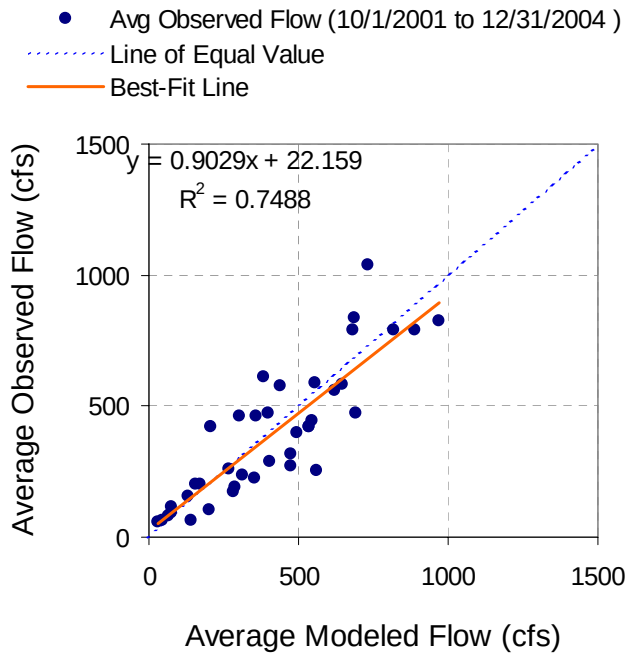


Figure D-7. Model flow simulation results against observed flow

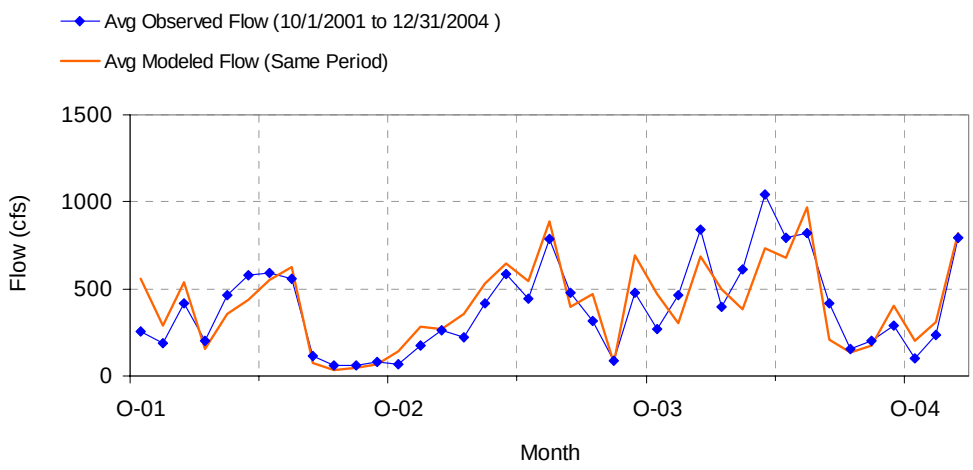


Figure D-8. Monthly model and observed flow data

Table D-6. Statistical comparison between the simulated and the observed flow

LSPC Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM SUBBASIN 35(usgs 4209000) 3.25-Year Analysis Period: 10/1/2001 - 12/31/2004 Flow volumes are normalized, with total observed as 100		USGS 4209000	
Total Simulated In-stream Flow:	**104.67**	Total Observed In-stream Flow:	**100.00**
Total of simulated highest 10% flows:	**42.97**	Total of Observed highest 10% flows:	**48.04**
Total of Simulated lowest 50% flows:	**12.84**	Total of Observed Lowest 50% flows:	**12.05**
Simulated Summer Flow Volume (months 7-9):	**13.68**	Observed Summer Flow Volume (7-9):	**11.34**
Simulated Fall Flow Volume (months 10-12):	**32.16**	Observed Fall Flow Volume (10-12):	**26.79**
Simulated Winter Flow Volume (months 1-3):	**26.51**	Observed Winter Flow Volume (1-3):	**29.20**
Simulated Spring Flow Volume (months 4-6):	**32.32**	Observed Spring Flow Volume (4-6):	**32.67**
Total Simulated Storm Volume:	**21.92**	Total Observed Storm Volume:	**26.37**
Simulated Summer Storm Volume (7-9):	**2.83**	Observed Summer Storm Volume (7-9):	**3.53**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	4.67	10	
Error in 50% lowest flows:	6.60	10	
Error in 10% highest flows:	-10.56	15	
Seasonal volume error - Summer:	20.58	30	
Seasonal volume error - Fall:	20.05	30	
Seasonal volume error - Winter:	-9.20	30	
Seasonal volume error - Spring:	-1.08	30	
Error in storm volumes:	-16.89	20	
Error in summer storm volumes:	-19.80	50	

BMP Set up

Stormwater BMPs for both peak discharge control and infiltration of stormwater from impervious surfaces were assessed using the LSPC model. On the ground, these practices will include many individual infiltration basins and detention basins. However, it is not feasible to simulate these engineered structures individually within a large-scale watershed model. Therefore, methods were developed to represent the performance of these practices on a per-acre basis at the model sub-basin scale.

In the model, both infiltration and retention practices were represented by surrogate stream reaches, defined on a per-acre basis. Acreage served in each model subbasin was determined by an analysis of land use and it was assumed that infiltration and retention basins will primarily receive flow from impervious surface areas. Infiltration BMPs were only used for subwaterhseds that have hydrologic group A and B soil types whereas detention BMPs were used in subwatersheds with hydrologic group C soil types. This selection was based on the premise that A and B soil types should have more water storage capacity for the appropriate use of infiltration techniques.

Infiltration

Hydrologically, infiltration BMPs result in movement of surface runoff (primarily derived from impervious surfaces) into the soil layers, from which it may evapotranspirate or percolate to active ground water. Simulating the storm peak response is straightforward, only requiring the abstraction of the appropriate amount of water. However, representing these requirements in a continuous simulation model requires considerably more thought, as the infiltrated water will serve to replenish groundwater levels and maintain higher base flows during dry periods.

The approach selected for implementation simulates the infiltration basin on a per acre basis, with one outlet going to the stream reach and a second outlet used as a source of water to subsurface layers. The infiltrated water is routed by assigning it as active groundwater lateral input (AGWLI) on an appropriate pervious land segment. Assignment to AGWLI is optimal because the active ground water storage (AGWS) in LSPC does not effect the infiltration of water or movement of water among stores in the unsaturated soil layers. Instead, the infiltrated water will reappear as baseflow. The simulation then results in clipping of flow peaks (particularly peaks for small events in which most of the direct runoff derives from impervious surfaces) and lengthening of the hydrograph tails.

Detention

For the cases where infiltration BMPs are not appropriate, detention-type BMPs were simulated. As with infiltration, the operation of a detention pond was approximated on a per-acre basis. Only runoff from impervious surfaces is routed through the pond, as this is the dominant source of peak flow.

While there are procedures to develop a rigorous hydraulic design, this is not necessary or appropriate within a watershed-scale model that represents detention ponds on an aggregated, per-acre basis. Surface area of the permanent pool was assumed to be around 1 percent of the total land area for residential and 2 percent for commercial development. This can be approximated as about 0.02 acres of pond surface per acre of impervious surface served by ponds. The permanent pool was assumed to have an average depth of 3 feet (plus 2 feet for sediment storage), resulting in water storage of 0.06 AF/acre-impervious. The spillway of the pond was located at the volume associated with the 10-yr storm, and flow volume between the spillway and the Extended Detention pool is assumed to be released over a 2.5 day period.

References

Dave Rosgen, 1996. *Applied River Morphology*.

EPA BASINS Technical Note 6; Estimating Hydrology and Hydraulic Parameters for HSPF. 2000, office of water, Unites States Environmental Protection Agency

David B. Baker, R. Peter Richards, Timothy T. Loftus, and Jack W. Kramer, 2004. *A New Flashiness Index: Characteristics And Applications To Midwestern Rivers And Streams*. Journal of the American Water Resources Association. April, 2004