

Chapter 20

GIS in Stormwater Management

Uzair M. Shamsi and Bruce A. Fletcher

Chester Environmental
P.O. Box 15851,
Pittsburgh, Pennsylvania, 15244

This chapter presents a case study illustrating an application of Geographic Information System (GIS) in developing watershed rainfall-runoff simulation models to be used for state-wide watershed stormwater management plans mandated by the Stormwater Management Act of Pennsylvania. GIS is used to estimate input parameters for Penn State Runoff Model (PSRM), a watershed rainfall-runoff simulation model. The model is used to simulate runoff hydrographs for various durations and frequencies. Hydrographs are manipulated to create *peak flow presentation* and *release rate* tables which are used to develop a watershed stormwater management plan. The use of GIS eliminates the subjectivity of the modeler in manually estimating certain model input parameters. The application is illustrated for the Bull Run watershed, an 8.4 square miles rural catchment, located in Union County, Pennsylvania.

20.1 Introduction

The objective of stormwater management is to prevent or mitigate the adverse impacts related to conveyance of excessive rates and volumes

Shamsi, U.M. and B.A. Fletcher. 1995. "GIS in Stormwater Management." *Journal of Water Management Modeling* R183-20. doi: 10.14796/JWMM.R183-20.
© CHI 1995 www.chijournal.org ISSN: 2292-6062 (Formerly in Modern Methods for Modeling the Management of Stormwater Impacts. ISBN: 0-9697422-4-X)

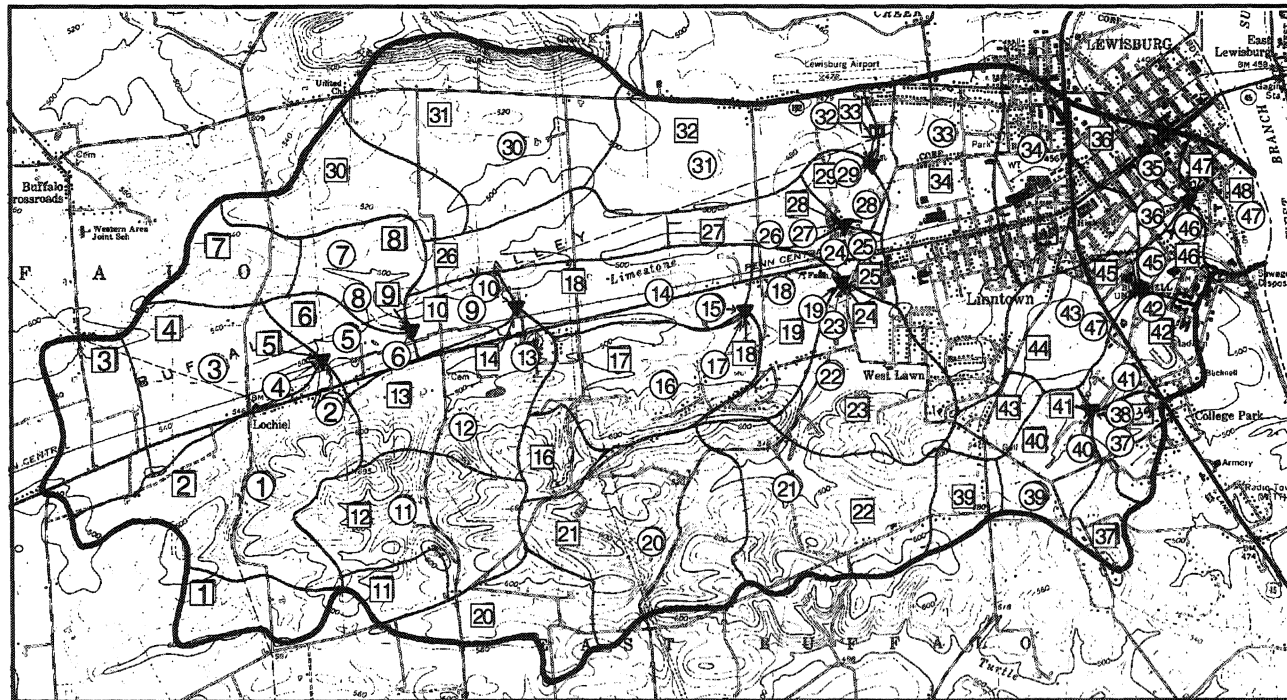


Figure 20.1 General watershed map.

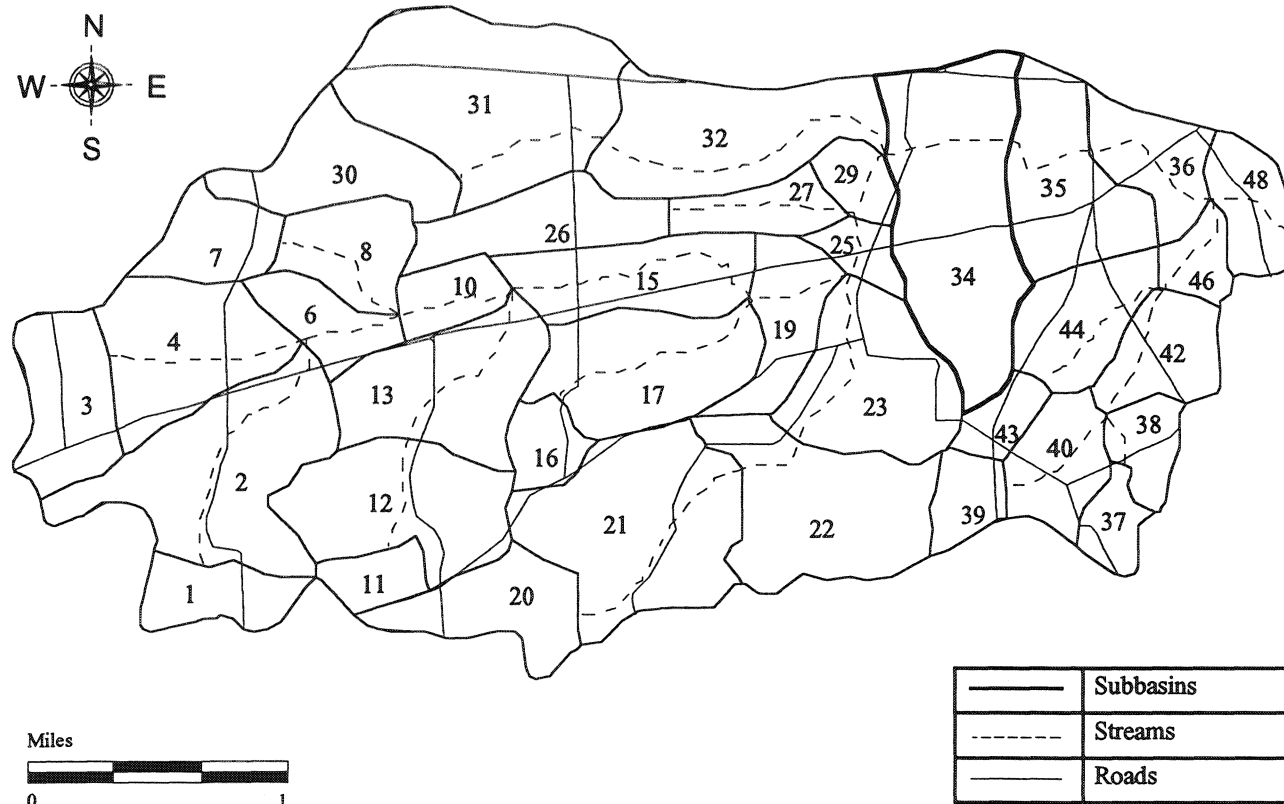


Figure 20.2 Subbasins, streams, and roads.

collected by field measurements. Initial estimates of hydraulic parameters are generally defaulted to the literature values and fine-tuned during the calibration. Manual estimation of physical parameters for large watersheds is not only tedious but also highly subjective. For instance, consider subbasin 34 in Figure 20.1: a 352-acre subbasin apparently covered by residential, commercial, and perhaps industrial land-use classes. How accurately can one “eye-ball” the percent imperviousness for this subbasin, or “guesstimate” an SCS curve number, without actually measuring the land-use classes and corresponding soil types? Is planimetering the land-use classes feasible or is a field survey warranted? We have found that a watershed GIS offers a bird’s-eye view to instantly estimate the needed physical model parameters without any subjectivity. The GIS approach employed in this project to capture PSRM physical input parameters for model subbasins and reaches is described below.

20.2 Watershed GIS

Watershed GIS was used to estimate the physical parameters of PSRM. There are two major formats for digital storage and manipulation of spatial information: *vector* and *raster*. The vector format is a topologically constructed set of points, nodes, lines and polygons which defines locations, boundaries, and areas. A raster format is a regular grid of uniform size cells called *pixels* each with an associated data value. The vector-based GIS analysis was performed by using PC ARC/INFO software developed by the ESRI (Environmental Systems Research Institute, Redlands, California). ARC/INFO offers versatility, efficiency in assisting digitization and attribute entry, automatic editing and database creation, interactive nature, and easy spatial data display and management. The raster-based GIS analysis was conducted by using ERDAS, an image processing program from ERDAS Inc. (Earth Resource Data Analysis System, Atlanta, Georgia).

The primary objective of all the GIS analyses was the derivation of subbasin characteristics. The central database for the storage, manipulation, and display of the collective analytical products was the ARC/INFO polygon attribute file associated with the subbasin information layer. Products of vector and raster overlay analyses were merged into this common database. In turn, ARC/INFO attribute file, compatible with dBASE database handling software, was used to refine and display the pertinent information. All analyses were conducted on IBM/DOS compatible personal computers equipped with VGA graphics capabilities.

20.2.1 Primary Coverages

The following four primary coverages (layers, themes, maps) were created to compute subbasin area, overland flow width, overland flow slope, and centroids; and stream length and slope.

1. Vector coverage for subbasins, streams, and roads was created by digitization of Lewisburg 7.5 minute USGS topographic map (Figure 20.2). Stream length, slope, and cross section dimensions were used to compute stream capacity and travel time
2. 36 soil types were digitized from Union County SCS Soil Survey maps. SCS has assigned hydrologic soil groups A, B, C, or D to each of approximately 16,000 soil types found in the United States. These data were used to merge the 36 digitized soil types into the four hydrologic soil groups and create a vector coverage (Figure 20.3).
3. Vector coverage for land use, consisting of fourteen land use classes, was created by supervised classification of 1990 color infrared 1:40,000 scale NAPP (National Aerial Photography Program) transparencies (Figure 20.4).
4. Raster coverage of subbasin slopes was created from Lewisburg USGS Digital Elevation Model (DEM) (Figure 20.5).

20.2.2 Secondary Coverages

The remaining physical parameters of the model were computed by post-processing the primary layers. SCS has published tables which give average percent imperviousness for different land-uses, and runoff curve numbers for different combinations of land uses and hydrologic soil groups (SCS, 1986). Table 20.1 shows the SCS percent imperviousness and runoff curve number data for the fourteen land use classes of the Bull Run watershed. Figure 20.6 shows how the basic coverages were overlaid to delineate the percent imperviousness and runoff curve number polygons for subbasin 34. Figure 20.6(a) shows an overlay of three basic coverages: subbasins, land use, and hydrologic soil groups.

- Subbasin percent imperviousness was computed by overlaying the basic layers for subbasins and land-use to delineate the percent imperviousness polygons for each subbasin, as shown in Figure 20.6(b). Each polygon had two attributes: subbasin

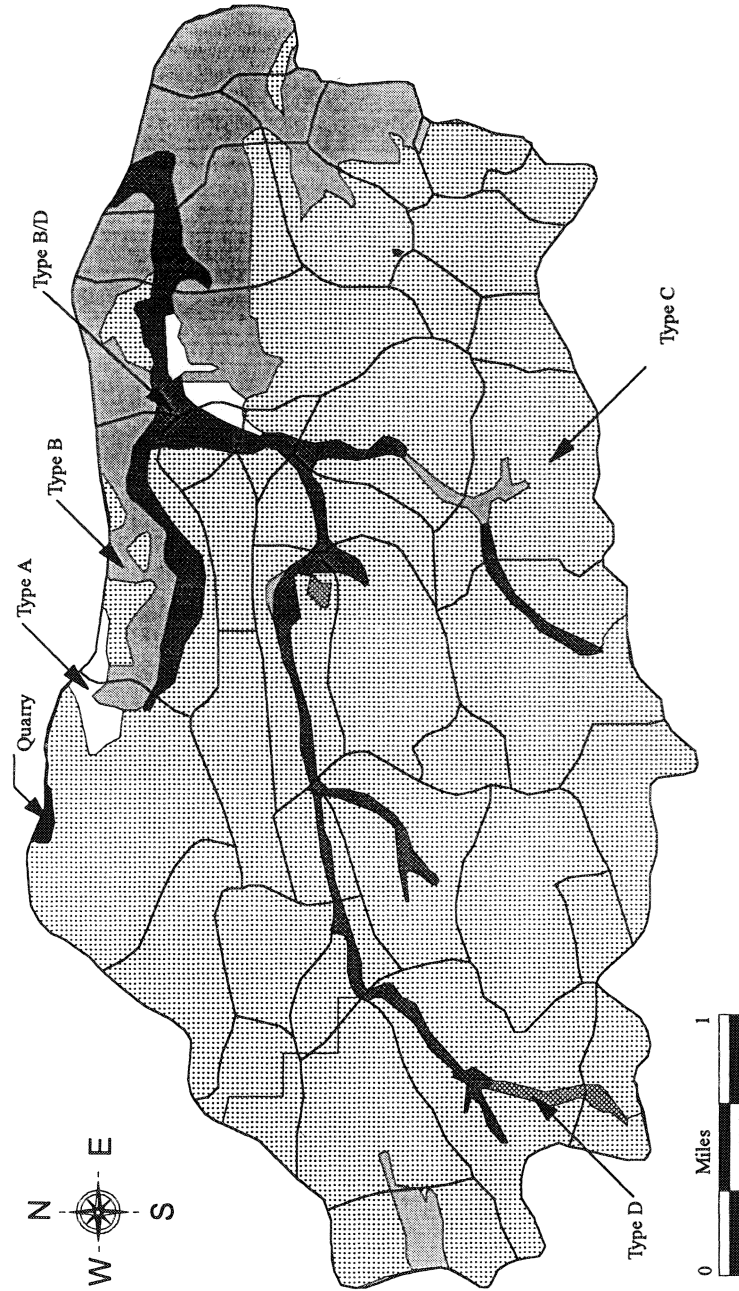


Figure 20.3 Hydrologic soil groups.

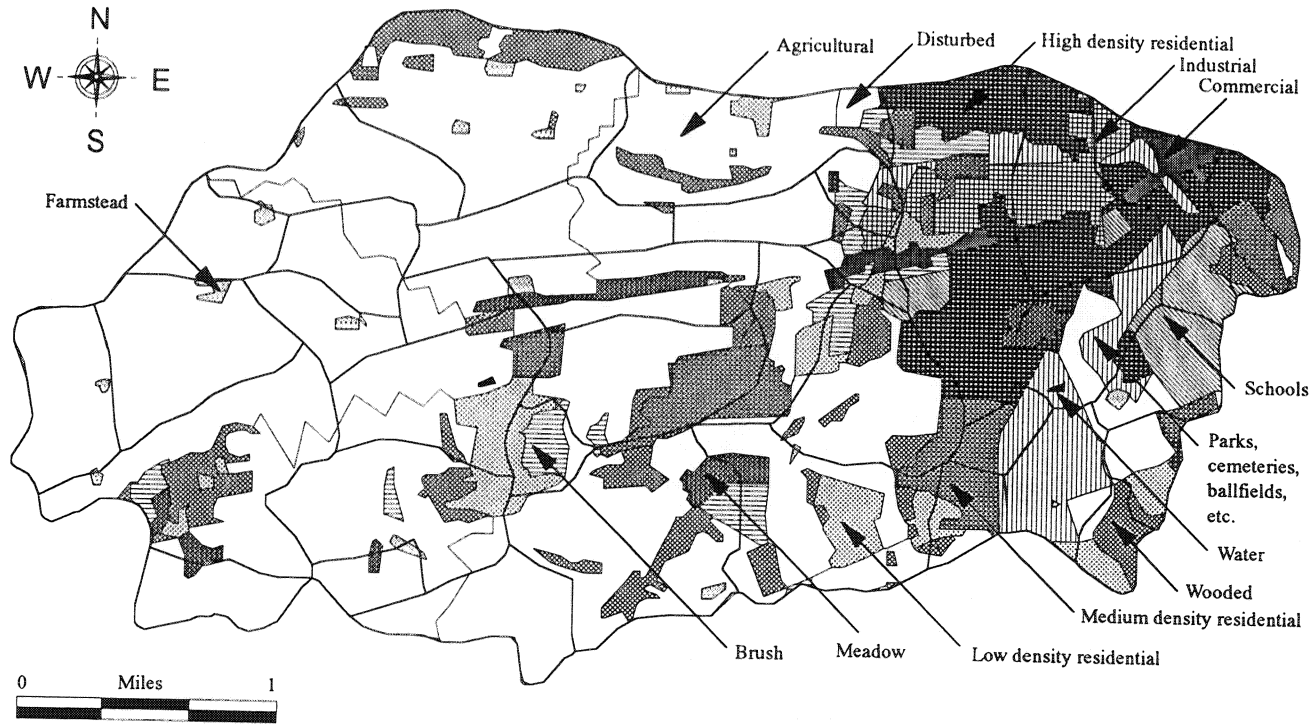


Figure 20.4 Land use.

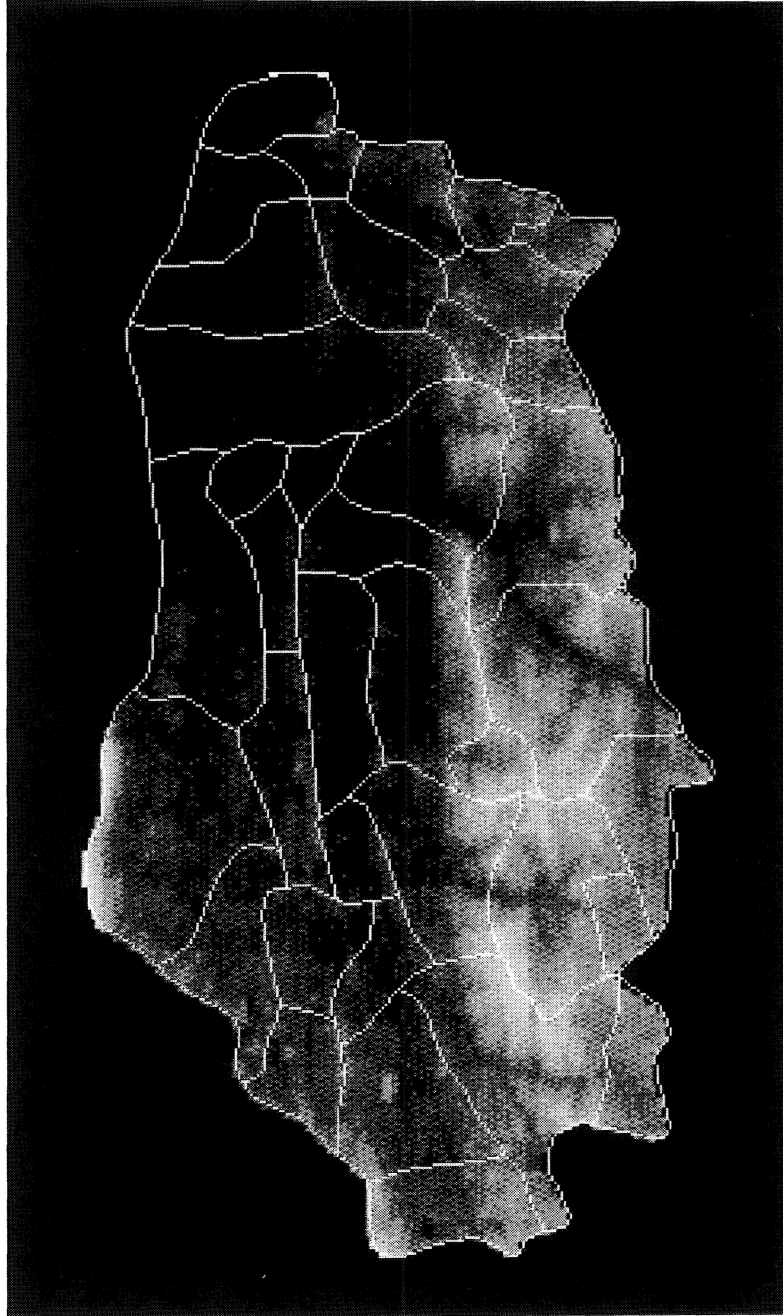


Figure 20.5 Digital elevation model (DEM).

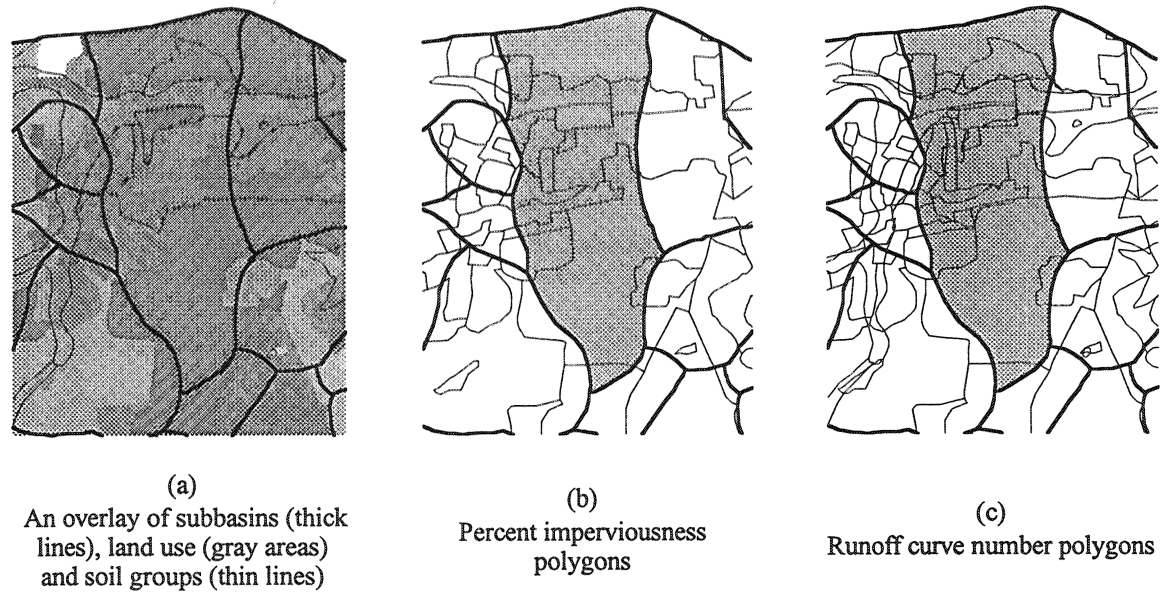


Figure 20.6 Derivation of secondary coverages.

Table 20.1 SCS runoff curve number table.

Watershed Land Use Class	SCS Equivalent Land Use Class	Percent Imperviousnes	Runoff Curve Number for Hydrologic Soil Group			
			A	B	C	D
High density residential	Average lot size 1/8 to 1/4 acres	51	69	80	87	90
Medium density residential	Average lot size 1/3 to 1/2 acres	28	56	71	81	86
Low density residential	Average lot size 1 to 2 acres	16	49	66	78	83
Commercial	Commercial and business	85	89	92	94	95
Industrial	Industrial	72	81	88	91	93
Parks, cemeteries, ballfields, etc.	Open space	0	39	61	74	80
Schools	Average lot size 1/3 to 1/2 acres	28	56	71	81	86
Wooded	Woods (good condition)	0	30	55	70	77
Brush	Brush (good condition)	0	30	48	65	73
Meadow	Meadow	0	30	58	71	78
Agricultural	Row crops, small grain, straight and contoured	0	64	75	83	87
Farmstead	Farmstead	51	59	74	82	86
Disturbed	Newly graded areas	35	77	86	91	94
Water	None	0	100	100	100	100

ID and land use. Table 20.1 was used to assign percent impervious values to these polygons according to their land use. Polygon percent imperviousness values were area weighted to compute the mean percent imperviousness for each subbasin.

- Subbasin runoff curve numbers were estimated by overlaying three basic layers: subbasins, soil types, and land-use to delineate the runoff curve number polygons for each subbasin, as shown in Figure 20.6(c). Each polygon had three attributes: subbasin ID, land use and hydrologic soil group. Table 20.1 was used to assign runoff curve numbers to these polygons according to their land use and hydrologic soil group. Polygon runoff curve number values were area-weighted to compute the mean runoff curve number for each subbasin.

Other data not required by the model itself but useful or essential for the development of a comprehensive stormwater management plan, include administrative boundaries, transportation networks, flood hazard areas, and land development zoning boundaries. These data layers were included to serve as information layers in an integrated GIS suitable for a variety of planning and siting purposes in addition to the basic requirement for the rainfall-runoff modeling.

An example of GIS's versatility: while the visual inspection of USGS topographic map could not reveal more than three land use classes for subbasin 34, the GIS based land use map of Figure 20.4 identified nine. They were: high-density residential 54.9%, medium-density residential 7.7%, low-density residential 3.1%, commercial 4.2%, industrial 12.1%, parks 4.3%, schools 4.0%, woods 2.2% and brush 7.4%. Such a microscopic classification makes computation of subbasin percent imperviousness and runoff curve number more accurate.

20.3 Results and Discussion

The model was set up by entering the GIS based subbasin and reach physical parameters in ASCII database files and operational parameters in the traditional PSM ASCII input file. This approach eliminates the need to edit the input file if physical parameters are changed in the future.

20.3.1 Model Calibration

Data assembly was followed by model calibration. The objective of calibration was to change some model parameters within acceptable limits established in literature until an agreement between some observed and modeled hydrographs was obtained. The watershed GIS provided an opportunity to, as closely and accurately as possible and practical, quantify the reach and subbasin physical characteristics. GIS-based physical input parameters were, therefore, not intended to be altered during the calibration process. Rather, to the extent possible, calibration was intended to be applied to the adjustment of the most-difficult-to-define *hydraulic* parameters and the refinement of standard default coefficients included in the model.

Calibration process requires continuous, preferably hourly, rainfall and stream flow data. Rainfall input data were taken from the Selinsgrove raingage, the nearest recording type raingage operated by the National Oceanic and Atmospheric Administration (NOAA) and located approximately thirteen miles south of the watershed. The advantage of using a NOAA recording raingage is the availability of historical hourly precipitation data in ASCII format on personal computer diskettes from the National Climatic Data Center (NCDC). An in-house program RAP (Rainfall Analysis Program) was used to convert 41 years (1949-90) of raw NCDC data into meaningful hourly rainfall hyetographs (Shamsi, 1989). The only available continuous stream flow data consisted of three observed hydrographs collected by the Department of Civil Engineering, Bucknell University, at a point approximately one mile upstream of the watershed outlet.

Fortunately, the model was calibrated well to one of the three observed hydrographs. As endeavored, the calibration did not require modification of any physical parameters. The adjusted hydraulic parameters remained within the recommended ranges (Aron, 1990), as given below:

- Manning's "n" on pervious surfaces = 0.20
- Manning's "n" on impervious surfaces = 0.02
- Depression storage on pervious surfaces = 0.00 inches
- Depression storage on impervious surfaces = 0.06 inches
- SCS initial abstraction factor = 0.10

Figure 20.7 compares an observed and modeled hydrograph. The two hydrograph shapes are reasonably similar and difference between

modeled and observed peak flow and volume is 6% and 11%, respectively, indicating a satisfactory calibration. The peak time for the two hydrographs did not match initially, and the modeled hydrograph was manually shifted to the right. This step was justified due to the use of external rainfall data and associated possibility of later arrival of the storm in the watershed. Furthermore, for design hydrographs, quantity of the peak runoff and the time to peak, inherent in the shape of a hydrograph, are more important than the absolute clock time of the peak runoff.

The calibrated model was run to develop 3, 6, 12, and 24-hour runoff hydrographs for return periods of 2, 5, 10, 25, 50, and 100 years corresponding to SCS Type II rainfall distribution (SCS, 1986). The modeled peak flows are shown in Figure 20.8. The modeled peak flows compared well to available Federal Emergency Management Agency (FEMA) peak flow estimates based on the regional flood-frequency method developed by U.S. Army Corps of Engineers (FEMA, 1984).

Our experience with similar projects indicates that the GIS-based models require considerably less calibration time. This observation implies that GIS-based model parameters are more accurate than those computed from traditional manual measurement techniques.

20.3.2 Model Application to Stormwater Management

A runoff hydrograph at a given point of a drainage system is the sum of individual flow contributions from all the subbasins draining to that point. PSRM displays this information in a *Peak Flow Presentation Table* (PFPT). The main function of PFPT is to display the individual runoff contributions from upstream subbasins to any point of interest, including the timing of such peak flow contributions. *Release rate* for a subbasin is defined as the ratio of “subbasin pre-development peak flow contribution to watershed peak flow” to “subbasin peak flow.” Tables 20.2 and 20.3 show 100-year, 24-hour PFPT and release rates table, respectively. For convenient implementation, modeled (raw) release rates were post-processed and aggregated into twelve bands of *assigned* release rates. The storm water management plan will be implemented in the watershed by enforcing the release-rate-based, allowable, post-development peak flows which are calculated as “the pre-development subbasin peak flow” multiplied by subbasin assigned release rate.

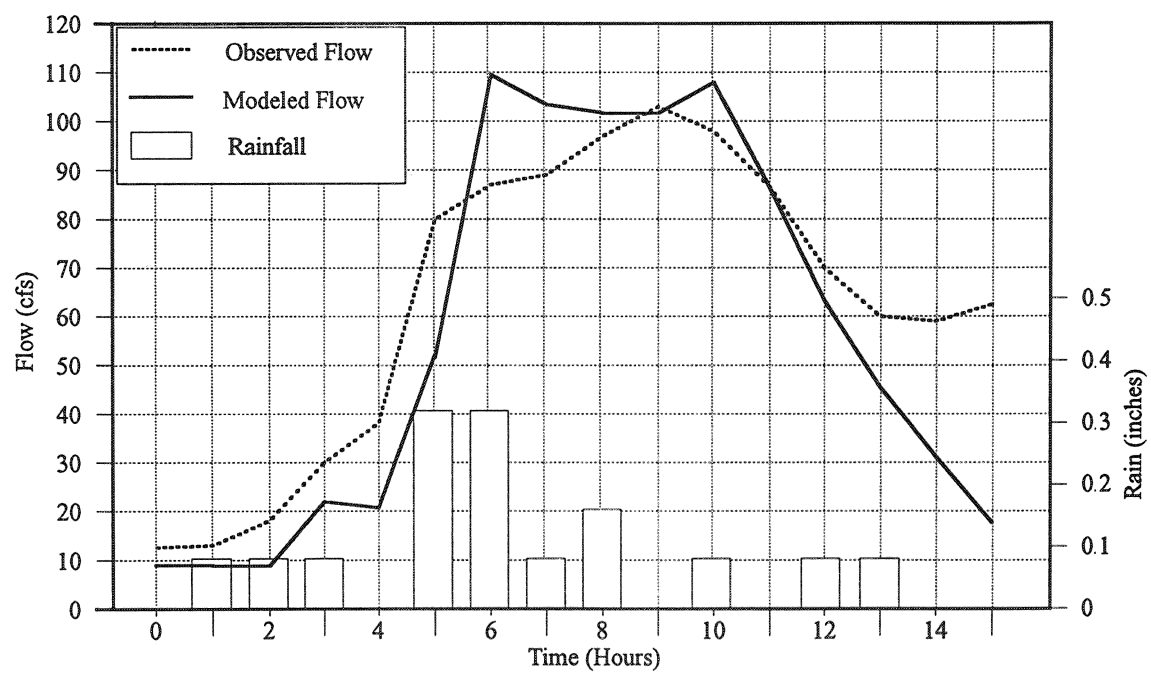


Figure 20.7 Observed versus modeled hydrograph.

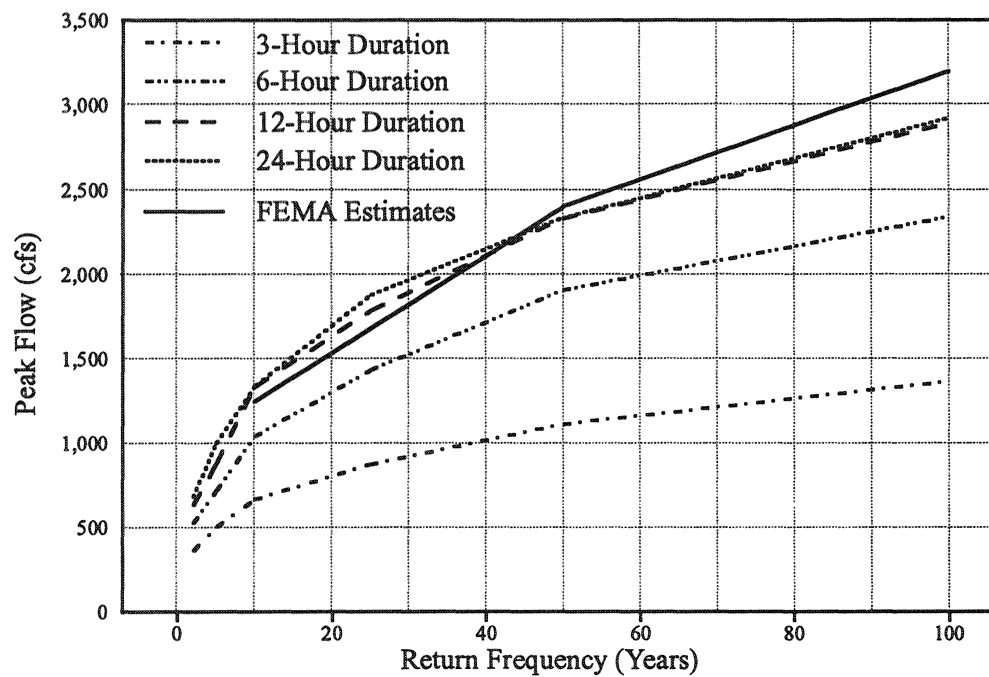


Figure 20.8 Comparison of discharge/frequency estimates.

Table 20.2 Peak flow presentation table for outlet No. 48.

Subbasin		Flows (cfs) arriving at specified time (minutes)														
ID	TT	780	840	900	960	1020	1080	1140	1200	1260	1320	1380	1440	1500	1560	1620
1	494.5	0.6	0.8	1.2	1.8	2.6	3.0	4.3	10.0	135.4	27.2	13.6	10.5	8.6	7.6	6.8
2	433.2	4.1	5.6	8.9	13.2	19.5	23.6	39.1	280.3	151.8	49.8	30.4	24.6	22.1	20.1	17.7
3	477.6	0.2	0.3	0.7	1.5	2.4	3.1	5.5	16.8	205.0	36.0	18.7	14.3	11.9	10.5	9.3
4	433.2	5.0	6.1	8.5	11.7	16.2	19.1	30.3	198.5	105.2	34.8	21.6	17.6	15.9	14.5	12.9
6	408.7	3.3	4.0	5.1	7.2	9.1	11.9	20.3	153.3	20.7	10.4	7.1	6.0	5.7	5.1	4.6
7	444.6	2.4	2.9	3.9	5.3	7.1	8.4	13.7	36.6	41.6	15.2	9.7	7.9	7.1	6.5	5.8
8	408.7	3.9	4.8	6.4	9.2	11.8	15.7	27.0	212.6	30.0	14.8	10.0	8.5	7.9	7.2	6.4
*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
30	374.6	6.4	8.0	11.4	22.3	20.9	33.3	246.4	40.1	24.6	17.5	13.8	12.1	11.1	9.9	9.0
31	310.3	6.6	10.1	15.4	42.5	40.6	415.3	241.2	101.9	65.9	45.9	35.4	30.6	26.8	23.5	20.2
32	176.5	27.3	42.3	129.1	496.4	132.9	66.0	44.1	32.1	24.5	18.6	16.7	14.6	13.1	9.5	3.5
34	129.4	66.2	88.0	534.9	277.7	149.9	100.9	75.4	57.9	45.7	37.5	32.5	28.3	25.7	17.6	11.5
35	93.2	63.9	263.3	271.5	90.5	53.7	38.2	30.0	24.0	19.8	17.5	15.5	13.8	12.2	6.3	3.7
36	41.5	120.0	180.0	39.1	22.7	16.7	13.4	11.2	9.4	8.5	7.9	7.0	6.5	3.7	1.3	0.5
37	116.2	2.7	3.8	13.5	45.0	10.8	6.6	4.9	3.9	3.0	2.5	2.3	2.0	1.7	1.2	0.2
38	100.6	6.8	7.9	57.3	43.3	18.7	11.9	8.9	7.0	5.6	4.8	4.3	3.7	3.4	2.3	1.2
39	128.5	5.5	6.3	11.6	76.3	20.9	11.8	8.6	6.8	5.4	4.5	4.1	3.7	3.3	2.8	1.2
40	100.6	8.2	10.1	100.8	63.4	24.0	15.2	11.3	8.8	6.9	5.9	5.3	4.5	4.1	2.3	0.6
42	67.5	19.7	109.4	114.7	37.2	20.6	14.0	11.0	8.6	7.1	6.4	5.6	4.9	4.1	1.5	0.5
43	103.9	7.3	11.8	59.4	20.4	10.1	6.8	5.3	4.3	3.5	3.1	2.8	2.5	2.2	1.3	0.3
44	67.5	27.6	153.8	156.3	45.0	24.5	17.0	13.5	10.7	8.9	8.2	7.2	6.3	5.3	1.7	0.4
46	41.5	45.4	72.4	14.4	8.0	5.7	4.4	3.5	2.7	2.4	2.2	1.8	1.6	0.7	0.0	0.0
48	0.0	171.6	38.3	19.5	13.0	9.6	7.5	5.8	4.8	4.5	3.9	3.3	3.1	0.5	0.1	0.0
Total Q		873.3	1548.9	2131.1	2480.4	2621.6	2839.3	2793.8	1730.2	1161.3	744.3	571.5	413.9	342.4	280.9	210.2

Notes: TT = Travel time in minutes, Q = outflow in cfs, * = Data for subbasins 9 to 29 truncated to save space

Table 20.3 Release rate table.

At Subbasin	From Subbasin																							
	1	2	3	4	6	7	8	*	30	31	32	34	35	36	37	38	39	40	42	43	44	46	48	
1	100	0	0	0	0	0	0	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2	11	100	0	0	0	0	0	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	0	0	100	0	0	0	0	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
4	0	0	8	100	0	0	0	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
6	9	81	9	81	22	0	0	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
7	0	0	0	0	0	100	0	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
8	0	0	0	0	0	12	100	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
30	0	0	0	0	0	0	0	*	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
31	0	0	0	0	0	0	0	*	11	100	0	0	0	0	0	0	0	0	0	0	0	0	0	
32	0	0	0	0	0	0	0	*	10	79	13	0	0	0	0	0	0	0	0	0	0	0	0	
34	3	7	3	8	13	8	12	*	42	39	8	12	0	0	0	0	0	0	0	0	0	0	0	
35	4	9	3	10	53	11	53	*	22	30	7	11	6	0	0	0	0	0	0	0	0	0	0	
36	2	3	1	4	5	4	5	*	11	57	16	19	10	6	0	0	0	0	0	0	0	0	0	
37	0	0	0	0	0	0	0	*	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	
38	0	0	0	0	0	0	0	*	0	0	0	0	0	0	59	100	0	0	0	0	0	0	0	
39	0	0	0	0	0	0	0	*	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	
40	0	0	0	0	0	0	0	*	0	0	0	0	0	0	0	0	30	100	0	0	0	0	0	
42	0	0	0	0	0	0	0	*	0	0	0	0	0	0	65	96	36	95	29	0	0	0	0	
43	0	0	0	0	0	0	0	*	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	
44	0	0	0	0	0	0	0	*	0	0	0	0	0	0	0	0	0	0	0	13	100	0	0	
46	0	0	0	0	0	0	0	*	0	0	0	0	0	0	9	29	10	27	85	31	84	17	0	
48	2	4	1	4	7	4	6	*	10	84	13	17	9	5	7	12	11	8	8	7	7	4	4	
Minimu	2	3	1	4	5	4	5	*	10	30	7	11	6	5	7	11	9	8	8	7	7	4	4	

*: Data for subbasins 9 to 29 truncated to save space

20.4 Conclusions

A watershed GIS consisting of subbasins, streams, soils, and land use coverages can be effectively utilized to estimate physical input parameters for a rainfall-runoff simulation model. In PSRM such parameters are subbasin area and centroid coordinates, overland flow width and slope, percent imperviousness, SCS curve number, and stream capacity and travel time. Manual estimation of certain input parameters for a watershed rainfall-runoff model, such as subbasin percent imperviousness and SCS runoff curve numbers can be both subjective and hectic, especially for large watersheds. The GIS approach presented in this chapter eliminates both these drawbacks and assists in expeditious model assembly and calibration.

References

- Aron, G. 1987, 1990. Penn State Runoff Model for IBM-PC, User's Manual, Department of Civil Engineering, Pennsylvania State University, University Park, Pennsylvania, 25pp.
- Chester Environmental. 1992. Draft Act 167 Bull Run Watershed Stormwater Management Plan, P.O. Box 15851, Pittsburgh, Pennsylvania, 130pp .
- Commonwealth of Pennsylvania. 1985. Storm Water Management Guidelines and Model Ordinances, Department of Environmental Resources, Harrisburg, Pennsylvania, 35pp.
- Federal Emergency Management Agency. 1984. Flood Insurance Study, Township of East Buffalo, Pennsylvania, Flood Map Distribution Center, Baltimore, Maryland, 28pp.
- Shamsi, U.M. 1988. Chester's Penn State Runoff Model (CPSRM), Users' Manual, Chester Environmental, Pittsburgh, Pennsylvania, 20pp.
- Soil Conservation Service. 1986. Urban Hydrology for Small Watersheds, Technical Release 55, U.S. Department of Agriculture, Washington, D.C., pp:2.5-2.8.