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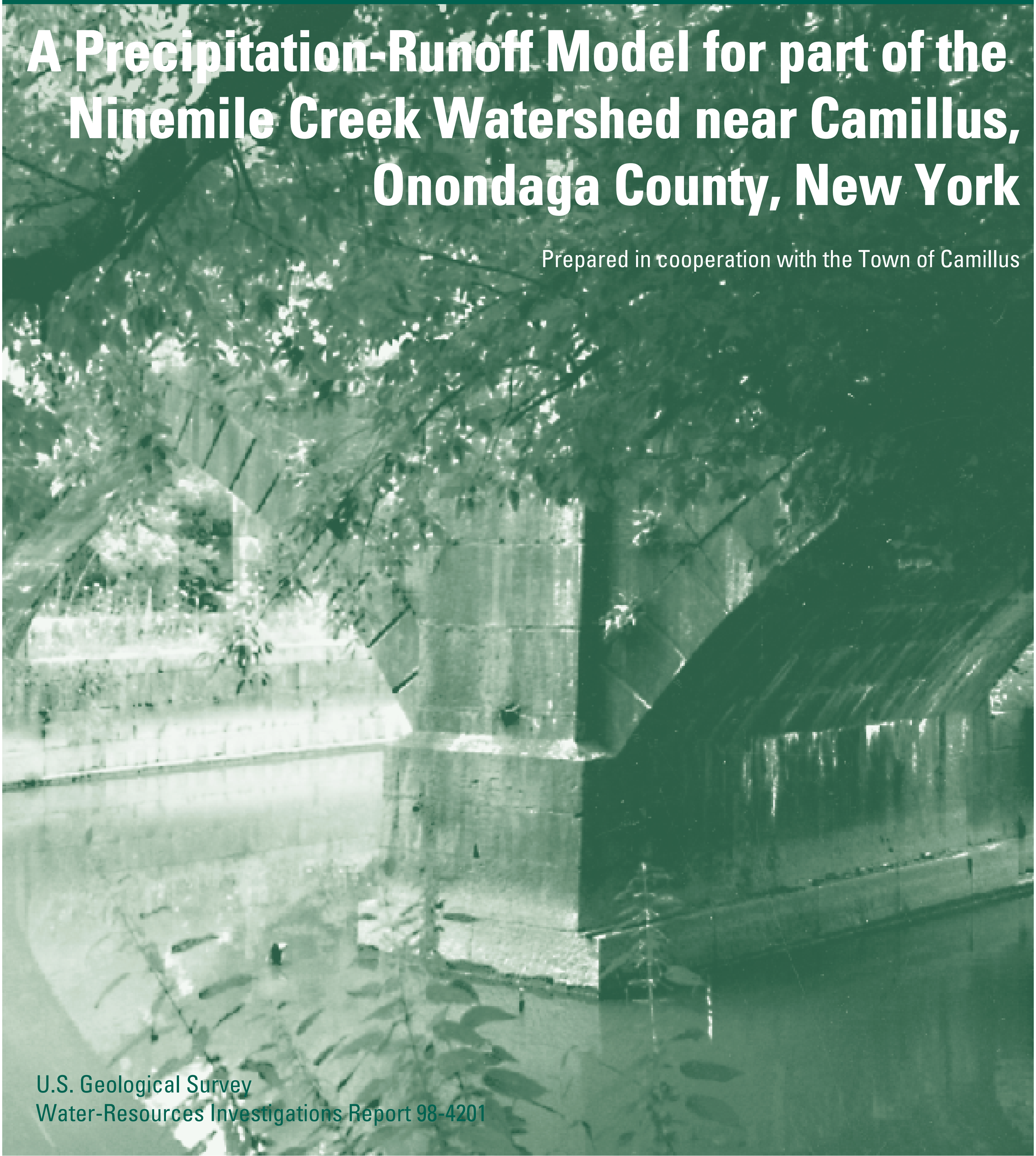
A Precipitation-Runoff Model for part of the Ninemile Creek Watershed near Camillus, Onondaga County, New York

Prepared in cooperation with the Town of Camillus



U.S. Geological Survey
Water-Resources Investigations Report 98-4201

A Precipitation-Runoff Model for part of the Ninemile Creek Watershed near Camillus, Onondaga County, New York

BY PHILLIP J. ZARRIELLO

U.S. GEOLOGICAL SURVEY

WATER-RESOURCES INVESTIGATIONS REPORT 98-4201

Prepared in cooperation with the Town of Camillus

Ithaca, New York
1999

Cover Photo: View of Ninemile Creek at the Erie Canal aqueduct crossing. The aqueduct was completed in 1841 as part of the first enlargement of the Canal and carried canal traffic from 1845 until the 1890's, when it was abandoned for the present day New York State Barge Canal. The aqueduct is 140 feet long and rests on its original wooden pillars.

Photo courtesy of William M.Morse

Historical notes from David Beebe and Donald Postle

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	4,047	square meter
acre	0.4047	hectare
square mile (mi^2)	259.0	hectare
	Volume	
cubic foot (ft^3)	0.02832	cubic meter
acre-foot (acre-ft)	1,233	cubic meter
	Flow rate	
acre-foot per day (acre-ft/d)	0.01427	cubic meter per second
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
inch per hour (in/h)	0.0254	meter per hour

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32) / 1.8$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

A Precipitation-Runoff Model for part of the Ninemile Creek Watershed near Camillus, Onondaga County, New York

by Phillip J. Zarriello

Abstract

A precipitation-runoff model, HSPF (Hydrologic Simulation Program Fortran), of a 41.7 square mile part of the Ninemile Creek watershed near Camillus, in central New York, was developed and calibrated to predict the hydrological effects of future suburban development on streamflow, and the effects of stormwater detention on flooding of Ninemile Creek at Camillus. Development was represented in the model in two ways: (1) as a pervious area (open and residential land) that simulates the hydrologic response from mixed pervious and impervious areas that drain to pervious areas, or (2) as an impervious area that drains to channels. Simulations indicate that peak discharges for 30 non-winter storms in 1995-96 would increase by an average of 10 to 37 percent in response to a 10- to 100-percent buildup of developable land represented as open/residential land and by 40 to 68 percent in response to 10 to 100 percent buildup of developable area represented as impervious area. A 10 to 100 percent buildup of developable area represents an impervious area of about 1 to 7 percent of the watershed. A log Pearson Type-III analysis of peak annual discharge for October 1989 through September 1996 for simulations with full development represented as impervious area indicates that stormflows that formerly occurred once every 2 years on average will occur once every 1.5 years, and stormflows that formerly occurred once every 5 years will occur once every 3.3 years.

Simulations of a hypothetical 147-acre residential development in the lower part of the watershed with and without stormwater detention indicate that detention basins could cause either increase or decrease downstream flooding of Ninemile Creek at Camillus, depending on the basin's available storage relative to its inflows and, hence, the timing of its peak outflow in relation to that of the peak discharge in Ninemile Creek; and the degree of flow retention by wetlands and other channel storage that affect the timing of peak discharges. Design and management of detention basins in the watershed will require analysis of each basin's hydraulic characteristics and location relative to Ninemile Creek to predict their effect on downstream flooding. The runoff model described herein can be used to evaluate alternative detention basin designs and locations.

INTRODUCTION

Increases in the magnitude and frequency of storm-related flooding as a consequence of urbanization has been well documented (Leopold, 1968; Sauer and others, 1983). New York State guidelines for mitigating the increases in runoff volume and decreases in watershed response time are designed to limit peak discharges to their predevelopment conditions and to minimize the effects of urban runoff on stream-water quality (New York State Department of Environmental Conservation, 1992). One of the most practical Best Management Practices (BMP's) for controlling storm runoff from urban areas and it's associated nonpoint-source pollutants is to provide temporary storage of stormwater in detention basins. Under certain conditions, however, the delay in peak discharge from a detention basin can coincide with the peak discharge from other areas and, thereby, increase downstream flooding (Hawley and others, 1981). Precipitation-runoff models can help those responsible for managing storm runoff by simulating the effects of the timing and magnitude of a basin's outflow relative to that of the receiving stream for a range of storm conditions. This information can indicate the likelihood that a detention basin will exacerbate, rather than mitigate, downstream flooding and enable an evaluation of alternative basin designs.

The Town of Camillus, a suburb of Syracuse, N.Y. (fig. 1), like many other upstate suburban communities, has undergone recent growth and is expecting continued residential and commercial development. The town is concerned over the likelihood that (1) increased urbanization could increase flooding of Ninemile Creek in parts of Camillus by decreasing the amount of pervious area available for infiltration, and (2) the use of stormwater-detention basins to mitigate flooding could in fact worsen flooding in Ninemile Creek by creating a condition in which the peak outflow from the basin coincides with the peak discharge in Ninemile Creek, thereby producing a larger peak discharge in Ninemile Creek than would occur otherwise.

In 1995, the U.S. Geological Survey, in cooperation with the Town of Camillus, began a 3-year study to examine the effects of urbanization and the use of detention basins in developing areas. A precipitation-runoff model was developed for a 41.7 mi^2 part of the Ninemile Creek watershed from the Marietta stream gage to slightly below the Camillus stream gage (fig. 1). The model allows assessment of the timing and magnitude of peak discharges in Ninemile Creek at Camillus that would result from these two conditions.

Purpose and Scope

This report describes the HSPF (Hydrologic Simulation Program- Fortran) runoff model development and calibration for a 41.7-mi^2 part of the Ninemile Creek watershed for water years 1989-96[a]. The report also presents two applications of the model: (1) the changes in Ninemile Creek flow that would result from incremental increases in development as (a) open and residential land, and (b) impervious land, and (2) the effects of a hypothetical 147-acre moderate-density residential development, with and without stormwater detention, on peak discharges at the Village of Camillus.

Acknowledgments

Thanks are extended to the Town of Camillus Engineer, William Morse, W-M Engineers, who provided detailed information on watershed characteristics.

Previous Studies

A storm-drainage study for the Village of Camillus (Pickard and Anderson, 1977) focused on the flooding along Ninemile Creek in the Village of Camillus and on measures to mitigate the flooding. Two recommendations were to: (1) develop planning programs to control runoff within the watershed, and (2) develop drainage controls. A follow-up study (Lumia and Dunn, 1978) provided a flood analysis of Ninemile Creek from the Village of Camillus to about 3 mi downstream for floods with a 2-, 5-, 10-, 25-, 50-, and 100-year recurrence interval and flood profiles for 50- and 100-year floods for 1978 channel conditions and modified channel conditions.

A watershed approach for managing nonpoint-source runoff to Onondaga Lake, 7.3 mi downstream from the Village of Camillus, was investigated by Moffa, P.E., and others (1994). That report describes use of the HSPF model to simulate nonpoint-source loading from the Ninemile Creek watershed to Onondaga Lake. The simulations indicated that Ninemile Creek watershed is a major source of total phosphorous to the lake.

Traveltime in Ninemile Creek was measured by Shindel and others (1977) by dye-tracer methods under two different flow regimes at several points along the 5-mile reach between Marcellus and Camillus. Traveltimes ranged from about 9 hours at flows of about 50 ft^3/s to about 6 hours at flows of about 200 ft^3/s.

A general description of the hydrogeology of bedrock and surficial deposits of Onondaga County is

[a]Water year is a 12-month period that begins October 1 and ends September 30.

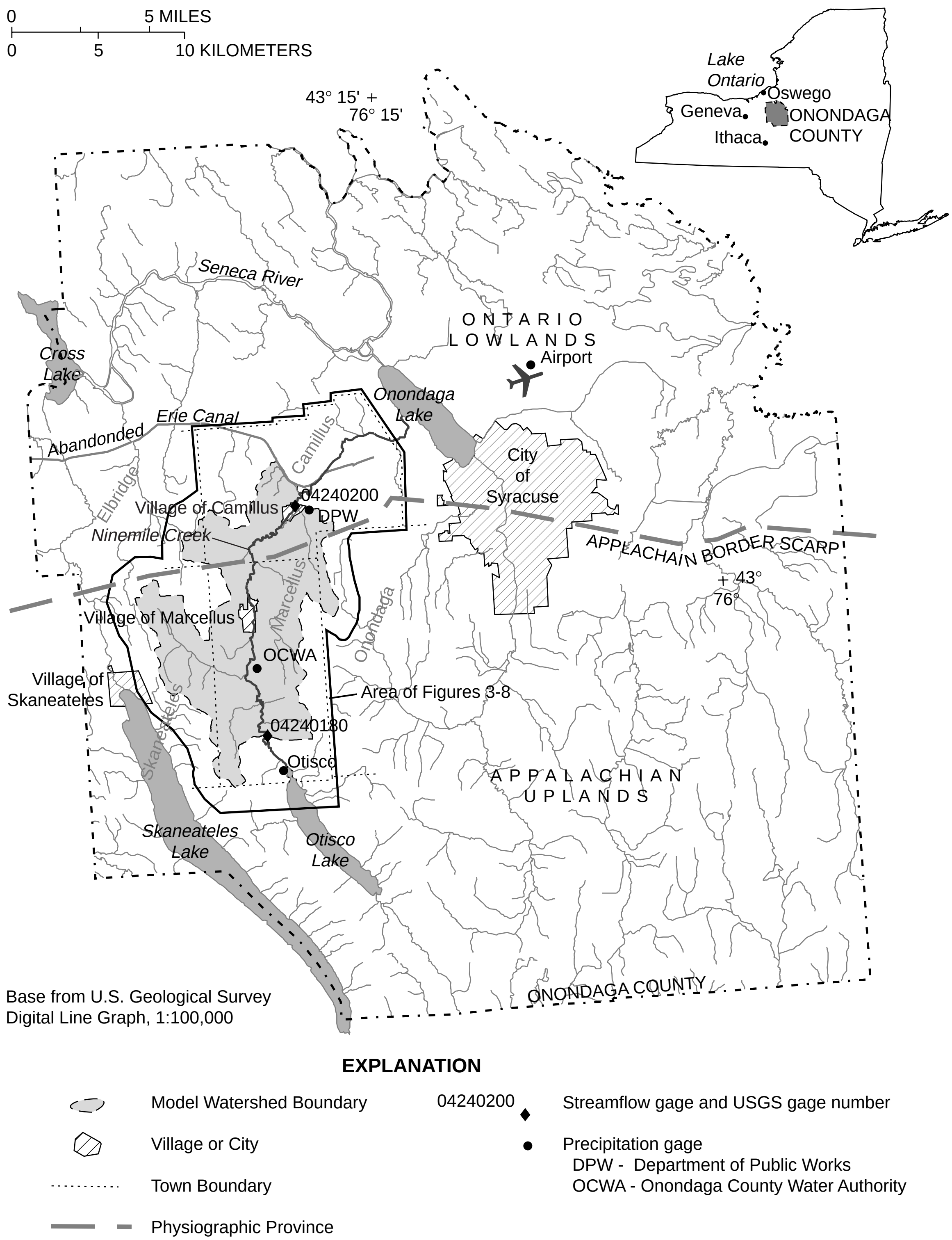


Figure 1. Principal geographic features of Onondaga County, N.Y., and location of Ninemile Creek watershed.

given by Winkley (1989), and the hydrogeology of “Disappearing Lake” in the Town of Marcellus (fig. 8, further on) is given by Proett (1978).

WATESHED CHARACTERISTICS

The Ninemile Creek watershed (fig. 1) encompasses a 115 mi^2 area that originates at the outlet of Otisco Lake (the easternmost Finger Lake), 6.0 mi upstream of the Village of Camillus. The drainage area to Otisco Lake is 42.5 mi^2. Outflow from Otisco Lake is regulated by the Onondaga County Water Authority (OCWA) for water supply, except during periods of extreme flooding, when it discharges, uncontrolled, into Ninemile Creek. The mouth of Ninemile Creek is 7.3 mi below the Village of Camillus, at the southwestern shore of Onondaga Lake. The modeled area of Ninemile Creek watershed encompasses the 41.7-mi^2 drainage from the streamflow gage which lies mostly between the upstream gage at Marietta (04240180) and the Camillus gage (04240200) and includes a 5-mi^2 area just downstream from the Camillus gage (fig. 1).

Climate

Climate in this area is characterized as humid-continental and is moderated somewhat by the Great Lakes, especially Lake Ontario, over which the prevailing west winds pass (Ruffner and Blair, 1979). Climate also is affected by the physiographic transition from the Ontario lowlands to the Appalachian uplands (fig. 1); the study area straddles the boundary between these provinces and receives some precipitation from the orographic uplift of northwest winds. This, together with moisture acquired from Lake Ontario when relatively cool air passes over relatively warm lake waters, creates frequent cloudiness and “lake-effect” precipitation. Precipitation from late October through late March can be in the form of local snow squalls that produce an average snowfall of 109 in/yr.

The 40 in/yr average precipitation reported at the Syracuse and Skaneateles meteorologic stations (National Oceanic and Atmospheric Administration, 1996) is relatively evenly distributed throughout the year (fig. 2), although precipitation is slightly less in the winter, when moisture-holding capacity of the air is diminished. Surface evaporation is about 28 in/yr (Farnsworth and others, 1982), and evapotranspiration, reported as the difference between annual runoff and annual precipitation, is about 20 in/yr (Randall, 1995). Average annual runoff in this area is about 19 in. (Randall, 1995).

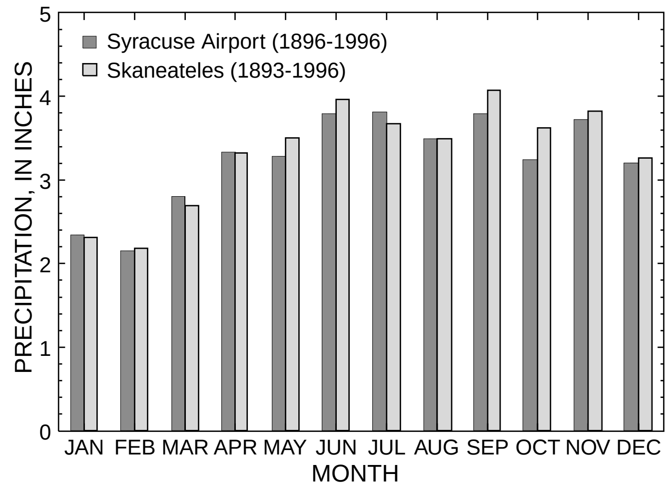


Figure 2. Mean monthly precipitation at Syracuse Airport and Skaneateles, N.Y. (Locations are shown in fig. 1)

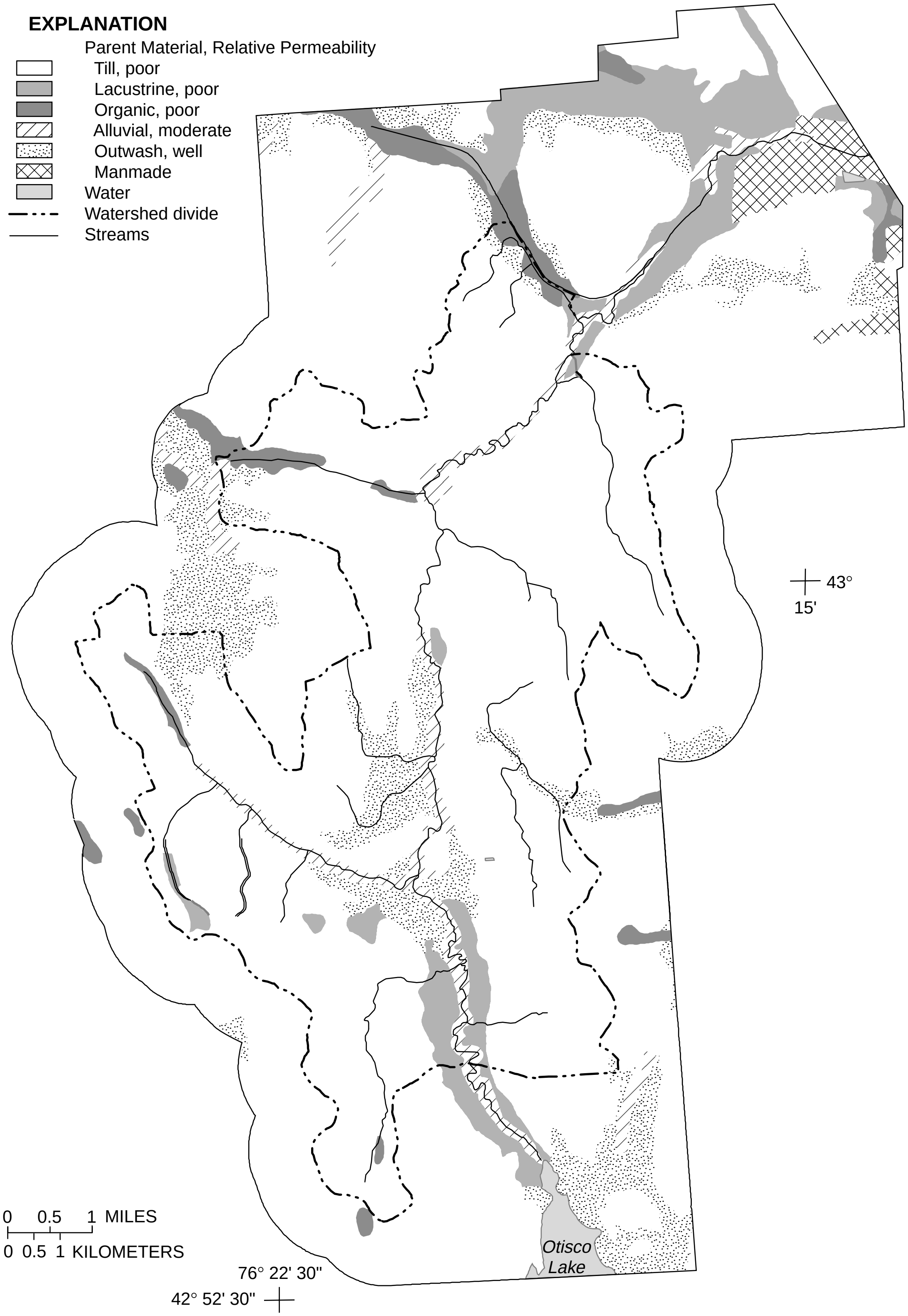
Soils

The Onondaga County soil survey (Hutton and Rice, 1977) indicates that most soils in the study area are derived from till (83 percent); the rest are derived from glaciofluvial sediments such as outwash, kames, and terraces (8.9 percent), postglacial lake sediments (2.6 percent), recent alluvial sediments (4.3 percent), and recent organic deposits (1.1 percent).

Soil permeability ranges from less than 0.06 to more than 2.0 in/h (Hutton and Rice, 1977). Permeability of soils derived from till typically range from 0.6 to 0.20 in/h but may be less where fragipans are present. Permeability of soils derived from well-sorted glacial outwash typically is greater than 2.0 in/h, and that of soils derived from fine-grained lacustrine deposits or organic-rich soils is typically less than 0.06 in/h. The distribution of soil associations in the watershed is shown in figure 3.

Land Use

Land use within the study area is generally categorized as open, forested, agricultural and residential, with small amounts of commercial



Base from U.S. Department of Agriculture, Natural Resource Conservation Service
General Soil Map, Onondaga County, N.Y., 1974, 1:62,000

Figure 3. Generalized soil permeability of the Ninemile Creek watershed model area, Onondaga County, N.Y. (Location is shown in fig. 1.)

development in and near the Villages of Marcellus and Camillus (fig. 4). Urbanization has expanded into the watershed from the northeast. Designation as urban or built-up land, water, agricultural land, quarries and gravel pits, and urban transitional areas required a minimum area of 10 acres; all other categories represent a minimum of 40 acres.

Topography

Topography in the study area reflects (1) the sloped and terraced character of the scarp zone between the Appalachian Upland and the Ontario Lowland, and (2) the effects of glacial and glaciofluvial erosion (Winkley, 1989). Elevations in the study area range from about 400 ft in the northern part to about 1,200 ft on the hilltops in the southern part. Slopes are generally steep along the valleys of Ninemile Creek and it's tributaries. The hilltops are gently rolling. The Ninemile Creek valley floor generally has relatively low relief and a broad flood plain. Channel gradients are low, about 0.001 to 0.002, but steepen to about 0.014 between Marcellus and Martisco where the creek flows over the Onondaga Limestone outcrop (fig. 6). Tributary streams are deeply incised into the Ninemile Creek valley walls and rapidly descend as much as 300 ft to the valley floor. Most tributary channel gradients from the valley floor to the hilltops exceed 0.06 (fig. 5).

Geology

The surficial and bedrock features of a watershed affect the local hydrology. The extent and type of surficial deposits determines the amount of water that can be held in subsurface storage and that will infiltrate into the deep ground water flow system which is typically controlled by the characteristics of the bedrock.

Surficial Deposits

The surficial deposits in the study area consist mostly of till, an unsorted mix of materials ranging from boulders to clay. Till deposits are generally thinnest on the steep valley walls and on the Appalachian border scarp (fig. 1) and thickest on the southward facing slopes in the lee of glacial advance. Ice-contact deposits, including kames and till moraines, are found in several locations in the watershed. These deposits are moderately to poorly sorted but generally are more permeable than till. Outwash sand and gravel is found in meltwater channels that drained proglacial lakes. These deposits are well sorted and highly permeable. Lacustrine silt and clay deposits, which formed in the deeper proglacial lakes in the Otisco Valley and the Ontario lowlands, are poorly permeable. Postglacial alluvial deposits are found along the main stream-valley floors. These deposits rarely exceed 15 ft in thickness and are generally moderately permeable.

Bedrock

Bedrock in the study area consist primarily of Silurian- and Devonian-age interbedded shales and carbonates (dolomite and limestone) that dip about 1˚ southward (fig. 6). The carbonate formations are less erodible than the shales and form the northern scarp of the Appalachian Uplands (fig. 1) (Muller, 1964). Carbonate bedrock, unlike shale, provides a significant pathway for ground-water flow. Wells that tap carbonate units have a reported median yield of 43 gal/min, and some yield as much as 700 gal/min (Winkley, 1989). The drainage area referred to as "Disappearing Lake" (fig. 8) is underlain in its lower northern part by the Onondaga Limestone Formation. This drainage area has no apparent surface outlet and probably drains through solution-enlarged openings in the limestone bedrock and possibly along the "Marcellus Fault," a thrust fault that strikes northeast near this area (Proett, 1978). Dye-tracer studies by Proett (1978) of ground-water flow below Disappearing Lake suggest that water from the Onondaga Limestone Formation discharges through springs along Ninemile Creek just below Marcellus Falls.

PRECIPITATION-RUNOFF MODEL

The model chosen to simulate runoff in the study area was HSPF (Hydrological Simulation Program Fortran), release 11, developed by the U.S. Environmental Protection Agency (Bicknell and others, 1993). The HSPF model can incorporate several hydrologic features of the watershed that were considered important including; (1) extensive wetlands, (2) ground-water flux to the carbonate bedrock, and (3) snowmelt runoff. It also can simulate water quality if desired. HSPF is a continuous-simulation model that is based on conservation-of-mass principles and simulates

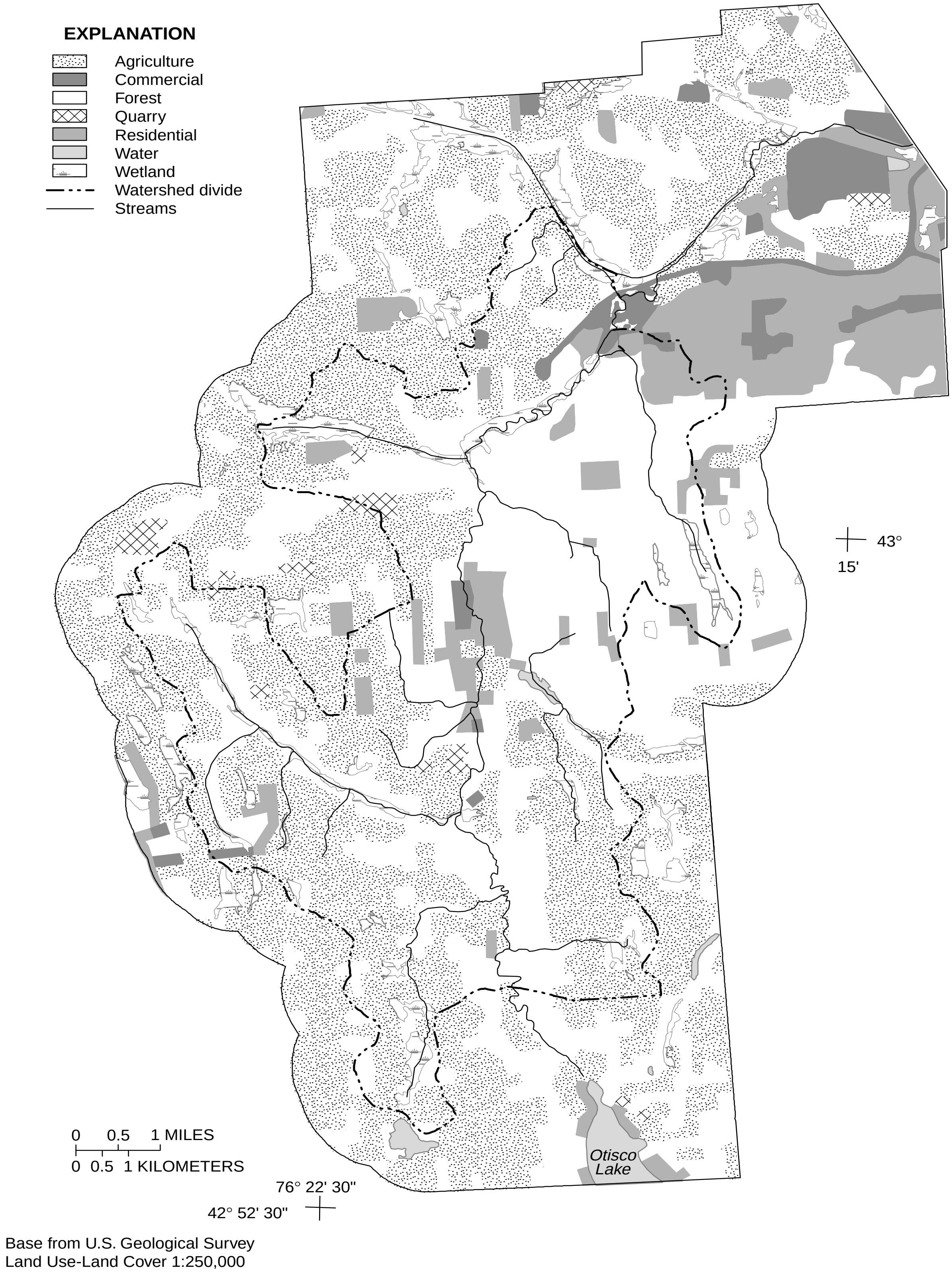


Figure 4. Generalized land use within the Ninemile Creek watershed model area, Onondaga County, N.Y. (Based on GIRAS maps [Mitchell and others, 1977]. Scale 1:250,000. Compiled from 1985 high-altitude aerial photographs. Location is shown in fig. 1.)

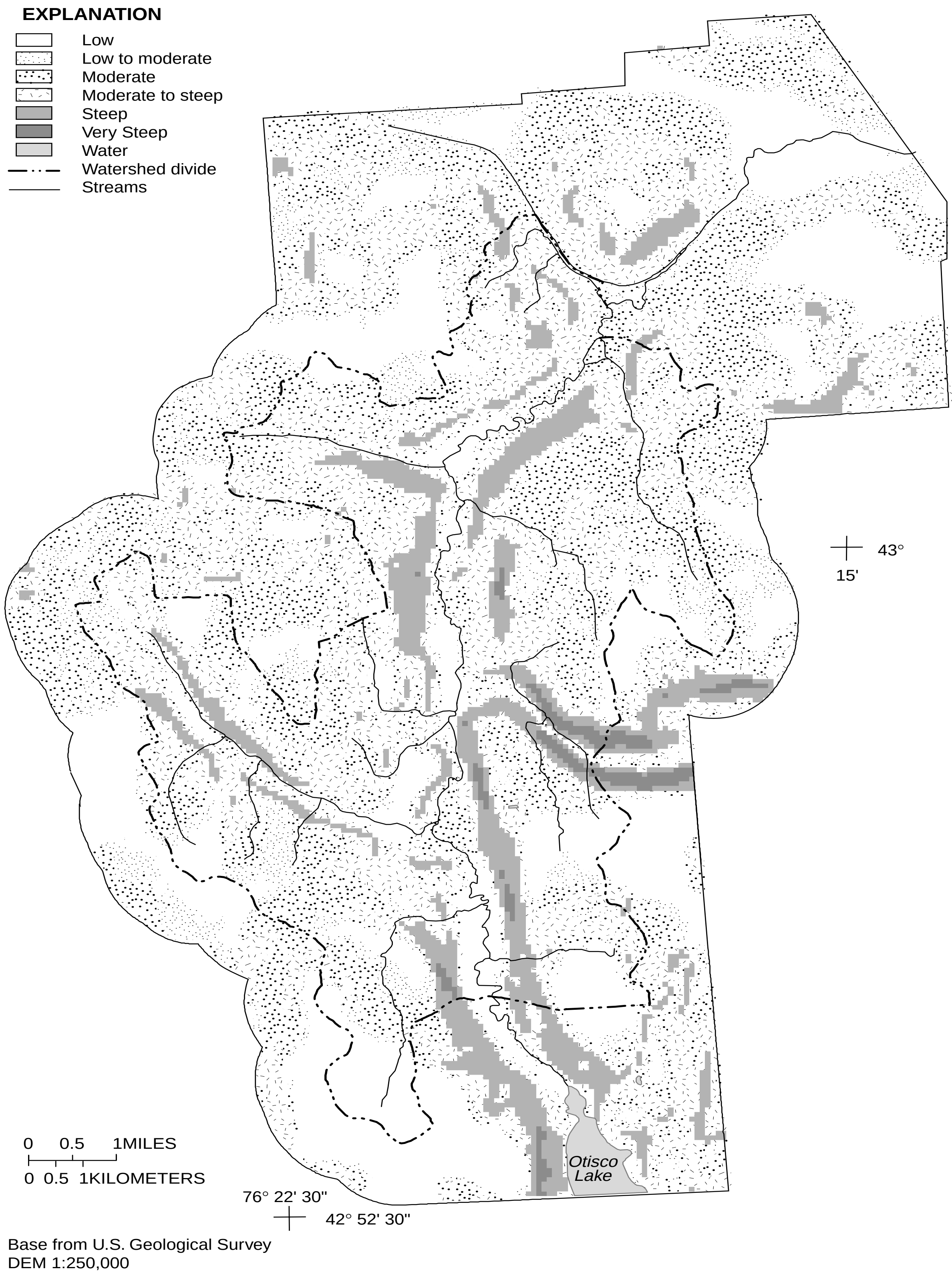
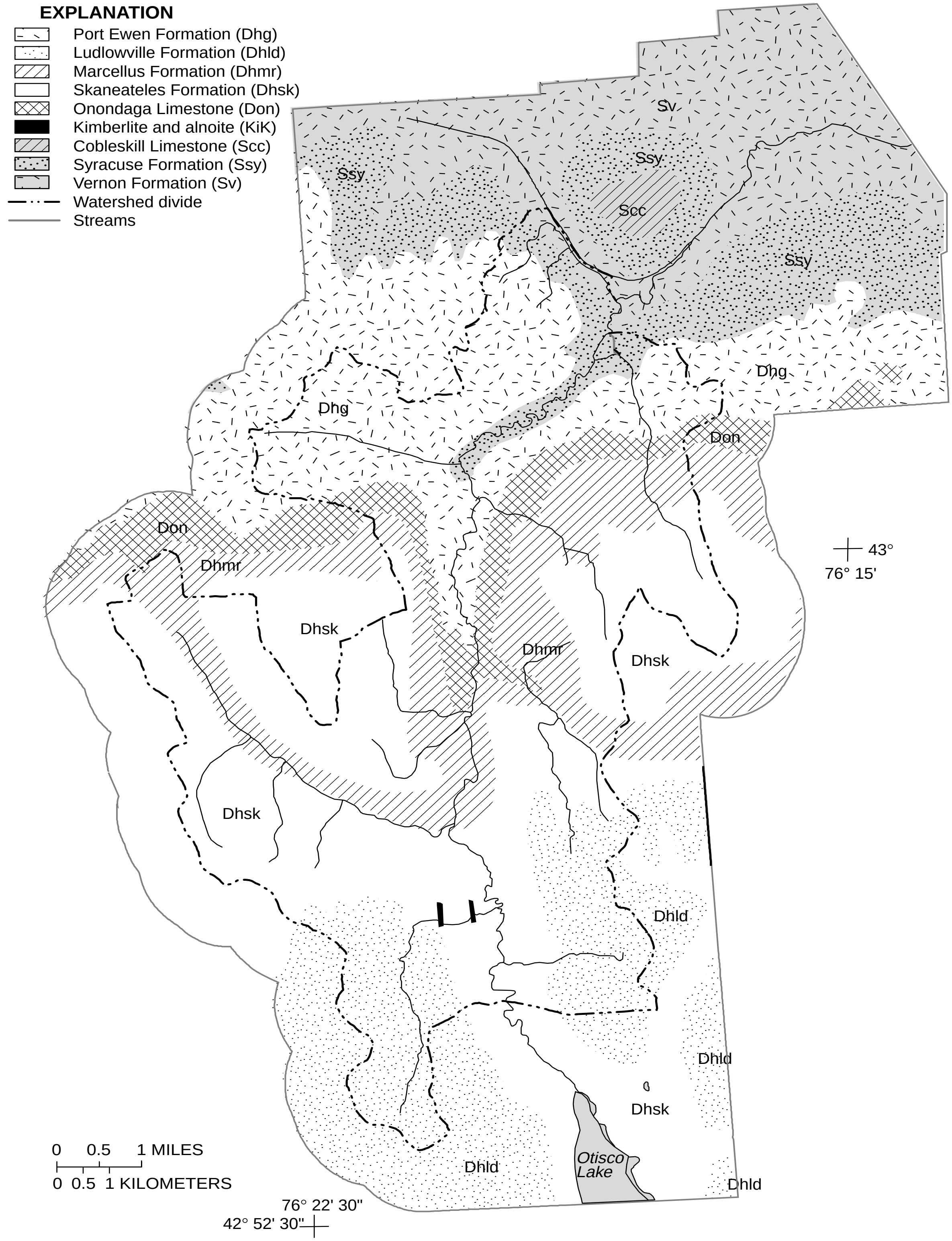


Figure 5. Generalized land-surface slope within the Ninemile Creek watershed model area, Onondaga County, N.Y. (Location is shown in fig. 1.)



Base from N.Y. State Geological Survey
Geologic map of New York (Richard, L.V. and Fisher, W.D., 1970)
1:250,000

Figure 6. Generalized surficial geology of the Ninemile Creek watershed model area, Onondaga County, N.Y. (Location is shown in fig. 1.)

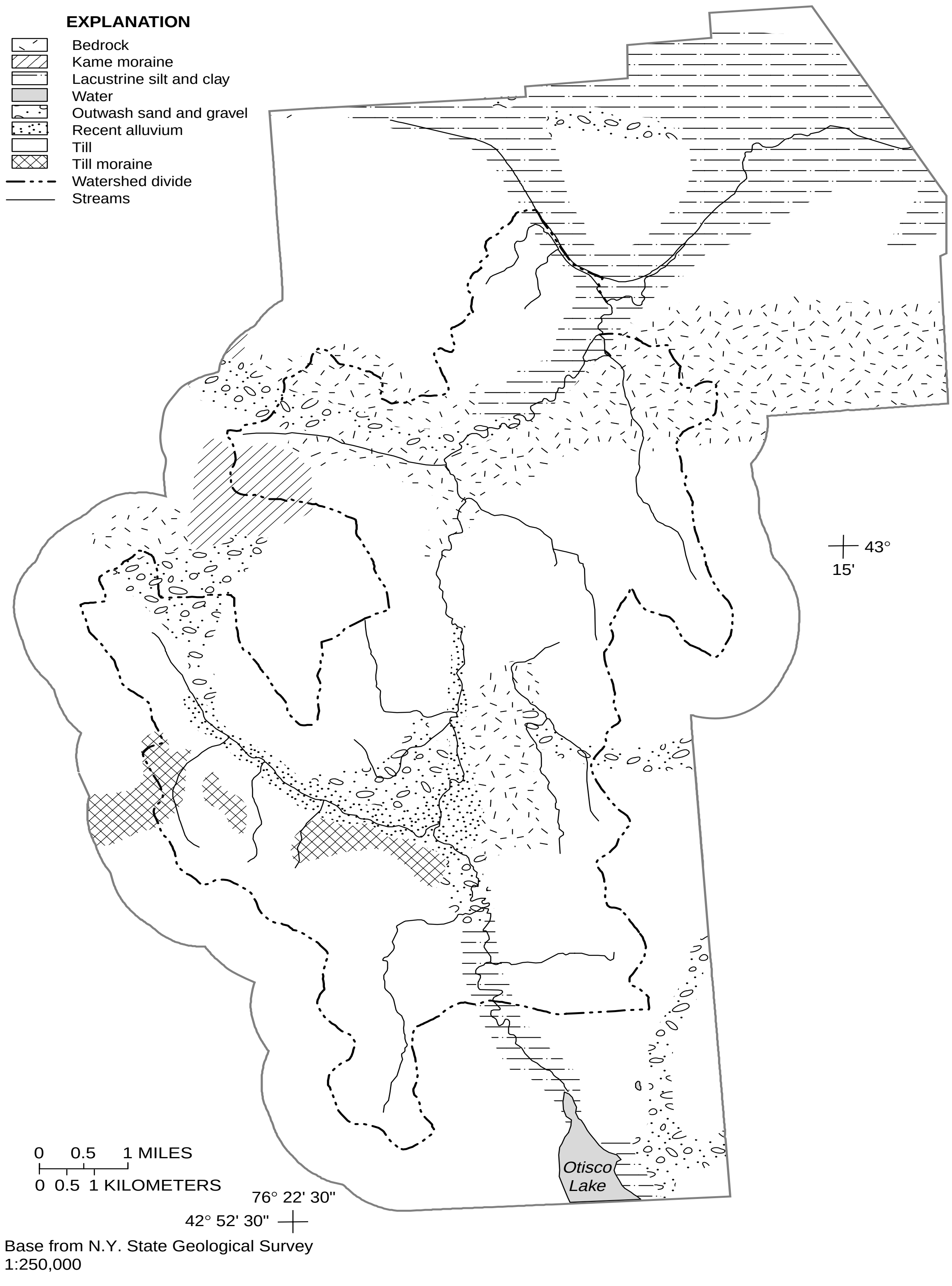


Figure 7. Generalized bedrock geology of the Ninemile Creek watershed model area, Onondaga County, N.Y. (Location is shown in fig. 1.)

runoff by processes that move water (inflows and outflows) or store water among model elements. Model elements represent three types of land segments—pervious lands (PERLND's), impervious lands (IMPLND's), and stream channels or reservoirs (RCHRES's). Unique model elements are developed for land segments with areally uniform properties and are linked together to represent the watershed. The model schematization defines these elements and how they are linked to simulate water movement.

Schematization

Schematization is the method of representing the physical and spatial characteristics of the watershed in the model. A Geographic Information System (GIS) was used to assemble the spatial characteristics, which included soils, land use, percent slope, surficial geology, and bedrock geology. This information was simplified and grouped to obtain categories that could be manageably incorporated into the model. Specifically, (1) the 38 soil associations in the watershed were grouped into three types on the basis of permeability—low, moderate, and high; (2) slopes were classified into two groups— less than 5 percent and greater than 5 percent; and (3) land use was simplified from 17 categories into four types of pervious land cover (forested, agricultural, wetlands, and a combination of open land and developed land, hereafter referred to as open/residential) and two types of impervious land cover (residential and commercial). The GIS was used to integrate these characteristics into hydrologic response units (HRU's) such that each would contain similar types of reclassed land use, soils, and slope. Development of HRU's did not include the surficial geologic characteristics directly; the soil permeability was assumed to reflect the parent surficial geologic material from which the soil was derived and was later applied when the subsurface storage was adjusted.

Not all combinations of land use, soils, and slope categories occur in the watershed, and some are present only in small areas. The watershed was ultimately represented by 14 PERLND's (pervious areas) and 3 IMPLND's (impervious areas) as summarized in table 1. This simplification resulted in more than 1,500 polygons, each representing one of the 17 HRU's. Schematization also required dividing Ninemile Creek and its tributary channels into reach segments (RCHRES's) to represent the drainage network. Nodes (points defining the junction of two or more RCHRES's) were placed at the confluence of Ninemile Creek with major tributary streams and in channel sections where channel slope changed significantly. A total of 24 RCHRES's were used to define the channel geometry—10 for Ninemile Creek, and 14 for its tributaries (fig. 8) Some of the tributary RCHRES's have multiple nodes. After the RCHRES's were defined, the GIS was used to obtain the area of each PERLND and IMPLND (HRU) that contributes flow to each RCHRES.

Data

Hydrologic and meteorologic data needed for model simulations were obtained from a variety of sources. Records ranged in length from 2 to 36 years, depending on the source and type of data. The types of data assembled and the collection-site location, source, recording frequency, and period of record are given in table 2. Not all of these data were required as input to the model; some were used for model calibration, as indicated in table 2. All data used in the model were obtained from existing sources, except for two tipping bucket rain gages that were installed in the northern and southern part of the watershed (DPW and OCWA in fig. 1) at the beginning of the study to provide local precipitation data for comparison with long-term precipitation data from National Oceanic and Atmospheric Administration (NOAA) gage at the Syracuse Airport and from the Onondaga County Water Authority (OCWA) gage at the north end of Otisco Lake (fig. 1). Local rainfall data were also used in model simulations that incorporated both local gages to evaluate model error, but most simulations were made from precipitation data collected at the north end of Otisco Lake, which was considered the most representative long-term precipitation record available for the study area. The later data were used to simulate runoff for the 6-year period from January 1, 1990 to December 31, 1996 but were first disaggregated into hourly data on the basis of Syracuse Airport hourly precipitation patterns. The Syracuse Airport precipitation data were used to simulate runoff from October 1988 through January 1990.

The Northeast Regional Climatic Center (NRCC) supplied daily evapotranspiration and solar-radiation values for the 31-year period from January 1, 1965 to January 31, 1996; daily evapotranspiration values.

Table 1. Model hydrologic response units (HRU's) in Ninemile Creek watershed, Onondaga, N.Y.

[> - greater than, - indicates not classified].

Hydrologic Response Unit	Description			Area represented in model		Area above Camillus Gage	
	Land use	Permeability	Percent Slope	Acres	Percent	Acres	Percent
Impervious land surface (IMPLND)							
IMPLND 1	Residential	Impervious	0 - 5	69	0.3	19	0.1
IMPLND 2	Residential	Impervious	>5	37	0.1	24	0.1
IMPLND 3	Commercial	Impervious	-	140	0.5	55	0.2
Pervious land surface (PERLND)							
PERLND 1	Forested	poor	0 - 5	2566	9.6	2226	9.5
PERLND 2	Forested	poor	>5	2719	10	2465	10
PERLND 3	Forested	moderate	0 - 5	2898	11	2093	8.9
PERLND 4	Forested	moderate	>5	2740	10	2419	10
PERLND 5	Forested,	high	0 - 5	541	2.0	541	2.3
PERLND 6	Forested,	high	>5	637	2.4	614	2.6
PERLND 7	Agricultural	poor	0 - 5	1890	7.1	1855	7.9
PERLND 8	Agricultural	poor	>5	1158	4.3	1116	4.8
PERLND 9	Agricultural	moderate	0 - 5	4307	16	4204	18
PERLND 10	Agricultural	moderate	>5	2616	9.8	2236	9.5
PERLND 11	Agricultural	high	0 - 5	441	1.7	437	1.9
PERLND 12	Agricultural	high	>5	3‘70	1.4	318	1.4
PERLND 13	Wetlands	poor	-	1370	5.1	1160	5.0
PERLND 14	Open/residential	poor	-	2134	8.0	1627	6.9

were calculated by the Penman-Monteith equation (DeGaetano and others, 1994), and the solar radiation values by a modified Meyers Dale model (DeGaetano and others, 1993). Daily evaporation values for February 1, 1996 through September 30, 1996 were calculated by the Penman (1948) method, and solar radiation values for this period were estimated by a weighted distance average from daily observations at Ithaca, Geneva, and Oswego. Daily values of evapotranspiration and solar radiation were disaggregated into hourly data by the computer program METCMP (Kathleen Flynn, U.S. Geological Survey, written commun., 1995) which was developed for meteorologic data analysis and data management.

Data listed in table 2 were entered into ANNIE (Flynn and others, 1995), a watershed data management system designed to read and write data directly to the HSPF model; ANNIE also provides interactive access to manage, transform, plot, and analyze time-series data. Certain model-input data sets sporadically lacked one or two consecutive values. The isolated missing values were estimated by linear interpolation between known values, a procedure considered to provide a reasonable approximation for most variables except wind-speed; the few wind speed values that were estimated probably have a negligible effect on the model predictions, however.

Several blocks of hourly discharge data from the Camillus and Marietta gages were missing, but for

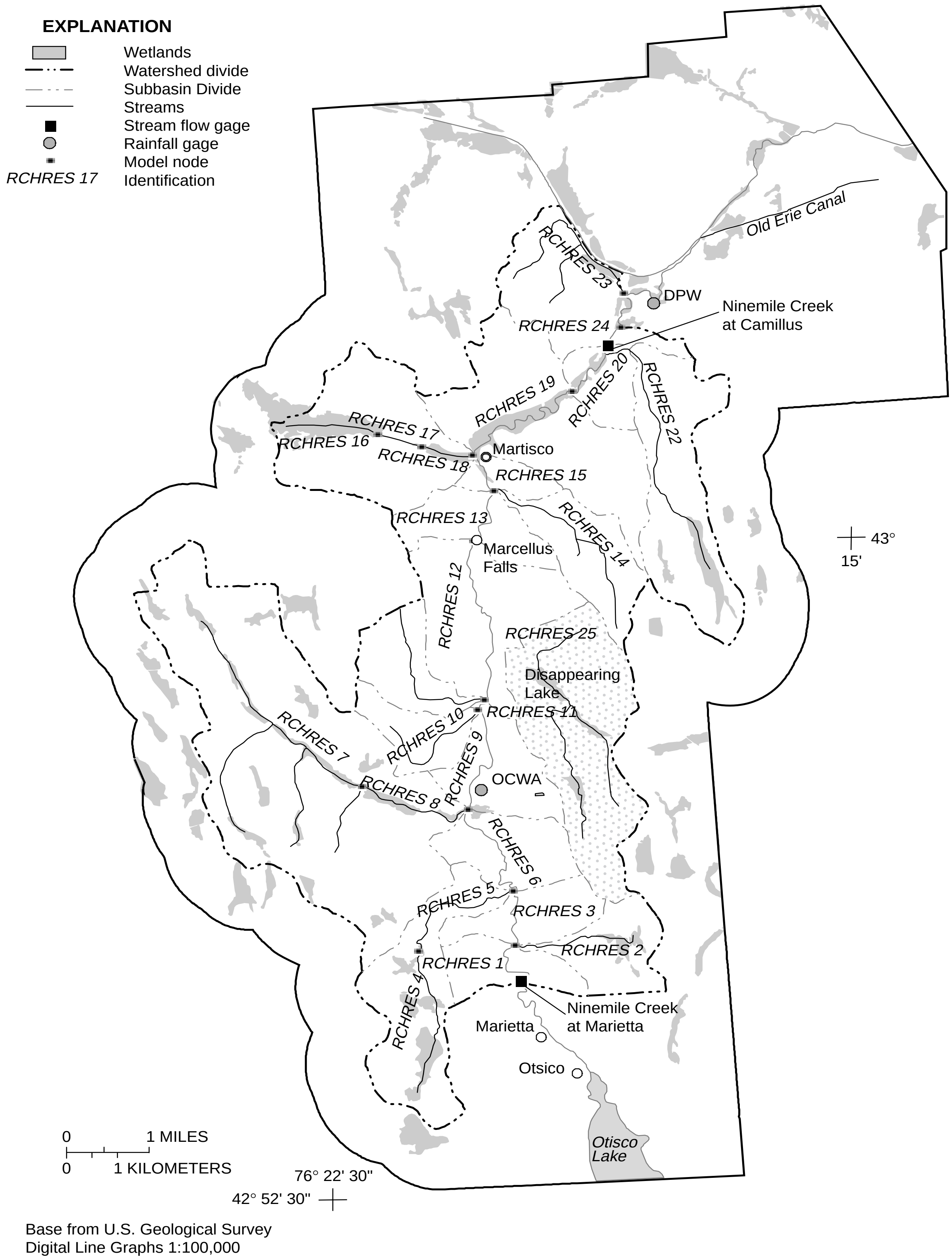


Figure 8. Subbasin boundaries, stream schematization, and gages in the Ninemile Creek watershed model area, Onondaga County, N.Y. (Location is shown in fig. 1.)

differing time periods. Discharges for these periods were estimated by a weighted-area method that relates the drainage area of known upstream or downstream discharge to the drainage area of the point where discharge is desired, by the relation;

$$Q_u = \left(\frac{A_u}{A_k}\right) \cdot Q_k$$

where Q_u = Unknown discharge at desired location,
A_u = Watershed area at point where discharge is desired,
A_k = Watershed area at the point where discharge is known, and
Q_k = Known discharge at upstream or downstream location.

Table 2. Types, locations, source, and period of record of data assembled for input and calibration of runoff model of Ninemile Creek, Onondaga County, N.Y.

[˚F - degrees Fahrenheit; in. - inches; ft^3/s - cubic feet per second. Asterisk indicates data used for model input. Locations are shown in fig. 1]

Type of data	Location[1]	Source[2]	Recording Frequency	Period of Record (mo/d/yr)
Discharge (ft^3/s)	Ninemile Creek at Camillus	USGS	1 hour 1 day	6/27/88 - 9/30/95 10/1/59 - 9/30/82; 10/1/88 - 9/30/96
Discharge (ft^3/s)*	Ninemile Creek at Marietta	USGS	1 hour 1 day	10/1/87 - 9/30/95 10/1/63 - 9/30/96
Rainfall (in.)*	DPW Town of Camillus	USGS	10 min	5/18/95 - 10/31/95 4/1/96 - 9/30/96
Rainfall (in.)*	OCWA Filtration Plant	USGS	10 min	5/18/95 - 10/31/95 4/1/96 - 9/30/96
Precipitation (in.)*	Syracuse Airport	NRCC	1 hour 1 day	1/1/65 - 8/31/96 1/1/65 - 8/31/96
Precipitation (in.)*	Otisco Lake North Shore	OCWA	1 day	1/1/90 - 12/1/96
Air temperature (˚F)*	Syracuse Airport	NRCC	1 hour	1/1/65 - 2/19/97
Dew-point temperature (˚F)*	Syracuse Airport	NRCC	1 hour	1/1/65 - 2/19/97
Wind speed (mile per hour)*	Syracuse Airport	NRCC	1 hour	1/1/65 - 2/19/97
Solar Radiation (Langleys)*	Syracuse Airport Ithaca, Geneva, Oswego	NRCC NOAA	1 day 1 day	1/1/65 - 1/31/96 2/1/96 - 1/31/97
Evapotranspiration (in.)*	Syracuse Airport	NRCC NOAA	1 day	1/1/65 - 1/31/96 2/1/96 - 1/31/97
Snow cover (in.)	Skaneateles	NOAA	1 day	11/1/93 - 4/30/94
Snow water equivalent (in.)	Syracuse Airport	NOAA	1 day	11/95 - 4/96

[1]DPW, Department of Public Works
OCWA, Onondaga County Water Authority
[2]USGS, U.S. Geological Survey (National Water Information System, electronic data)
NRCC, Northeast Regional Climate Center (Cornell University, Ithaca, N.Y., electronic data)
OCWA, Onondaga County Water Authority
National Oceanic and Atmospheric Administration (monthly climatological data, 1993-96)

Comparison of estimated hourly discharge daily summaries with reported daily discharge (U.S. Geological Survey, 1988-96) indicates that, on average, these estimates differ by 20 percent.

Calibration

Initial model parameter values were calculated from measured watershed characteristics to the extent possible, then an iterative calibration process was used to refine the initial parameter values. HSPF was calibrated in accordance with guidelines by Donigian and others (1984) and Lumb and others (1994). In general, the model was calibrated to annual and seasonal hydrologic water budgets for water years 1989-96 (October 1, 1988 to September 30, 1996) and were then adjusted to improve stormflow simulations while maintaining the annual and seasonal water-budget values.

Pervious Areas

HSPF is a continuous simulation model and, thus, requires calibration of the hydrologic processes that occur between storms as well as during storms, to correctly simulate runoff during storms. Calibration for periods between storms largely entailed adjusting the parameter values for the HRU's representing pervious areas (PERLND's). Annual and seasonal hydrologic budgets for large rural watersheds such as that above Camillus are largely controlled by the amount of precipitation that is allowed to enter and be retained in subsurface storage and is largely represented by parameters for the two soil storages—upper-zone (UZSN) and lower-zone (LZSN), soil infiltration rate (INFILT), and lower-zone evapotranspiration (LZEPT).

UZSN and LZSN—initial values were calculated as the water-holding capacity times depth of the applicable soil horizon(s) reported in the Onondaga County soil survey (Hutton and Rice, 1977). Values for soil storage were computed for each soil association and spatially weighted for each type of PERLND; the calibrated UZSN values ranged from 0. 3 to 1.2 in. and the calibrated LZSN values ranged from 3.0 to 3.7 in. The values are nominal capacities, rather than absolute capacities.

INFILT—values were computed for each soil association on the basis of the soil horizon with the lowest infiltration rate and spatially weighted for each HRU; calibrated INFILT values ranged from 0.018 to 0.162 in/hr.

LZEPT—is unitless index to the amount of deep rooted vegetation that can take water from lower zone storage. Initial LZETP values were estimated from the percentage of forested land in each HRU; calibrated LZETP values ranged from a summer high of 0.85 to a winter low of 0.002.

Many other PERLND parameters affect annual and seasonal water budgets, snow accumulation and snowmelt, and the timing and magnitude of stormflows. Many of these parameters were assigned monthly values to improve the agreement between the simulated and observed seasonal runoff. The calibrated PERLND parameter values are given in the model UCI (User Controlled Input) PERLND block in Appendix A.

Impervious Areas

Impervious areas (IMPLND's) have little effect on the annual and seasonal water budget because they incorporate no storage components other than interception storage, such as puddles or snowpack storage. They have a relatively large effect on the magnitude and timing of stormflow, however, because all water falling onto an IMPLND was routed to a RCHRES, except for the small amounts that are retained by interception storage and lost through evaporation.

The major consideration in IMPLND calibration is to determine the area that is "hydrologically effective impervious"— the area that drains directly to channels. Runoff from impervious areas that drains to pervious areas ("hydrologically ineffective impervious" areas) can be directed into PERLND's as lateral surface inflow (SURLI), although this requires a unique PERLND to account for the area of the SURLI directed to it. This was attempted at first, but a simpler approach was later used that incorporates a type of PERLND that reflects the hydrologic response from mixed pervious and hydrologically ineffective impervious areas (open/residential PERLND). The impervious area above the Camillus gage, as estimated from land-use characteristics, was decreased from about 1,400 acres to about 100 acres during the calibration process. The open/residential PERLND (no. 14 in table 1) also includes a small amount of disturbed land such as quarries. The calibrated IMPLND parameter values are provided in the model UCI (User Controlled Input) IMPLND block in appendix A.

Channels

HSPF simulates hydraulic routing from information supplied in a table (FTABLE) that defines the stage, storage, and discharge characteristics for each channel segment (RCHRES). A Channel Geometry Analysis Program (CGAP) by Regan and Schaffranek (1985) was used to define the average geometry and conveyance characteristics for each RCHRES from multiple channel cross sections and estimates of channel roughness through procedures described by Arcement and Schneider (1989) and Coon (1995). Cross sections of the lower four reaches of Ninemile Creek (Ninemile-6 to Ninemile-9) and Gulf Brook (fig. 8) were obtained from unpublished flood-investigation maps and reports by O'Brien and Gere, Engineers and Surveyors, Syracuse, N.Y. and a storm-drainage study by Pickard and Anderson Engineering (1977); cross sections of all other reaches were estimated from topographic maps and field observations.

The Disappearing Lake subbasin in the east-central part of the modeled area (fig. 8) has no surface outlet and is believed to drain through the Onondaga Limestone to springs along Ninemile Creek near Marcellus Falls. To represent the lake storage and the delayed drainage through the limestone bedrock, runoff from this subbasin was routed to a RCHRES with an artificially high storage-to-outflow ratio.

Simulation Error

Simulation error can be divided into (1) *input source-error,* which results from error in the observed data used to calibrate the model, and (2) *model error*, which results from incorrect model schematization and/or parameter values that describe the runoff process.

Input-Source Error

Errors associated with input data are broadly classified into measurement error and regionalization error (Winter, 1981). Measurement error results from faulty monitoring equipment, poor equipment calibration, and environmental factors, whereas regionalization error is associated with extrapolation of point data over time and space. Winter (1981) describes how errors from these sources, which can be substantial, affect the calculation and interpretation water budgets for lakes. These errors can similarly affect the calculation and interpretation of simulated flows in a watershed model. Information was available for examination of the regionalization error associated with the precipitation data, which can be one of the largest sources of error in a runoff model.

Precipitation

Runoff models such as HSPF are highly sensitive to precipitation volume and intensity, which can differ appreciably over small areas. Although HSPF can incorporate multiple rain gages, data to support multiple gages were unavailable for long-term simulations. Rainfall data collected at two local gages from May 1995 through September 1996, as previously described, were incorporated into the model to evaluate storm runoff error in comparison to that of simulations that used a single rain gage.

Long-term simulations (1988-96) used precipitation records from (1) the Syracuse Airport gage, about 12 mi northeast of Camillus, for 1988-90, and (2) the gage at the north end of Otisco Lake, about 9.5 mi south of Camillus, for 1990-96 (fig. 1). The difference between the annual precipitation for 1990-96 at the Syracuse and the Otisco gages is generally less than 10 percent (fig. 9A), but values for individual years differed by as much as 32 percent (1994). Precipitation during 1990-96 at the Otisco gage was about 6 percent greater than at the Syracuse gage; this probably reflects the difference in precipitation characteristics of two physiographic provinces in which the gages are located (fig. 1). The difference in annual precipitation between these gages is apparent in the simulated annual water budgets; simulations that used Syracuse precipitation data required a multiplication factor of 1.07 to yield 1990-96 water budgets similar to those based on the Otisco data.

Total monthly precipitation for the Otisco and Syracuse gages during 1990-96 differed by an average of 24 percent but varied by as much as 196 percent (fig. 9B). Kendall Tau tests of the difference between gages do not indicate a trend in the data, however. The monthly precipitation differences between the two local rain gages (DPW and OCWA, fig. 1) were less than those between the Syracuse and Otisco gages. Total monthly precipitation (June - October 1995 and April - October 1996) at the DPW gage differed from that at the OCWA gage by an average 0.04 in., and the monthly precipitation for these two gages differed from the Syracuse gage by an average of 0.10 in. and from the Otisco gage by an average of 0.23 in.

Precipitation at the four gages varied more during storms than over monthly and annual periods. Precipitation of at least 0.50 in. was recorded during 30 storms from June through November 1995 and from April through September 1996 (Appendix B); the average total precipitation from these storms at the four gages was 15.51 in. in 1995 and 16.40 in. in 1996 (table 3). The 1995 average storm precipitation at the DPW and OCWA gages (17.66 in.) and was about 32 percent greater than the average for the Syracuse and Otisco gages (13.36 in.) and the 1996 average storm precipitation at the DPW and OCWA gages (15.85 in.) was about 6 percent less than the average for the Syracuse and Otisco gages (16.94 in).

Storm precipitation varied more among the four gages during the summer than during the spring or fall. Although average total summer-storm precipitation (7.90 in.) was about equal to the average total spring- and fall-storm precipitation (8.06 in.), the standard deviation of the average storm precipitation at the four gages was 3 times greater during the summer (1.53 in.) than during the spring and fall (0.54 in.).

The storm of July 1-2, 1995 exemplifies the variability in summer-storm precipitation (fig.10). Total precipitation measured at the DPW, OCWA, Syracuse, and Otisco gages was 2.93, 0.52, 0.85, and 0.18 in., respectively. The relatively large rainfall at the DPW gage resulted in overprediction of runoff for this storm when the model was run with data from both local rain gages. This suggests that precipitation recorded at the DPW gage was not representative of the northern part of the watershed. For this reason, storms whose precipitation values differed widely among the four gages were given less weight during the storm hydrograph calibration process, than storms whose precipitation values were relatively uniform among the gages.

The difference between actual precipitation in the watershed and the measured value is a source of uncertainty and error that decreases over extended time spans because spatial differences between point data tend to diminish over time. Thus, the model error associated with regionalized precipitation error is less for seasonal and annual periods than for individual storms. Also, local precipitation is more varied in summer, when convective-type storms predominate, than during other seasons, when frontal-type storm systems predominate.

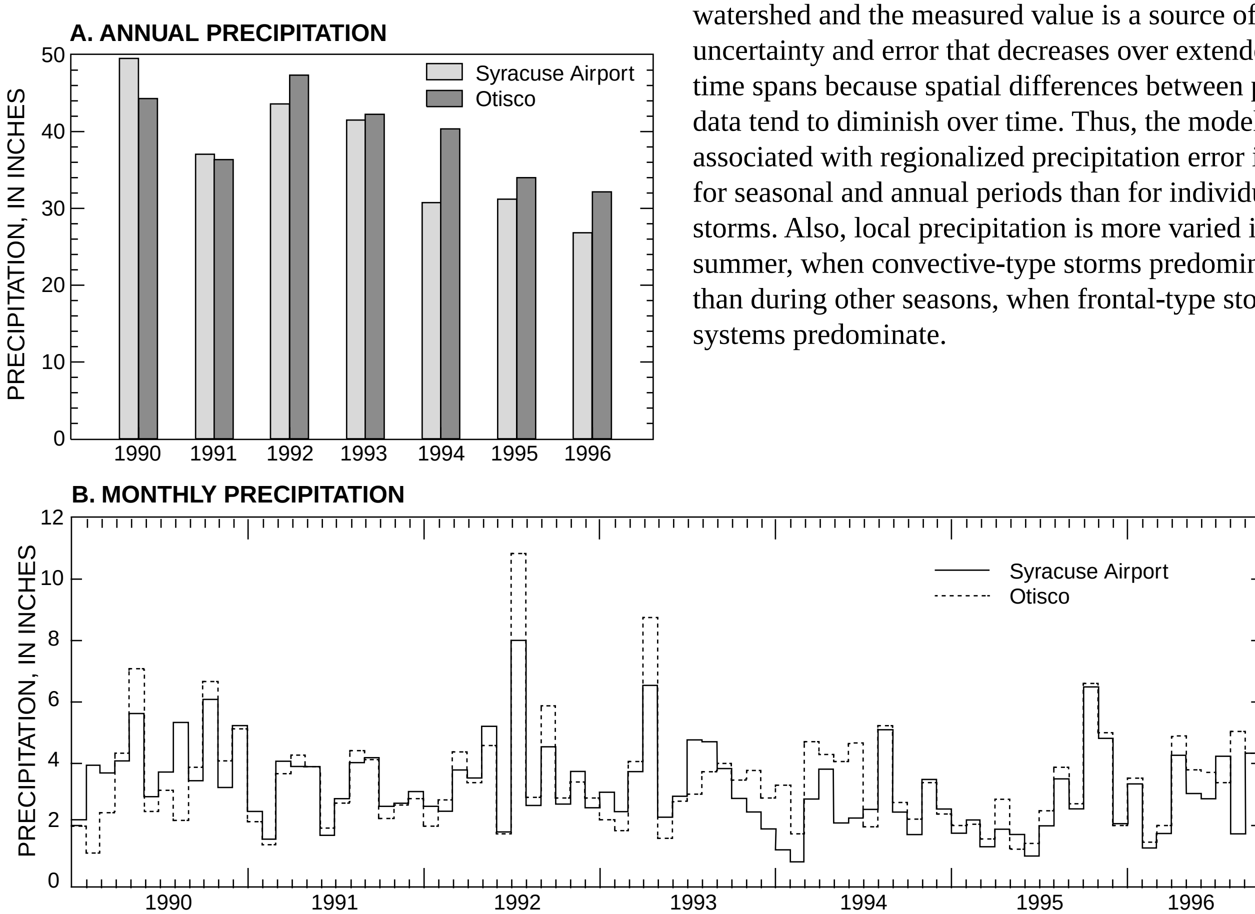


Figure 9. Precipitation at Syracuse Airport and Otisco gages, Onondaga County, N.Y., 1990-96: (A) Annual precipitation. (B) Monthly precipitation. (Locations are shown in fig. 1)

Table 3. Non-winter storm precipitation at four gages in, or near, the Ninemile Creek watershed, Onondaga County, N.Y.

[Locations are shown in fig. 1; storm characteristics listed in appendix B.]

Year	Gage[1]	Precipitation (inches)		
		Summer Storms[2]	Spring and Fall Storms[3]	Total Non-winter Storms
1995	DPW	9.14	8.38	17.52
	OCWA	10.14	7.65	17.79
	Syracuse Airport	5.72	7.67	13.39
	Otisco Lake	6.28	7.06	13.34
	Mean	7.82	7.69	15.51
	Std. deviation	2.15	0.54	2.48
1996	DPW	7.65	8.24	15.89
	OCWA	7.48	8.34	15.82
	Syracuse Airport	7.46	8.56	16.02
	Otisco Lake	9.31	8.55	17.86
	Mean	7.98	8.42	16.40
	Std. deviation	0.89	0.16	0.98
1995-96	Mean	7.90	8.06	15.96
	Std. deviation	1.53	0.54	1.81

[1]DPW, Department of Public Works, Town of Camillus
OCWA, Onondaga County Water Authority filtration plant at Marcellus, N.Y.
[2]Period; June to August 1995 and June to August 1996
[3]Period; September to October 1995, April to May 1996, and September to October 1996

Other input-source errors

Temperature, solar radiation, wind speed, and evaporation data, like precipitation data, are subject to measurement and regionalization error, but information is unavailable to evaluate these sources. The model is less sensitive to errors in these variables than to precipitation error, however.

Discharge of Ninemile Creek at the Marietta (upstream) and Camillus (downstream) gages is also subject to measurement error. Discharge at the Marietta gage provided runoff from the unmodeled part of the watershed; thus, measurement error associated with this gage is perpetuated in the model. Discharge at the Camillus gage was used for model calibration; thus, measurement error associated with this gage can result in improperly calibrated parameter values. Discharge values for the Marietta gage are generally rated fair to poor because of persistent backwater conditions, but discharge data for the Camillus gage are generally rated good, except for periods of missing record (U.S. Geological Survey, 1959-96).

Model Error

Model error was examined through a comparison of simulated and observed flows in Ninemile Creek at Camillus in terms of (1) annual and seasonal water budgets, (2) non-winter-stormflows, and (3) winter stormflows. The error for the area below the Camillus gage could not evaluated.

Annual and Seasonal Water Budgets

Total simulated and observed discharge for water years 1989-96 differed by about 1 percent. The yearly difference between simulated and

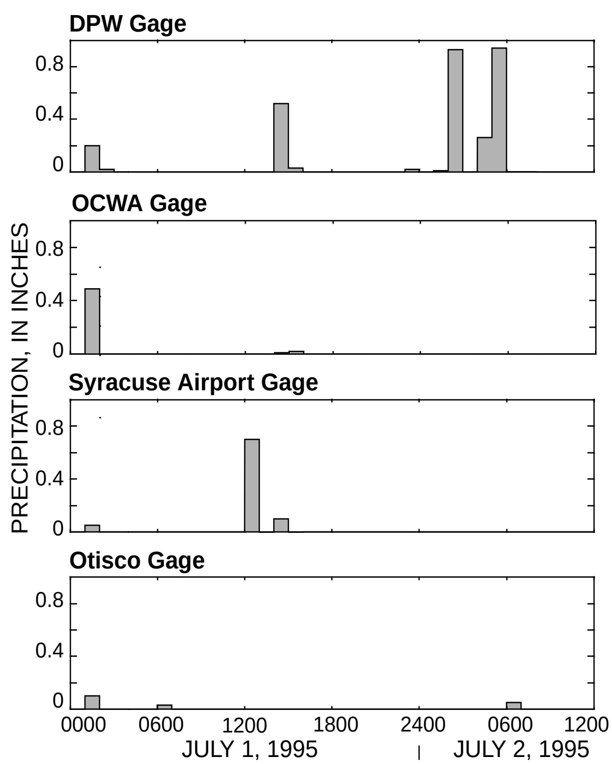


Figure 10. Precipitation recorded at four gages in and near the Ninemile Creek watershed, Onondaga County, N.Y., during storm of July 1-2, 1995. (Locations are shown in fig. 1)

observed discharge (table 4) during this period ranged from -19 to 14 percent (root mean square error of 4.3 percent); simulated annual and monthly discharge are plotted in relation to observed values in figure 11. The underprediction of discharge in water years 1989 and 1990 is consistent with the difference between precipitation at Otisco and that at Syracuse as described previously. The 1989 water-year simulations used only the Syracuse precipitation data, whereas the 1990 water year simulations used Syracuse precipitation data for the first 3 months and Otisco data thereafter. Hence, the difference between the observed and simulated annual discharge for the 1989 water year was considerably greater than the differences for the 1990 water year. Simulations that used only Otisco data (water years 1991-96) generally overpredicted discharge slightly.

The difference between the observed and simulated monthly discharge (figs. 12B, 12C) ranged from -30 to 126 percent. Seasonally, the differences between the simulated and observed

Table 4. Observed and simulated annual discharge, Ninemile Creek at Camillus, N.Y., water years 1989-90.

[Location are shown in fig.1]

Water Year	Observed (inches)	Simulated (inches)	Percent Difference
1989	38.2	31.0	-19
1990	65.3	60.3	-7.7
1991	55.7	56.5	1.5
1992	46.2	52.6	14
1993	62.9	64.0	1.9
1994	50.3	54.9	9.1
1995	28.2	30.2	-6.7
1996	49.2	50.6	2.9
1988-96	396	400	0.8
Mean Error			1.2
RMSE[1]			4.3

[1]RMSE, root mean square error

$$RMSE = \sqrt{\sum \frac{r^2}{n}}$$

where: $r = \left(\frac{Predicted - Observed}{Observed}\right) \cdot 100$

$n = Number\ of\ Storms$

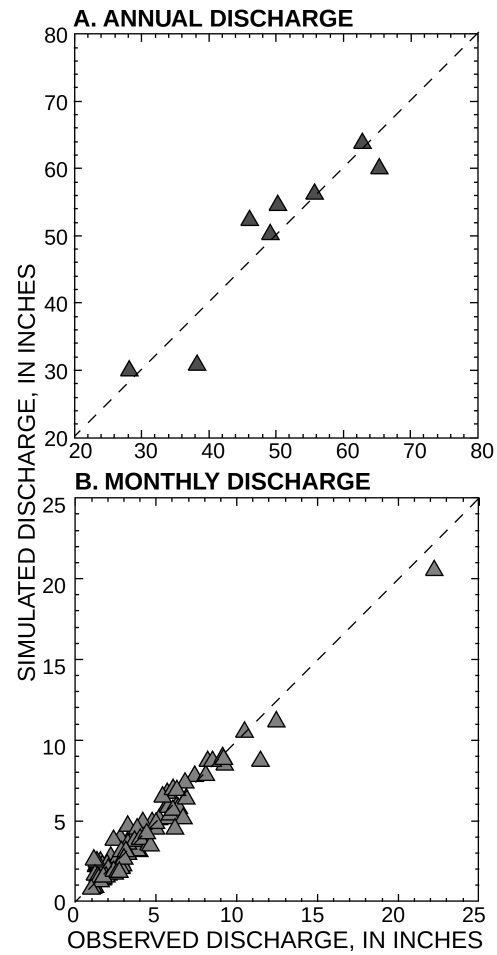


Figure 11. Simulated discharge in relation to observed discharge, at Ninemile Creek at Camillus, N.Y., water years 1989-96: (A) Annual discharge. (B) Monthly discharge. (Location is shown in fig. 1)

discharge (table 5) for the summer and fall (RMSE 29 and 44 percent, respectively) were greater than for the winter and spring (RMSE 15 and 11 percent, respectively). Discharge for summer and fall was generally overpredicted, and discharge for spring and winter was underpredicted (fig. 13).

Non-winter Stormflow

Non-winter storms flows of 1995-96 were used to assess simulated storm hydrographs because precipitation data from the two local gages (DPW and OCWA) for this period were available for comparison. The 30 storms that were used in this evaluation (summarized in appendix B) had at least 0.5 in. of precipitation but differed in volume, intensity, duration, and antecedent conditions. Differences

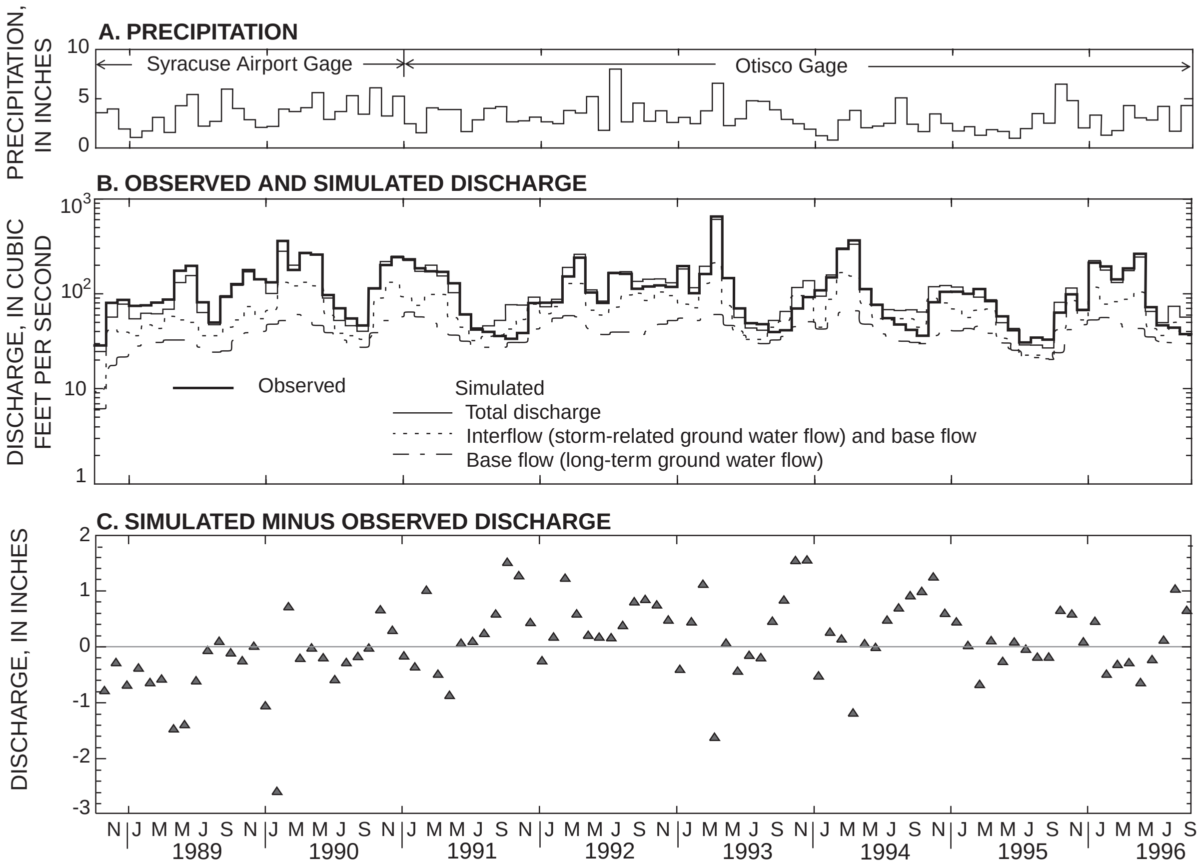


Figure 12. Monthly precipitation and discharge for Ninemile Creek at Camillus, N.Y., water years 1989-96: (A) Precipitation. (B) Observed and simulated discharge. (C) Simulated discharge minus observed discharge. (Location is shown in fig. 1)

Table 5. Observed and simulated seasonal discharges for Ninemile Creek at Camillus, N.Y., water years 1989-96.

[Location is shown in fig.1]

	Discharge, in inches			Percent Error	
Season[1]	Observed	Simulated	Difference[2]	Mean[3]	RMSE[4]
Spring	137	128	-9.0	-6.2	11
Summer	50.7	54.5	3.8	10	29
Fall	82.2	94.5	12.3	24	44
Winter	126	123	-3.0	-3.1	15

[1]Spring— April through June; Summer— July through September; Fall— October through December; Winter— January through March
[2]Observed minus simulated seasonal discharge
[3]Mean error for monthly discharge
[4]Root Mean Square Error for monthly discharge

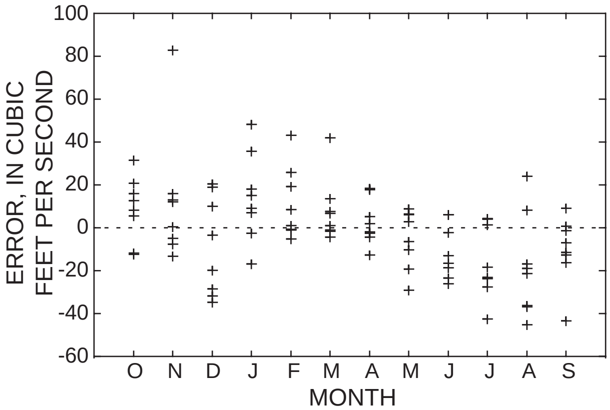


Figure 13. Monthly error for simulated discharge minus observed discharge of Ninemile Creek at Camillus, N.Y., water years 1989-96.

between observed and simulated storm volumes and peak discharges (fig. 14) are provided in appendix B and summarized in table 6.

The sum of observed non-winter-stormflow volumes differed from the sum of simulated values by an average of about 2 percent, but the difference for individual stormflow volumes ranged from -51 to 83 percent. Simulated peak discharge differed from the observed peaks by an average of about 2 percent, but the difference for individual storm peaks ranged from -77 to 280 percent. The simulated peak discharge generally occurred sooner than the observed peak but ranged from 13 hours sooner to 6 hours later.

In general, the error in the simulated stormflow volumes and peak discharges did not correlate with precipitation volume, duration, or intensity, nor with antecedent conditions or season (figs. 15, 16). Spearman correlation analysis indicates only a weak correlation between stormflow volume and peak discharge error and the time since the last precipitation of 0.10 in. or more (about 35 percent of the variance could be explained at the 95 percent confidence interval). The storm August 8, 1996, which had the second largest peak-discharge error (240 percent) and runoff-volume error (74 percent) also had the largest variation in volume among the four gages, indicating an uneven precipitation distribution across the watershed. The storm of October 21, 1995, had the largest peak-discharge error, (280 percent), and, along with the storm of August 8, 1996, also had the largest precipitation volumes of the 30 storms analyzed.

Table 6. Differences between observed and simulated 1995-96 non-winter storm runoff volume and peak discharge for Ninemile Creek at Camillus, N.Y.

[values are in percent; RMSE, root mean square error].

Water Year	Runoff volume Mean Error	Runoff volume RMSE	Peak discharge Mean Error	Peak discharge RMSE
1995	-20	30	-15	83
1996	16	34	18	69
1995-96	-1.8	32	1.9	76

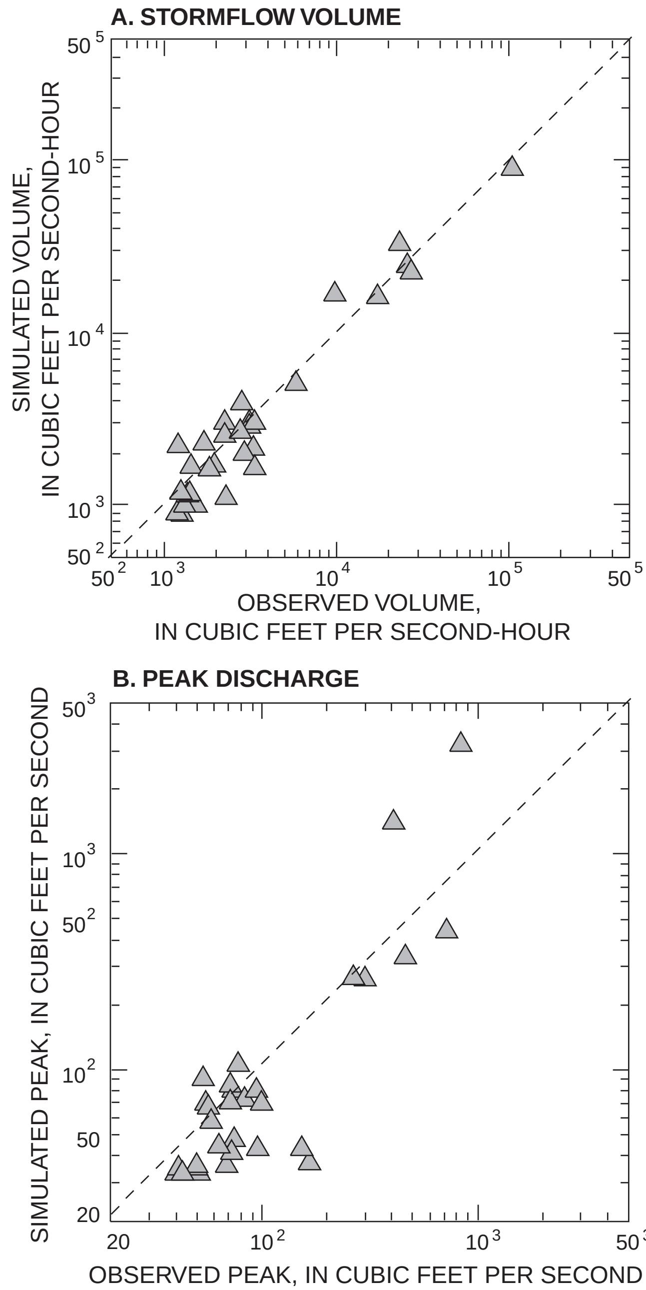


Figure 14. Simulated non-winter stormflow at Ninemile Creek at Camillus, N.Y., water years 1995-96, in relation to observed values: (A) Stormflow volume. (B) Peak discharge.

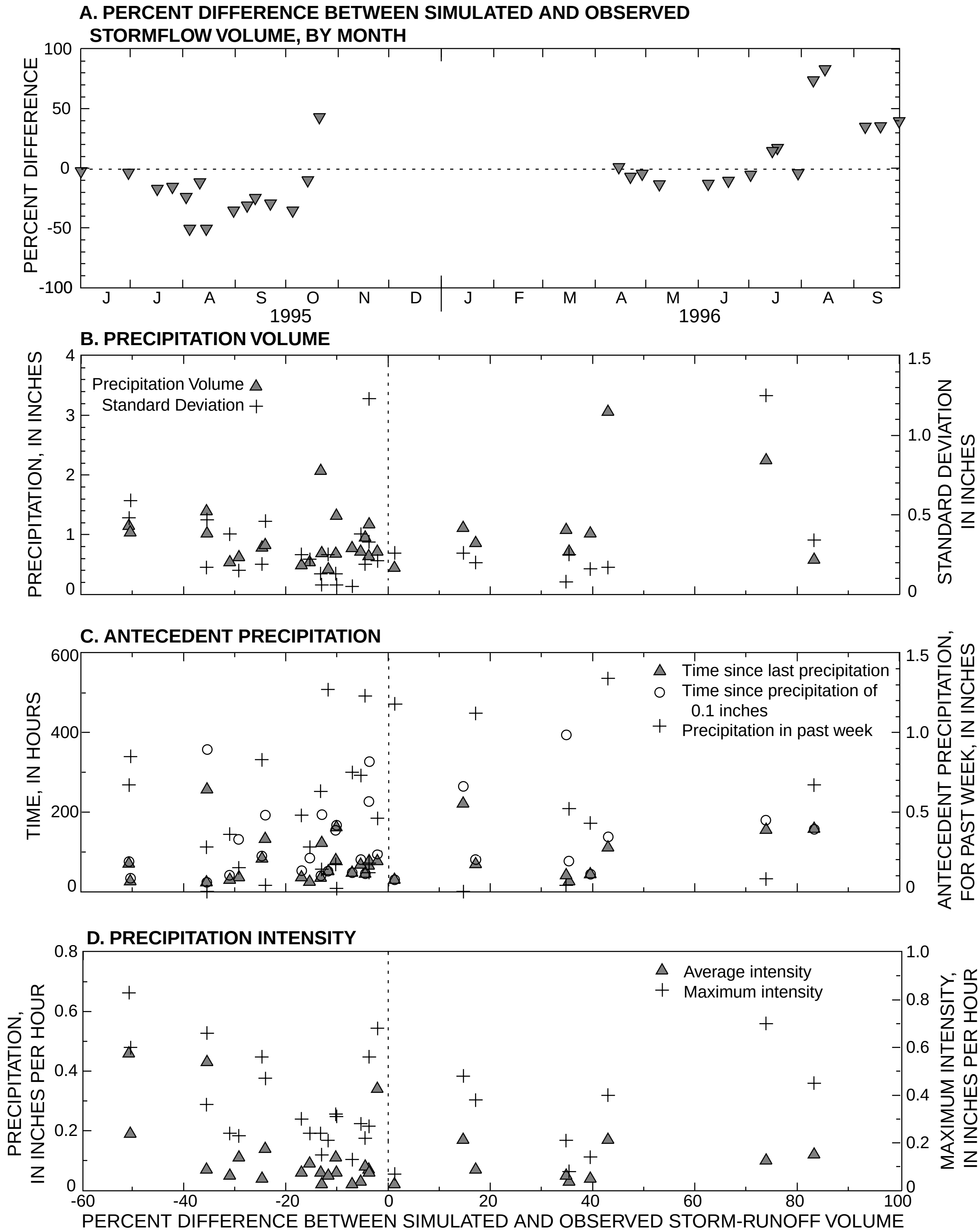


Figure 15. Percent difference between simulated and observed storm-runoff volume for Ninemile Creek at Camillus, N.Y., for 30 non-winter 1995-96 storms: (A) By month, and in relation to (B) Precipitation volume. (C) Antecedent precipitation. (D) Precipitation intensity.

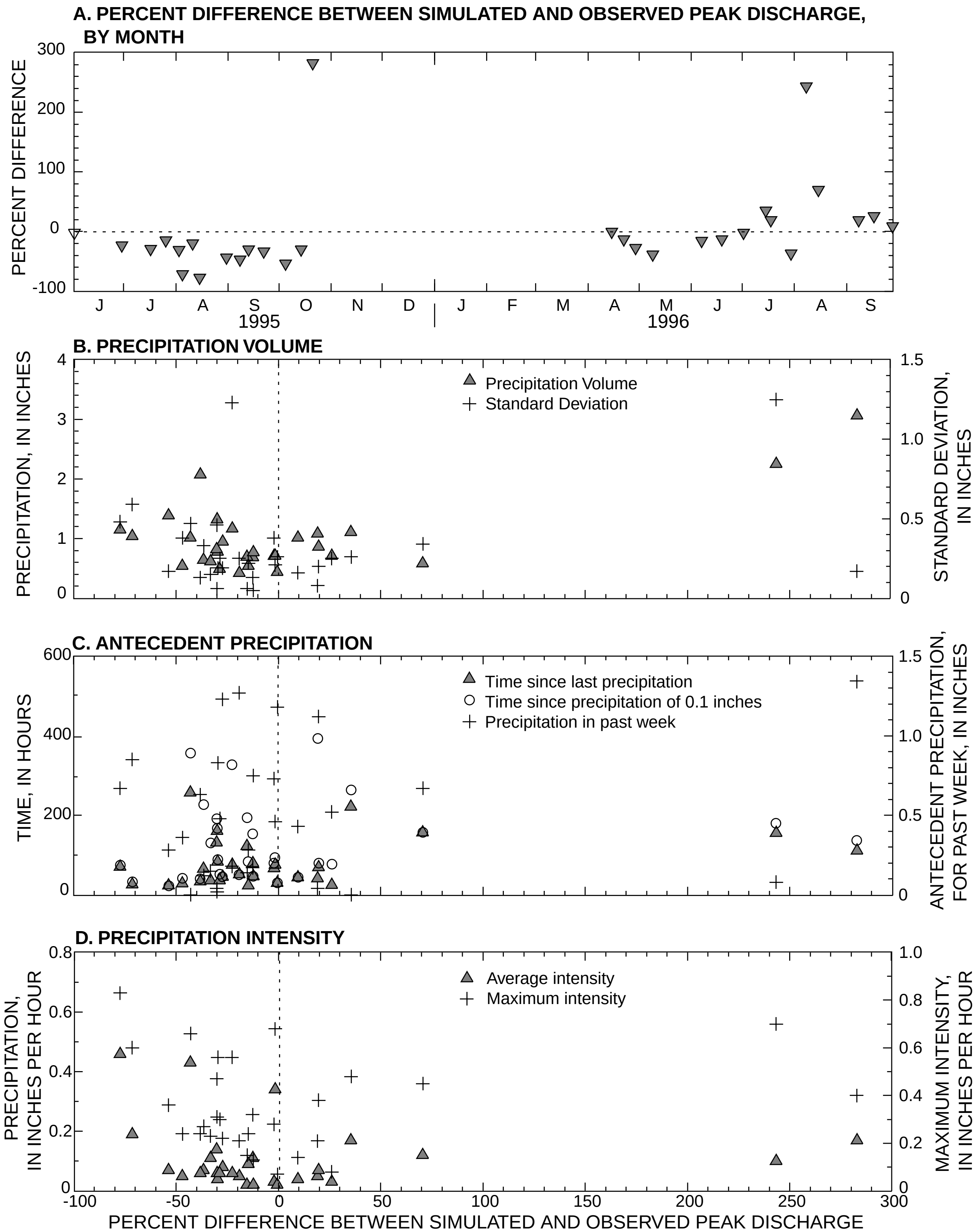


Figure16. Percent difference between simulated and observed peak discharge for Ninemile Creek at Camillus, N.Y., for 30 non-winter 1995-96 storms: (A) By month, and in relation to (B) Precipitation volume. (C) Antecedent precipitation. (D) Precipitation intensity.

Using data from the two local rain gages (DPW and OCWA) for simulations of these storms decreased the August 8, 1996 peak-discharge and volume error to 37 and 43 percent, respectively, and decreased the October 21, 1995 peak-discharge and volume error to 38 percent and 32 percent, respectively.

Winter Snowpack Buildup and Melt

Winter runoff is affected by several factors that regulate the buildup and melt of the snowpack. Only the snowpack buildup and melt for the 1995-96 winter was evaluated, however, because this was the only period for which snowpack-water-equivalent data were available. The hydrographs for water years 1989-96 (fig. 17) indicate a generally good agreement between observed and simulated winter discharge, however.

The simulated snowpack water equivalent generally agrees with the cycle of snowpack buildup and melt observed during the 1995-96 winter (fig. 17). Rain and snowmelt in January 1996 produced one of the largest recorded peak discharges (2,530 ft^3/s) on Ninemile Creek at Camillus— a estimated recurrence interval of about 15 years (Lumia, 1997); this also resulted in the highest mean daily discharge recorded at the Camillus gage (1,690 ft^3/s) since it began operation in 1958. Simulated discharge was within 3 percent of the observed peak discharge and within 10 percent of the observed runoff volume for the rain and snowmelt of January 18-20, 1996.

Other Analysis of Model Calibration

The ability of the model to produce reliable results is typically assessed through an evaluation of simulated values over a variety of conditions. Model testing (verification) can be considered an extension of model calibration; one commonly used method is to split historical data into independent data sets for calibration and verification. Hourly discharge data for the watershed upstream from the Marietta gage before October 1988 were unavailable; therefore, splitting data into independent data sets would have unduly limited the period of calibration. In addition, model “verification” is a term that Konikow and Bredehoeft (1992) argue is misleading in numerical ground-water models because it implies a degree of truth and accuracy that cannot be authenticated. A similar argument can be made for watershed models, particularly because alternative combinations of parameter values could produce similar results. Therefore, the model was evaluated through a comparison of four types of analysis of observed and simulated discharge related data; (1) streamflow traveltime, (2) flow duration, (3) log-Pearson Type III analysis, and (4) hydrograph separation.

Traveltime

Traveltime of a conservative tracer represents the combined effects of channel roughness, storage, and slope over a reach for a specified discharge (Jobson, 1996); thus, time-of-travel data collected over a range of flows can refine or verify the storage-to-discharge relations specified for a channel.

Traveltimes of a dye tracer in a 6-mi reach of Ninemile Creek from the Route 174 bridge at Martisco to the Route 5 bridge at Camillus (fig. 8) were about 6 h for discharges of 50 to 100 ft^3/s and about 4 h for a discharge of about 200 ft^3/s (Shindel and others, 1977). These values were compared with the traveltimes computed from the simulated average channel velocity for corresponding model reaches multiplied by the length of each reach (RCHRES 12, 13, 15, 19, and 20 in fig. 8). The resulting traveltimes were found to be comparable to the published traveltimes for similar flows (fig. 19).

Flow Duration

Flow-duration curves show the percentage of time a specified discharge is equaled or exceeded and represents the combined effects of climate, topography, and hydrogeologic conditions on the distribution of flow magnitude through time (Searcy, 1959). Comparison of flow-duration curves computed from observed daily discharge at Ninemile Creek at Camillus for water years 1989-96 (fig. 20A) with those computed from simulated flows indicates that the observed and simulated magnitude and frequency of daily flows are similar.

The recession-duration curve (fig. 20B), a modified form of the flow-duration curve, is computed from the ratio of the current day’s flow to the previous day’s flow during receding conditions and reflects storage, infiltration, and other factors that affect interflow (fast responding groundwater discharge from storm related streambank storage) and baseflow (ground-water discharge that is relatively constant over time). Comparison of recession-duration curves

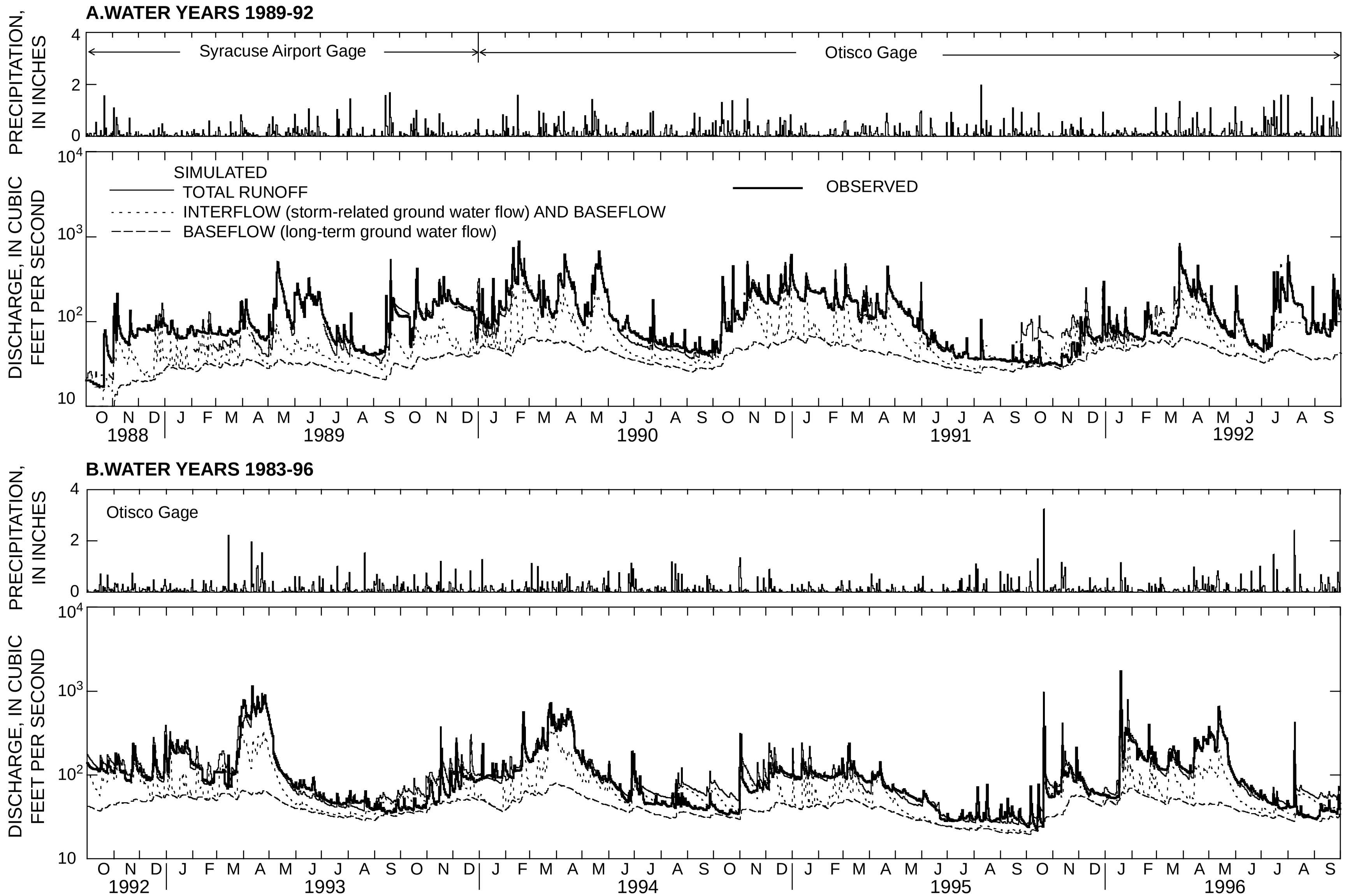


Figure 17. Daily precipitation, observed discharge, and simulated flow components for Ninemile Creek at Camillus, N.Y., water years 1989-96: (A) Water years 1989-92. (B) Water years 1993-96.

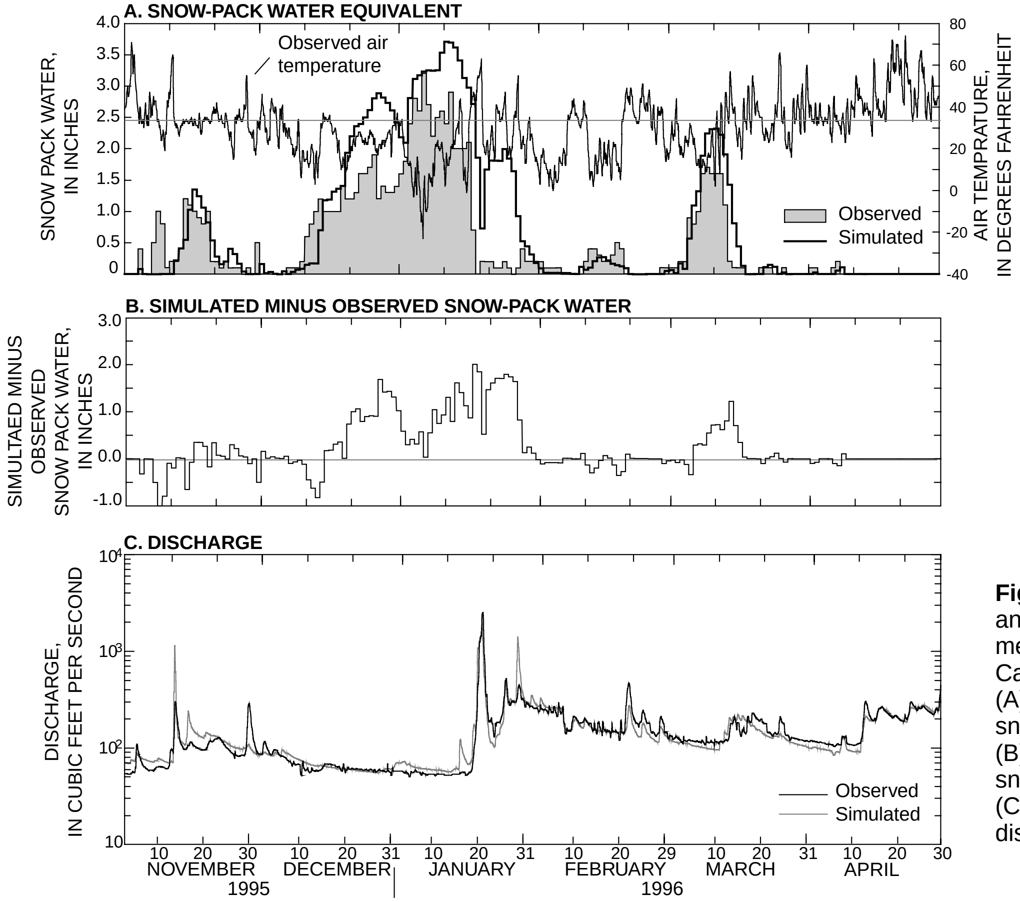


Figure 18. Winter discharge and snowpack buildup and melt at Ninemile Creek at Camillus, N.Y., 1995-96: (A) Simulated and observed snowpack water equivalent. (B) Simulated minus observed snowpack water equivalent. (C) Simulated and observed discharge.

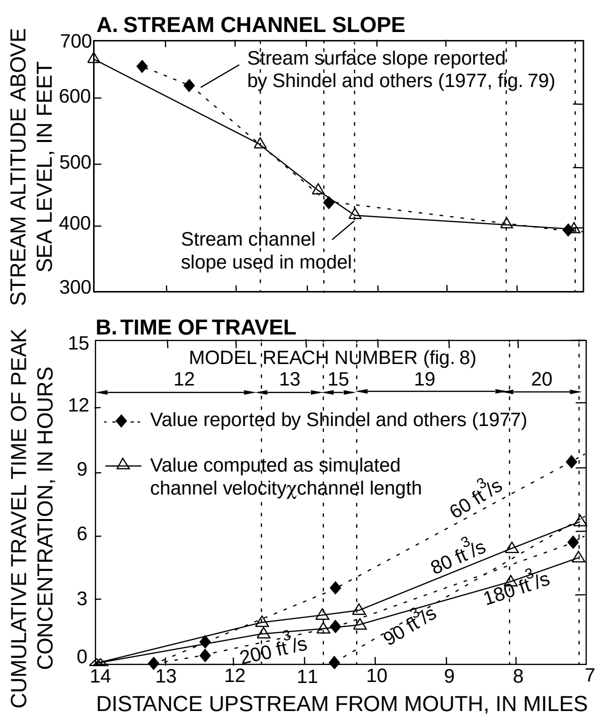


Figure 19. Observed and simulated traveltimes in Ninemile Creek for five discharges between Marietta and Camillus, N.Y.

computed from observed daily discharge at Ninemile Creek at Camillus for water years 1989-96 (fig. 20B) with those computed from simulated flows indicates similar recession rates.

Log-Pearson Type-III

Log-Pearson Type-III analysis is used for estimating the magnitude and frequency of flow characteristics and is the accepted method for calculating the probability of floodflow recurrence for the National Flood Frequency Program (Jennings and others, 1994). A log-Pearson Type III distribution was calculated for peak discharge and for the 3-day and 30-day low and high flows at Ninemile Creek at Camillus for (1) the entire period of record (water years 1959-82 and 1988-96), (2) an 8-year subset of the observed record that corresponds to the period of model simulations (water years 1989-96), and (3) simulated flows for water years 1989-96 (fig. 21). The simulated flow distributions differ from the observed flow distributions for the 1989-96 period as well as from the long-term flow distribution.

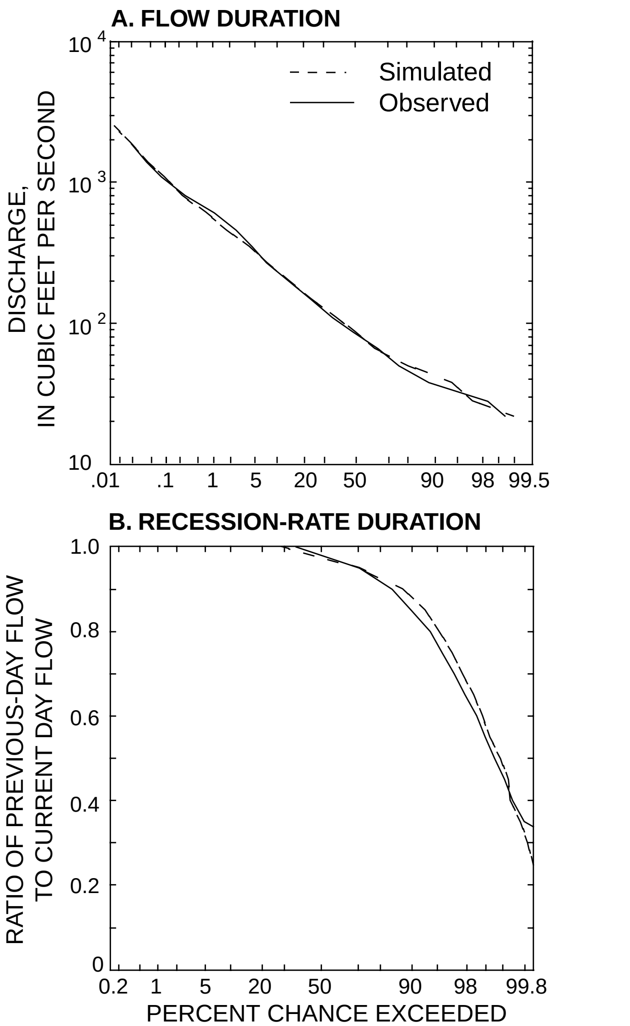


Figure 20. Duration curves for simulated and observed daily flows of Ninemile Creek at Camillus, N.Y., water years 1989-96: (A) Flow-duration. (B) Recession-rate duration.

Low Flow

The observed 3- and 30-day low-flow distributions indicate a larger low flow for a given recurrence probability for the 1989-96 water years than for the long-term record (1959-92, 1988-96); this indicates that the observed low flows during water years 1989-96 were larger than those observed during the long-term period. The simulated 3- and 30-day low-flow distribution indicates a slightly greater low flow for a given recurrence probability for the 1989-96 water years than the observed low flow for the same period (fig. 21). Bias in the 1989-96 period, and error in the simulated low-flow distribution, would be consideration in studies where low flow is of concern, such as in areas where changes in the low flow regime could affect municipal water supplies or fisheries.

High Flow

The peak-discharge distribution, and 3-day and 30-day high-flow distributions of Ninemile Creek at Camillus are depicted in figure 22, in which long-term records (water years 1960-82 and 1988-96) represent instantaneous peak discharge, and 1988-96 records represent hourly peaks. The curve for simulated peak flows (1988-96) is similar to the observed long-term curve (fig. 22A), but the simulated values for the 1988-96 are higher than the observed values for those years. The simulated 3-day high-flow curve (fig. 22B) is lower than the observed long- and short-term curves, but the simulated 30-day high-flow curve (fig. 22C) is nearly identical to the observed long- and short-term flow curves. Model bias and error in high-flow distribution would be a consideration in studies where absolute changes high flow is of concern, such as the design of bridges or culverts. Model error is less

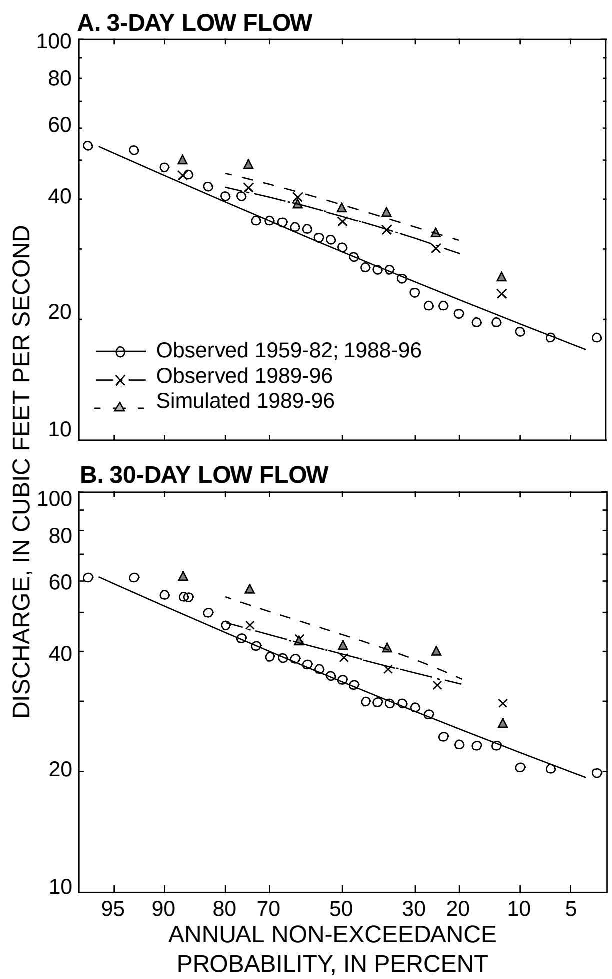


Figure 21. Log-Pearson Type III analysis of simulated and observed low-flows of Ninemile Creek at Camillus, N.Y: (A) 3-day low flows. (B) 30-day low flows.

of a consideration in studies where the model is used to examine relative changes in either low- or high-flow distribution.

Hydrograph Separation

Hydrograph-separation techniques are used to estimate individual flow components of baseflow, interflow, and total runoff. A computerized hydrograph-separation program by Sloto and Crouse (1996) that uses fixed interval hydrograph-separation techniques described by Petteyjohn and Henning (1979) was used to compare the simulated hydrograph of Ninemile Creek between the Marietta and the Camillus gages with the observed hydrograph. The contributions from base flow, interflow, and total runoff during water years 1989-96 are depicted in figure 23.

Although some differences between the simulated and observed flow components are evident, the relative magnitudes and frequencies are consistent. This indirectly indicates that the simulated hydrograph is representative of the interaction between ground-water and surface water and that the simulation of the Disappearing Lake subbasin, which probably accounts for much of the base-flow component, is adequately represented by the artificially large storage-to-discharge relation assigned to this reach.

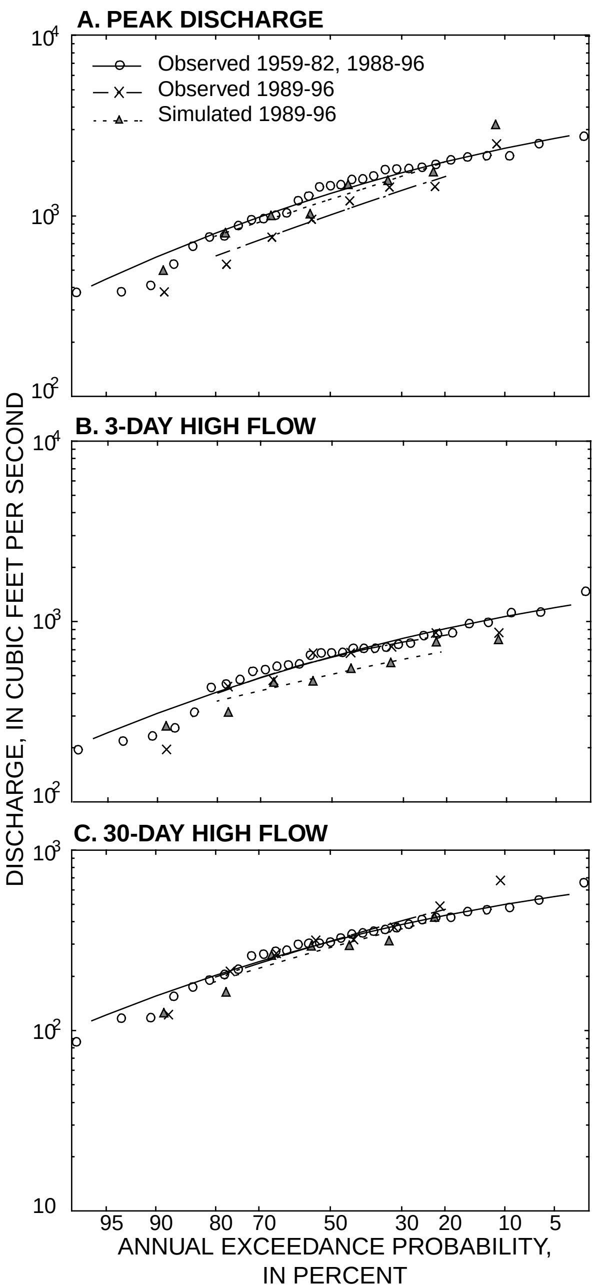


Figure 22. Log-Pearson Type III analysis of simulated and observed high-flows of Ninemile Creek at Camillus, N.Y: (A) Peak discharge. (B) 3-day high flows. (B) 30-day high flows.

Sensitivity Analysis

A sensitivity analysis describes the relative effect of individual watershed properties (model schematization and parameter values) on the runoff

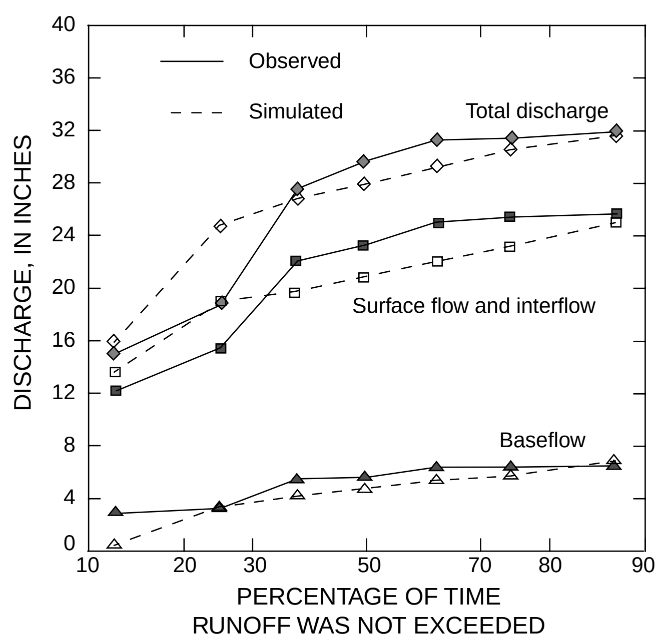


Figure 23. Hydrograph separation of simulated and observed daily flows of Ninemile Creek at Camillus, N.Y., by fixed interval method, water years 1989-96.

process. Evaluation of parameters to which the model is sensitive requires an understanding of the effect of the model schematization on the various flow components. An iterative process, whereby the value of a given parameter is varied while all others parameters are held constant, indicates the degree to which that parameter affects the model results.

Response of Overland Flow

The amount of surface runoff, interflow, and baseflow from each of the three IMPLND's and 14 PERLND's during water years 1989-96, and in a month of low flow and a month of high flow, are plotted in figure 24.

IMPLND's generate only surface runoff, and this occurs only after interception and surface storage are satisfied. Losses through evaporation (average 3.6 percent of total annual precipitation) are limited to water retained in these storage components. Consequently, a given IMPLND generates more runoff than a given PERLND, and the timing and magnitude of runoff from an IMPLND are not moderated by subsurface storage, as is flow from a PERLND. Runoff values for the three types of IMPLND's are nearly

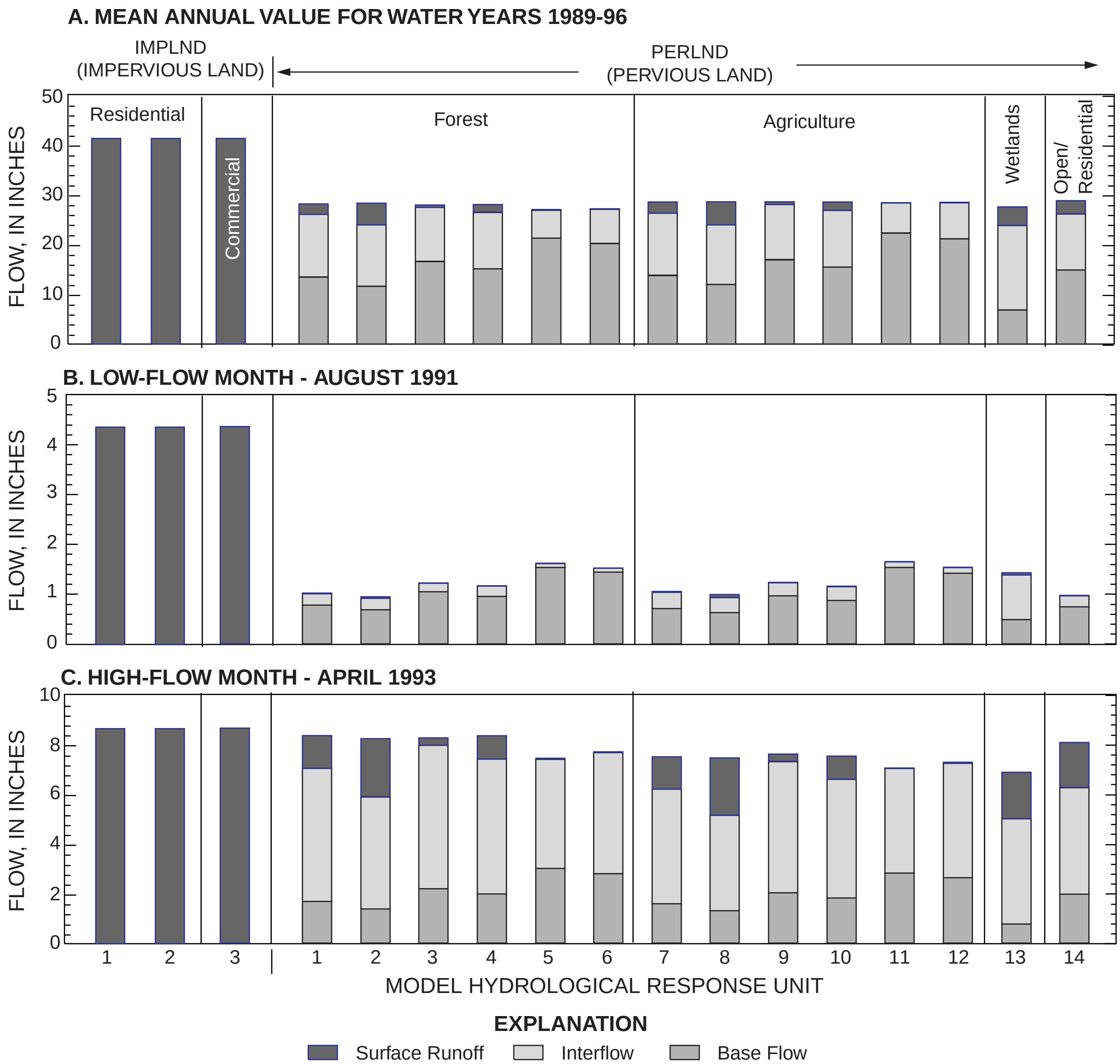


Figure 24. Simulated surface runoff, interflow, and baseflow for three types of impervious land surfaces (IMPLND's) and 14 types of pervious land surfaces (PERLND's) in the Ninemile Creek watershed model area, Onondaga County, N.Y.: (A) Average annual value for water years 1989-96. (B) A low-flow month (August 1991). (C) A high-flow month (April 1993). (Hydrologic response units are summarized in table 1)

identical (fig. 24), whether in a low-flow month (4.4 in.), a high-flow month (8.8 in.), or on an annual basis (42 in.); this indicates that runoff from IMPLND's is insensitive to the differences in slope (less than or greater than 5 percent) and land use (residential or commercial) as defined in table 1.

Annual surface-runoff rates ranged from less than 1 percent of total runoff for PERLND's with highly permeable soils (nos. 5, 6, 11, and 12 in fig. 24 and table 1) to about 10 percent for those with poorly permeable soils on slopes greater than 5 percent (nos. 2 and 8). Surface runoff from PERLND's during periods of low flow (August 1991) ranged from 0 to about 1 percent of total runoff; the only PERLND's with appreciable surface runoff that month were those with poorly permeable soils on relatively steep slopes (nos. 2 and 8) and wetlands (no. 13). Losses through evapotranspiration during this period ranged from 63 to 79 percent of total precipitation. Available soil storage is rarely exceeded during dry summer periods (periods of low precipitation and high evaporation), and surface runoff occurs only when rainfall intensity exceeds the soil's infiltration rate. Under these conditions, runoff is sensitive to parameters that represent infiltration and evapotranspiration.

Surface runoff during a high-flow period (April 1993) was less than 1 percent of total runoff for PERLND's with highly permeable soils (nos. 5, 6, 11, and 12) but was as much as 26 percent for PERLND's with poorly permeable soils (nos. 1, 2, 7, 8, 13, 14). Total runoff from any given PERLND during this high-flow period nearly equaled runoff from IMPLND's because evapotranspiration losses were small, and subsurface storage was at or near capacity. Under these conditions, runoff is sensitive to parameters that represent subsurface flow and overland flow.

Box plots of annual surface runoff, interflow, and base flow from each of the 14 PERLND's during water years 1989-96 are given in figure 25. In general, PERLND's with similar infiltration rates have similar flow distributions. PERLND's with poorly permeable soils (nos. 1, 2, 7, 8, and 13) yielded the most surface runoff and least interflow and base flow, whereas those with highly permeable soils (nos. 5, 6, 11, and 12) yielded the most interflow and base flow and the least surface runoff. PERLND's with relatively steep slopes (nos. 2, 4, 6, 8, 10, and 12) also yielded more surface runoff than those with relatively gentle slopes (nos. 1, 3, 5, 7, 9, and 11). Interflow was generally more consistent among the PERLND's than were surface runoff or base flow, although it decreased slightly as infiltration rates increased.

The wetland PERLND (no. 13) yielded the most interflow and the least base flow of all PERLND's, and its rate of surface runoff was generally comparable to those for PERLND's with poorly permeable soils (nos. 1, 2, 7, and 8). Wetlands, as simulated, are more representative of ground-water-recharge areas than of ground-water-discharge areas. Further information on the wetlands in the watershed would be needed, however, to assess (1) the representativeness of wetlands in the model, and (2) whether more than one type of wetland should be incorporated into model simulations.

The open/residential PERLND (no. 14) had one of the highest surface-runoff rates; its rate was comparable to those for PERLND's with poorly permeable soils (no. 1, 2, 7, and 8). Interflow and base flow from the open/residential PERLND was comparable to those from PERLND's with poorly to moderately permeable soils (nos. 1 through 4, and 7 through 10).

Channel Storage

Model sensitivity to the relation of stream-channel storage to discharge (RCHRES Ftable) was examined by modifying the channel storage; the error associated with the estimated storage was assumed to be larger in reaches with extensive wetlands than in those without wetlands; therefore, storage in reaches with wetlands was increased and decreased by 50 percent, and storage in reaches without wetlands was increased and decreased by only 20 percent. These changes had little or no effect on the annual or seasonal water budgets but affected storm-runoff volume and peak discharge. The average storm-volume and peak-discharge error for 30 non-winter storms (appendix B) for several different channel storage-to-discharge relations are summarized in table 7, which also gives errors for simulations that used data from the two local precipitation gages to indicate the sensitivity of simulated runoff volume and peak discharge to precipitation distribution. The changes in RCHRES storage increased the error in the simulated storm-volume and peak-discharge in about 20 storms, but these changes were typically small (fig. 26). RCHRES storage had a somewhat greater effect on peak discharges than on storm volumes. The change in the storm-volume and peak-discharge error

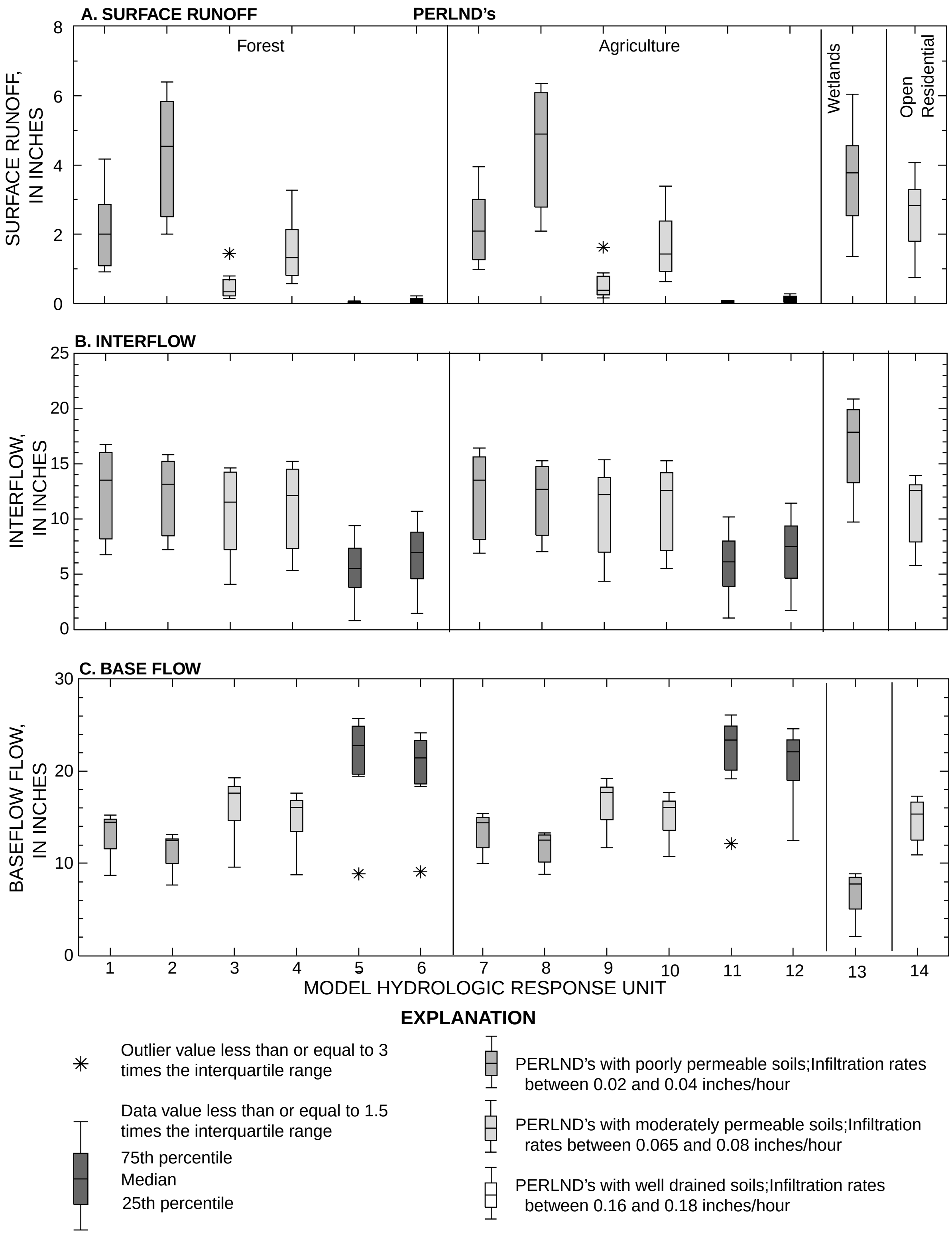


Figure 25. Distribution of simulated hydrologic-component values for each of the 14 pervious hydrologic response units (PERLND's) in the Ninemile Creek watershed model area, Onondaga County, N.Y., water years 1989-96: (A) surface runoff. (B) Interflow. (C) Base flow. (Hydrologic response units are summarized in table 1)

Table 7. Mean error and root mean square error (RMSE) for 30 non-winter-storm volumes and peak discharge in Ninemile Creek at Camillus, Onondaga County, N.Y., 1995-96

[Values are in percent. Storms are summarized in appendix B. Gage locations are shown in fig. 8]

Water Year	Volume: Mean error	Volume: RMSE	Peak discharge: Mean error	Peak discharge: RMSE
A. Calibrated Model Values				
1995	20	30	15	83
1996	-16	34	-18	69
1995-96	1.8	32	-1.9	76
B. Channel-storage modifications				
RCHRES decreased by 20 percent				
1995	22	31	20	74
1996	-15	33	14	58
1995-96	3.3	32	3.2	67
RCHRES increased by 20 percent				
1995	22	32	135	84
1996	-37	122	-32	110
1995-96	-7.5	89	-9.3	96
C. Simulations based on data from two local rain gages				
1995	20	48	29	43
1996	12	18	22	25
1995-96	16	36	26	35

that result from changes in channel storage are relatively small compared to the corresponding errors that result from simulations based on data from the two local precipitation gages (table 7), which decreased the largest storm-volume and peak-discharge errors (fig. 26).

Parameter Values

The response of the model to a specified change in a parameter value indicates the relative effect of that parameter on simulated runoff. The sensitivity analysis used only constant changes in parameter values, and the values were applied equally over seasons and among the hydrological response units.

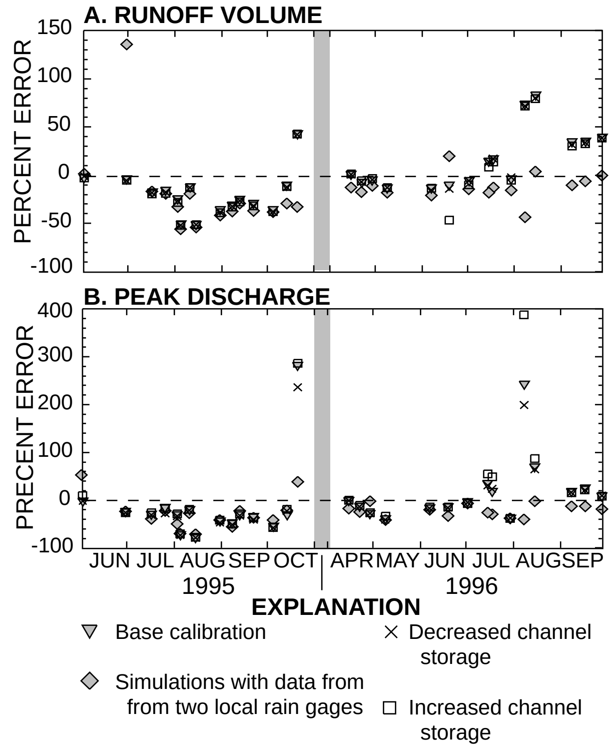


Figure 26. Percent error in four simulations of Ninemile Creek discharges at Camillus, N.Y., during 30 non-winter-storms of 1995-96: (A) Runoff volume. (B) Peak discharge.

Model sensitivity to nine PERLND parameters (table 8) was examined by doubling, then halving, the calibrated parameter value and measuring the effect on (1) the total runoff volume, (2) high- and low-flow distribution, (3) seasonal and summer runoff, (4) peak stormflow, and (5) interflow and surface runoff. The ground-water-recession parameter KVARY was increased and decreased by 20 percent of the calibrated value and the related AGWRC parameter was decreased by 20 percent but not increased because it calibrated value is near the maximum allowed value. The effect of altering the calibrated values is expressed in table 8 as the percent error relative to the observed values (for the six runoff characteristics) and as the percentage of total runoff that is represented by interflow and surface runoff. Model sensitivity to a parameter is indicated by the change in the simulated runoff values from their calibration values. For instance, the model is sensitive to INFILT in all phases of runoff except total runoff volume and summer runoff volumes. Winter and storm-runoff volumes indicated little change with respect to parameter value changes and are not reported. The following paragraphs summarize the

Table 8. Sensitivity of runoff characteristics in Ninemile Creek, Onondaga County, N.Y., to selected model PERLND (pervious area) parameters, October 1988 to September 1996.

[Error is the percent difference between simulated and observed values]

Parameter[1] and factor by which it was multiplied		Runoff error (percent difference						Percent of Total Runoff	
		Total Runoff Volume	50-percent low flow[2]	10-percent high flow[3]	Seasonal runoff volume[4]	Summer runoff volume	Average Storm Peak[5]	Inter-flow	Surface Runoff
Calibrated model values ⟶		0.79	3.5	-4.0	0.40	14	65	25	4.5
INFILT	(2x)	0.84	3.6	-3.9	0.10	14	44	25	4.6
INFILT	(0.5x)	0.87	-4.2	2.7	9.9	13	120	27	10
LZSN	(2x)	-0.51	2.8	-6.1	4.3	19	81	23	4.3
LZSN	(0.5x)	1.7	1.8	-1.6	7.0	0.70	60	28	5.1
UZSN	(2x)	-0.42	0.75	-6.4	8.0	7.5	19	24	3.9
UZSN	(0.5x)	2.10	7.2	-2.5	8.0	24	100	27	5.2
INTFLW	(2x)	1.0	3.9	-5.2	0.50	8.0	14	31	1.6
INTFLW	(0.5x)	0.45	1.9	-1.6	0	22	110	16	9.9
IRC	(2x)	0.70	6.6	-7.4	1.4	17	65	25	4.6
IRC	(0.5x)	0.90	-5.0	3.8	1.2	30	91	25	4.6
LZET	(2x)	0	2.2	-4.6	0.50	12	50	25	4.4
LZET	(0.5x)	2.9	6.1	-2.0	0.90	17	96	28	5.4
INTCEP	(2x)	0.39	1.2	-3.7	3.3	11	65	26	4.8
INTCEP	(0.5x)	1.2	5.4	-4.3	2.0	15	65	25	4.4
NSUR	(2x)	0.73	4.1	-5.1	0.70	10	39	26	3.4
NSUR	(0.5x)	0.84	2.8	-2.9	0.30	18	96	24	5.9
LSUR	(2x)	0.73	4.1	-5.1	0.70	10	34	26	3.5
LSUR	(0.5x)	0.84	2.8	-3.0	0.30	19	91	24	5.9
KVARY	(2x)	0.90	2.9	-3.7	2.1	12	62	25	4.6
KVARY	(-0.2x)	0.65	4.3	-4.4	1.8	16	65	25	4.6
AGWRC	(-0.2x)	3.0	-15.	5.4	29	2.9	70	25	4.6

[1]INFILT, Infiltration rate of soil
LZSN, Lower zone storage nominal
UZSN, Upper zone storage nominal
LZET, Lower zone evapotranspiration
IRC, Interflow recession parameter
INTFLW, Interflow inflow
INTCEP, Interception storage
KVARY, Ground water recession behavior
LSUR, Length of surface overland flow
NSUR, Roughness of surface overland flow
AGWRC, Active ground water recession rate

[2]50-percent flow is the flow that is equalled or exceeded 50 percent of the time (low flow)

[3]10-percent flow is the flow that is equalled or exceeded 10 percent of the time (high flow)

[4]Difference between summer and winter runoff

[5]Average of 30 non-winter 1995-96 non-winter storms (appendix B)

sensitivity of the model runoff characteristics listed in table 8 to the various parameters.

Total runoff volume is most sensitive to evapotranspiration from the lower soil- zone (LZET), which in turn is affected by the available lower-zone storage (LZSN). Total runoff volume is also moderately affected by upper soil-zone storage (UZSN), interception storage (INTCEP), and the active ground-water recession rate (AGWRC).

50-percent low-flow and 10-percent high flow[b] are inversely proportional in the sense that a change in value that decreases low flows increases high flows, and a change that increases low flows decreases high flows. These terms are most sensitive to the active ground water recession rate (AGWRC), and moderately sensitive to interflow-recession coefficient (IRC) and infiltration rate (INFILT).

S*easonal and summer runoff volumes* are most sensitive to soil-infiltration rate (INFILT), which controls the amount of water that drains to the subsurface, and by upper and lower zone soil storage (UZSN and LZSN), which determine the availability of water for evapotranspiration. Active ground-water recession rate (AGWRC) then regulates the rate at which water is released from active ground water storage. Increases in INFILT appear to have little or no effect on seasonal flow distribution and other runoff characteristics, probably because the calibrated INFILT value is high and, thus, allows most rainfall to infiltrate, so that further increases in this parameter value have little effect.

Peak stormflow is affected most strongly by interflow (INTFLW) and upper zone storage (UZSN) and, to a lesser extent, by infiltration (INFILT), interflow recession coefficient (IRC), surface roughness (NSUR), and length of the overland-flow surface (LSUR). Although peak flows appear to match the observed values poorly (table 8), the error values are skewed by data from stormflows of October 21, 1995 and August 8, 1996 which had large errors associated with precipitation characteristics. Excluding these storms from the computation and replacing them with values for the snowmelt and runoff event of January 19, 1996 gives a peak discharge error of only -11 percent, which indicates a satisfactory calibration of the storm hydrograph.

[b]50-percent flow is the flow that is equalled or exceeded 50 percent of the time (low-flow) and the 10-percent flow is the flow that is equalled or exceeded 10 percent of the time (high-flow)

Interflow and surface runoff as a percentage of the total runoff are most affected by interflow (INTFLW) and decreases in soil infiltration rate (INFILT). The distribution of interflow and surface runoff would likely be sensitive to increases in INFILT if its calibrated value did not already allow most rainfall to infiltrate.

Changes in some PERLND parameters improved model fit for some runoff characteristics but decreased it for others. Thus, the calibrated parameter values appear to yield least overall model error.

MODEL APPLICATION

A watershed-runoff model can be used to assess a variety of questions relating to expected development and population growth within a watershed and their effects on water resources. For example, engineers and planners often require hydrologic information to plan and design stormwater-drainage systems, culverts, detention basins, and other stormwater facilities. Two applications of the runoff model were examined in this study— (1) the effects of increased development in the Ninemile Creek watershed on runoff, and (2) the potential for increased flooding of Ninemile Creek at Camillus as a consequence of altering the time of peak flows by stormwater detention in newly developed areas.

Effects of Development on Runoff

The watershed model was used to compare runoff resulting from incremental increases in developed area with runoff under present conditions. Areas of new development were represented in two ways in the model— one as “hydrologically ineffective impervious” open/residential area, and the other as “hydrologically effective impervious” area. Neither the lateral extent nor the type of future urbanization are known; therefore, these two approaches represent lower and upper limits, respectively, of potential hydrologic changes associated with development. The changes reported herein that result from simulated development are relative to the calibrated model (referred to as the “base” calibration) for current conditions unless otherwise noted.

The extent of future development in the watershed was estimated on the assumption that development would be restricted to suitable areas as defined in guidelines by Burchell and others (1994). Lands that were deemed minimally developable include (1) those with slopes greater than 10 percent, which were given a maximum development potential of 30 percent of their area, and (2) wetlands, which were considered undevelopable (zero potential). Lands with slopes of 5 to 10 percent were considered moderately suitable for development and were given a maximum development potential of 70 percent of their area, and lands with slopes of less than 5 percent were considered to be fully developable and were given a development potential of 100 percent of their area.

Representing an entire developed area as an impervious surface (IMPLND) is generally not representative of an urbanizing area because it does not represent the “green space” that remains after development. Therefore, the maximum potential IMPLND area within the watershed was estimated from the suitability criteria previously described, in combination with current land-use zoning. The land-zoning classifications and amount of impervious area associated with each zone are listed in table 9. For an example, if 1,000 acres that are currently in agriculture were zoned for moderate-density residential development (25 percent development density per acre), and if 500 acres were considered moderately suitable for development (70 percent developable) and 500 acres were considered fully developable, the estimated impervious area is 212.5 acres, or about 21 percent of the total area. Applying this technique over the entire model area yielded a maximum development potential of 59 percent of the watershed, of which only about 7 percent would be designated as hydrologically effective impervious area under fully developed conditions. The calculated developed area and impervious area, in percent of the total watershed area, are summarized in table 10 for current conditions and incremental increases in development (herein referred to as buildup). Changes in zoning or in building practice could alter these percentages, however.

Table 9. Maximum future development density and percent impervious area estimated for six land-zoning categories in Ninemile Creek watershed, Onondaga County, N.Y.

[Zoning classification based on zoning maps of the Towns of Camillus, Eldridge, Marcellus, and Skaneat.eles]

Zoning Classification	Development Density (percent per acre)	Impervious Area (percent)
Rural residential	10	5
Low-density residential	20	10
Moderate-density residential	25	25
High density residential	30	30
Commercial	100	100
Municipal (parks)	No change	0

Representing Future Development as an Open/Residential Land

Representing future development as open/residential land (PERLND 14 in table 1), produced higher surface-runoff rates than did all other PERLND’s except those with poorly permeable soils on relatively steep slopes (See “Response of Overland Flow” on page 29.). Simulations of runoff from fully developed open/residential land indicated that high flows (flows that occur 10 percent of the time or less) during the 1998-96 water years increased by about 5 percent from an average of 110 in. to 116 in., but individual peak stormflows for 30 non-winter storms increased by an average of about 10 percent for a 10-percent buildup to about 37 percent for a 100-percent buildup (table 11). Increases in peak discharge in summer storms were larger than in fall and spring storms; 100-percent buildup simulations indicated peak-discharge increases of 64 percent for summer storms and 21 percent for spring and fall storms (table 11). The average increases in storm-runoff volumes ranged from 1.4 percent for a 10-percent buildup to 11 percent for a 100-percent buildup. Four hydrographs showing the predicted storm discharges of Ninemile

Table 10. Amount of developed area and impervious area in percent of the total watershed, for current conditions and for incremental increases in development in the Ninemile Creek watershed, Onondaga County, N.Y.

Percent increase in development	Percent of total watershed area: Developed area	Impervious area
0 (current conditions)	7	0.4
10	12	0.7
50	33	3.4
100	59	6.7

Table 11. Predicted increases in discharge in Ninemile Creek at Camillus, Onondaga County, N.Y., resulting from future development as open/residential land and as impervious land.

Percent Buildup	10-percent high-flow volume[1] (inches)	Average percent increase in stormflow					
		Peak discharge[2]			Runoff volume		
		Non-winter	Summer	Spring and fall	Non-winter	Summer	Spring and fall
A. Buildup as Open/Residential Land							
10	111	10	26	1.9	1.4	2.6	1.7
50	113	22	43	10	5.8	12	7.8
100	116	37	64	21	11	24	15
B. Buildup as Impervious Land							
10	111	13	18	11	2.1	1.9	1.8
50	111	38	69	32	7.5	5.5	6.1
100	112	68	125	56	13	9.0	11

[1] 10-percent high-flows are flows that occurred 10 percent of the time or less during the 1989-96 water years.
[2] Average increases in relation to calibrated vales for 30 non-winter 1995-96 storms listed in appendix B.

Creek at Camillus with future development represented as open/residential land are shown in figure 27. The added development resulted in a slight decrease in peak discharge for the large rainfall-snowmelt event of January 1996, probably because snowmelt in open/residential areas is relatively fast compared to that in other PERLND's and runoff from snowmelt therefore preceded the main peak runoff from snowmelt and precipitation. Peak discharges of the two summer storms increased in response to increased development— the increase for the 100 percent buildup simulation was significantly larger for the July 1996 (170 percent) than that of the June 1995 storm (38 percent). This probably was because the July storm had about 36 percent more precipitation than the June storm, even though antecedent conditions were dryer, and precipitation intensity was less— factors would normally be expected to damp the increase in peak discharge. The July storm produced more surface runoff than the June storm probably as a result of the soil-water-storage in the upper zone exceeding capacity.

The effects of soil-water storage are also exemplified by the watershed's response during spring runoff (fig. 27A, C). Peak discharge increased by 56 and 15 percent for the April 1995 and April 1996 storms, respectively, in simulations of 100-percent buildup, probably because soil-water storage during the spring is less variable (usually at or near saturation) than at other times; thus, the increase in peak discharge was less variable than for the summer storms— the standard deviation of the percent increase in peak discharge was 15 ft^3/s for spring and fall storms and 40 ft^3/s for summer storms (Storm data are summarized in appendix B).

The response of the watershed to future development will depend on several factors, however, among which is the amount of impervious surface area relative to the amount of pervious area to which it drains. If infiltration of water in pervious areas that receive runoff from impervious surfaces is less then predicted (such as where a relatively large impervious area drains to a relatively small pervious area), the model will underpredict surface runoff. Therefore, a second series of simulations was run in which the developable land was represented by an appropriate amount of impervious area, to provide an upper estimate of the potential increases in runoff that area associated with development.

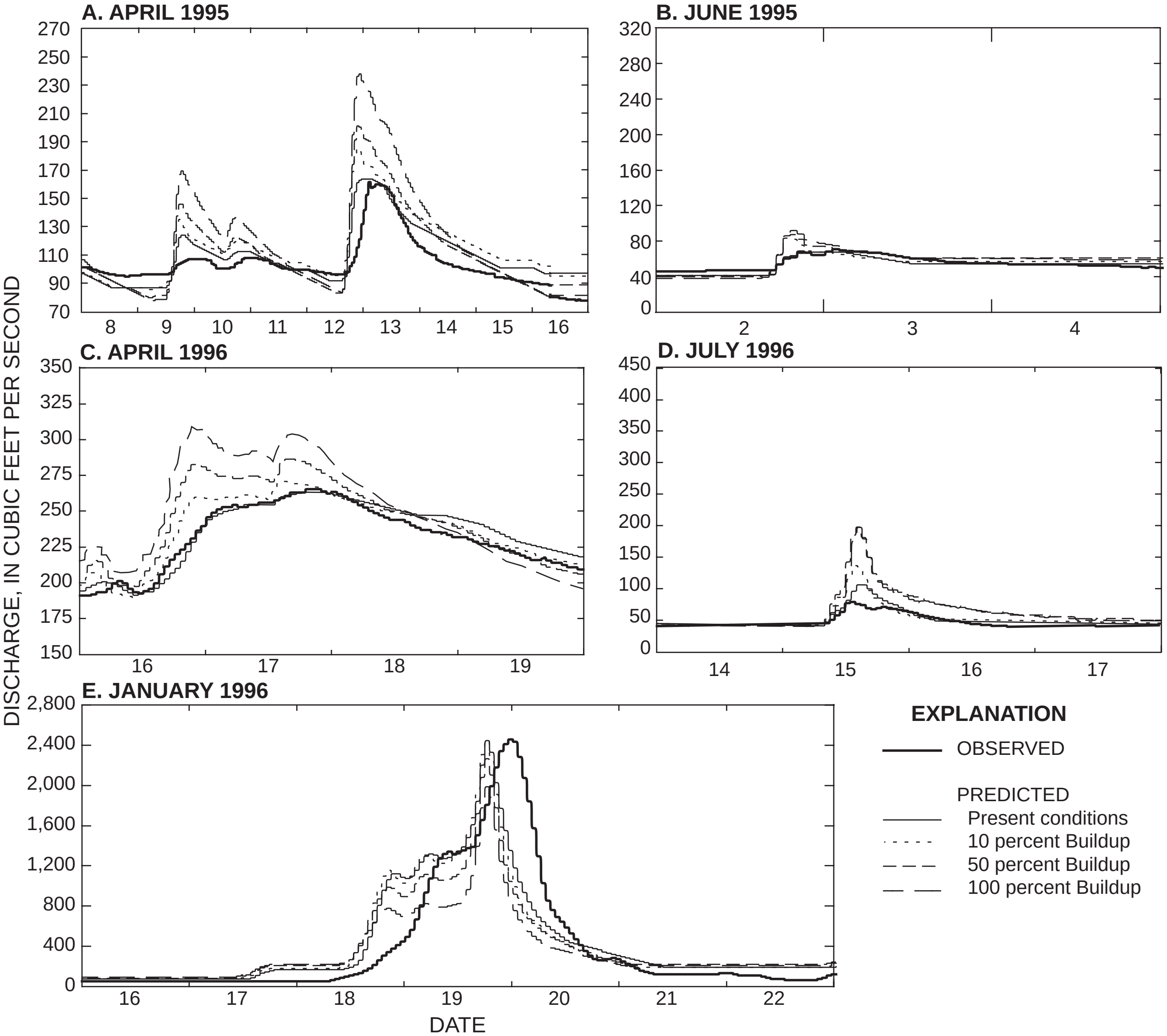


Fig. 27. Observed and simulated spring, summer, and winter stormflows of Ninemile Creek at Camillus, N.Y. under present conditions and with future development represented as open/residential land at 10-, 50-, and 100-percent buildup.

Representing Future Development as Impervious Land

Representing future development as impervious land (areas that are hydrologically effective impervious surfaces) entailed increasing the area of IMPLND, which generates only surface runoff and with little loss through evaporation, and decreasing appropriate PERLND's by an equal area. Runoff from IMPLND's was routed directly to stream channels.

Simulations of development as an impervious surface indicated that stormflows that occur 10 percent of the time or less (highest flows) during the 1998-96 water years increased by about 2 percent from an average of 110 in. to 112 in., but the increases in individual peak stormflows for the 30 non-winter storms ranged from an average of about 13 percent for a 10-percent buildup to 68 percent for a 100-percent buildup (table 11). Increases in peak discharge from summer storms were larger than those from spring and fall storms; simulations of 100-percent buildup indicated that peak discharges increased by 125 percent for summer storms and by 56 percent for spring and fall storms (table 11). The average increases in storm-runoff volumes ranged from 2.1

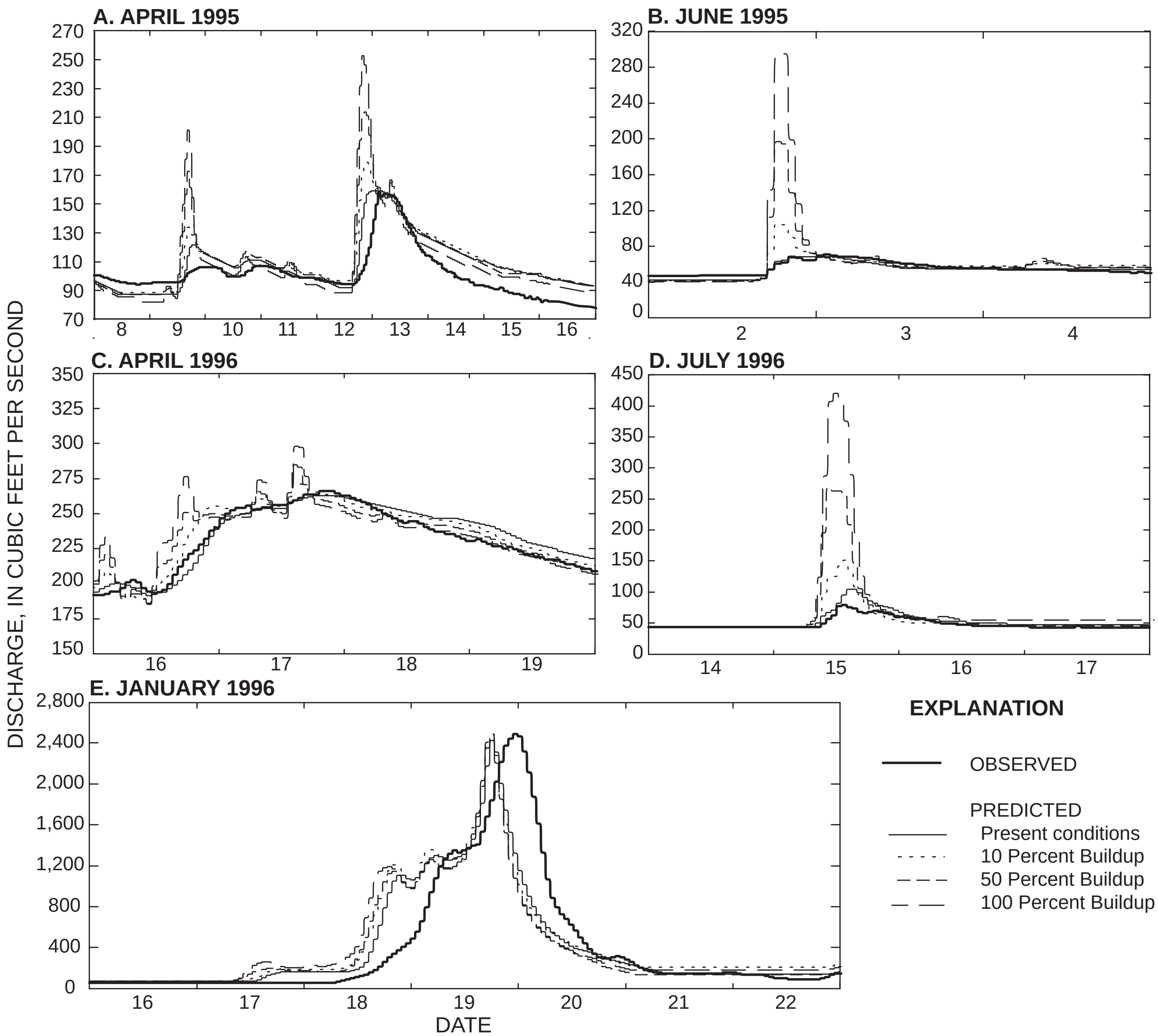


Figure 28. Observed and predicted spring, summer, and winter stormflows of Ninemile Creek at Camillus, N.Y. under present conditions and with future development represented as impervious land at 10-, 50-, and 100-percent buildup.

percent for a 10-percent buildup to 13 percent for a 100-percent buildup.

Four hydrographs showing the predicted storm discharges of Ninemile Creek at Camillus with future development represented as impervious land are shown in figure 28 (which uses the same storms as figure 27, where development is represented as open/residential land). The results show no significant effect on the January 1996 rainfall-snowmelt event but indicate a large and relatively consistent increase in peak discharge for both summer storms— the increase ranges from about 40 percent for a 10-percent buildup to about 300 percent for 100-percent buildup. Unlike the simulations with future development represented as open/residential land, antecedent conditions for the simulations with impervious land had little effect on runoff. Runoff from impervious land responds quickly to precipitation and therefore, was more sensitive spatial to variations in precipitation than runoff from pervious land. This is apparent in the wide standard deviation of the percent increase in peak discharges for the 30 summer storms listed in appendix B— from 28 ft^3/s for a 10-percent buildup to 207 ft^3/s for 100-percent buildup.

Model results also indicate that increased impervious land would cause an increase in peak flow of spring storms but the increase would be relatively small compared to that of summer storms because pervious land is at, or near, saturation during this time and, therefore responds to precipitation as though it were impervious. Peak flows for a 100-percent buildup increased by 40 percent for the April 1995 storm and by 13 percent for April 1996 storm.

Comparison of Runoff from Open/Residential Land with Runoff from Impervious Land

Runoff after future development will probably reflect a combination of open/residential and impervious lands, but the best representation of these factors in the model is uncertain because future drainage patterns are unknown. Comparing the simulated runoff from open/residential land with that from impervious land provides a general indication of the watershed's probable response to future development,however.

Peak stormflow and storm-runoff volumes of the 30 non-winter storms in simulations with development as open/residential land and as impervious land are plotted in figure 29 in relation to the simulations of

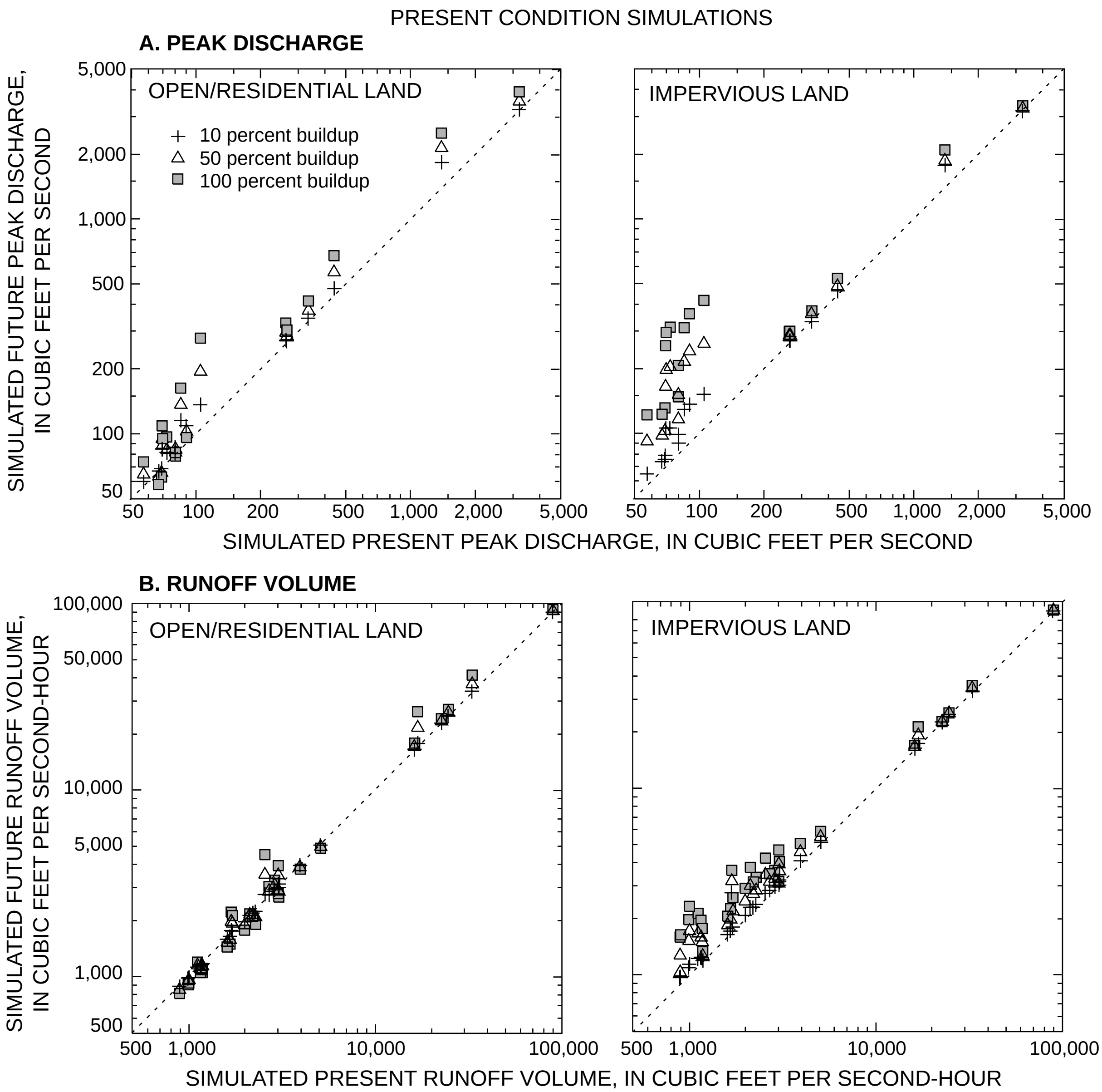


Figure 29. Simulated 1995-96 stormflows of Ninemile Creek at Camillus, N.Y., resulting from 10-, 50-, and 100-percent buildup as open/residential land and as impervious land in relation to simulated present stormflow: (A) Peak discharge. (B) Runoff volume. (Storm data are listed in appendix B)

present conditions. In general, both types of development resulted in increased peak stormflow, but those from impervious land were larger.

The two types of simulations produced differing distributions of flow components, as indicated in a plot of baseflow, interflow, and total runoff for the July 15, 1996 storm (fig. 30). Baseflow was only slightly lower in impervious-land simulations than in open/residential-land simulations. The impervious-land simulations for 100-percent buildup indicated slightly less infiltration of precipitation over the watershed than the open/residential simulations because infiltration was affected in only about 7 percent of the watershed in the impervious-land simulations. Areas with a large percentage of impervious land would have relatively little infiltration and, thus, would produce only a small baseflow. tributaries in such areas could have diminished low flows. The total predicted baseflow contribution to the July storm-runoff (fig. 30) was 0.116 in. for the impervious land simulations and 0.118 in. for the open/residential land simulations.

The interflow component for the July 1996 storm was 74 percent smaller in impervious-land simulations (0.029 in.) than in open/residential-land simulations (0.111 in.), whereas the surface-runoff component was about 165 percent greater in impervious-land simulations (0.114 in.) than in open/residential-land simulations (0.043 in). Accordingly, the peak discharges in impervious-land simulations were larger, and the response to precipitation more rapid, than in open/residential-land simulations. Differences among flow components in both types of simulation diminished as soil-water storage approached capacity. Once this capacity is reached, open/residential land produces mostly surface runoff and, thus, responds as though it were impervious.

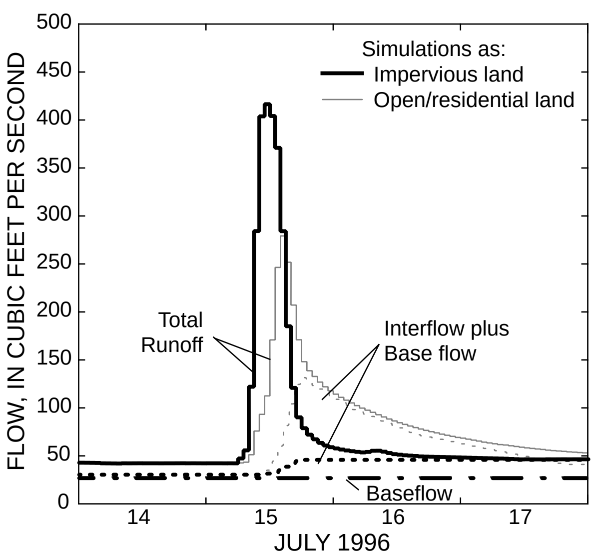


Figure 30. Simulated runoff components of Ninemile Creek at Camillus, N.Y., during storm of July 15, 1996, with buildup represented as open/residential land and as impervious land.

Effects of Development on High- and Low-Flow Distribution

As a watershed becomes developed, peak stormflows and runoff volumes typically increase, and the response time of runoff to precipitation decreases. The magnitude of these changes are usually greater among low-order floods (those that occur frequently) than among large floods (Sauer and others, 1983; Guay, 1996). The effects of urbanization on flow distribution were examined through a comparison of Log-Pearson Type-III probability curves for peak discharge, 3-day high and low flows, and 30-day high and low flows from simulations with development represented as impervious land. The impervious-land simulations were selected over the open/residential-land simulations for this analysis because the effects of impervious-land are generally more pronounced than those of open/residential and, thus, represent an upper limit (“worst case”) of the effects of urbanization on runoff. An exception to this might be during extended periods of high flow in which simulated high flows that occur 10 percent of the time or less were affected more by open/residential land development than by impervious-land development; the calibrated 10-percent high-flow distribution (110 in.) for 100-percent buildup increased by about 5 percent (116 in.) in open/residential-land simulations and by about 2 percent (112 in.) in impervious-land simulations (table 11).

Annual peak discharge for a given Log-Pearson Type-III probability distribution (fig. 31) increased for each increment of buildup (10-, 50-, and 100-percent), and each increment of buildup produced a relatively consistent increase in peak discharge of about 200 ft^3/s for each recurrence probability; therefore, as the magnitude of the peak discharge increases (recurrence probability decrease), the relative increase in peak discharge from development diminishes. The predicted increases in peak discharge for most non-winter storms (summarized in appendix B) approached, but did not exceed, the observed annual log-Pearson Type-III peak discharge (about 450 ft^3/s). Log-Pearson Type-III analysis of annual peak discharges for water years 1988-96 indicates that, for simulations of 100-percent buildup as impervious land, peak discharges that now occur on average once every 2 years will recur once every 1.5 years, and peak discharges that occur on average once every 5 years will recur once every 3.3 years. Peak discharges for large-magnitude (infrequent) storms did not increase significantly with increased development, however, as evidenced by the January 1996 storm (fig. 28). Thus, development is not expected a cause major increases in flooding of Ninemile Creek at Camillus during large storms but will increase the frequency and magnitude of flooding during small storms, and this, in turn, could change the rate of channel aggradation and degradation, and of streambank erosion which could affect the creek's ecology and geomorphology (Leopold and others, 1964).

Channel storage can have a mitigating effect on peak runoff (Sauer and others, 1983); thus, the extensive wetlands along Ninemile Creek and its tributaries (fig. 8) affect peak discharges. These wetlands were represented in the model as channels with a large storage-to-discharge ratios. If storage was overestimated, the storm runoff and peak discharges are probably underestimated, and if storage was underestimated, the storm runoff and peak discharges are probably overestimated. Additional time-of-travel studies would be needed to refine the channel storage-to-discharge ratio for these reaches to improve confidence in the model predictions.

The additional runoff caused by development as impervious land does not appear to affect high flows that last for extended periods. The log-Pearson Type-III distribution curves of predicted 3- and 30-day high flows (fig. 31B, C) are nearly identical to the base-calibration curve, which represents present conditions. Low-flow distributions are affected somewhat by development, however; increased development slightly decreased the 3-day low-flow probability and increased the 30-day low-flow probability. Low flows generally decrease because of decreased infiltration caused by development, but extended periods of low flow (such as the 30-day low flow) are typically offset by runoff from periodic storms.

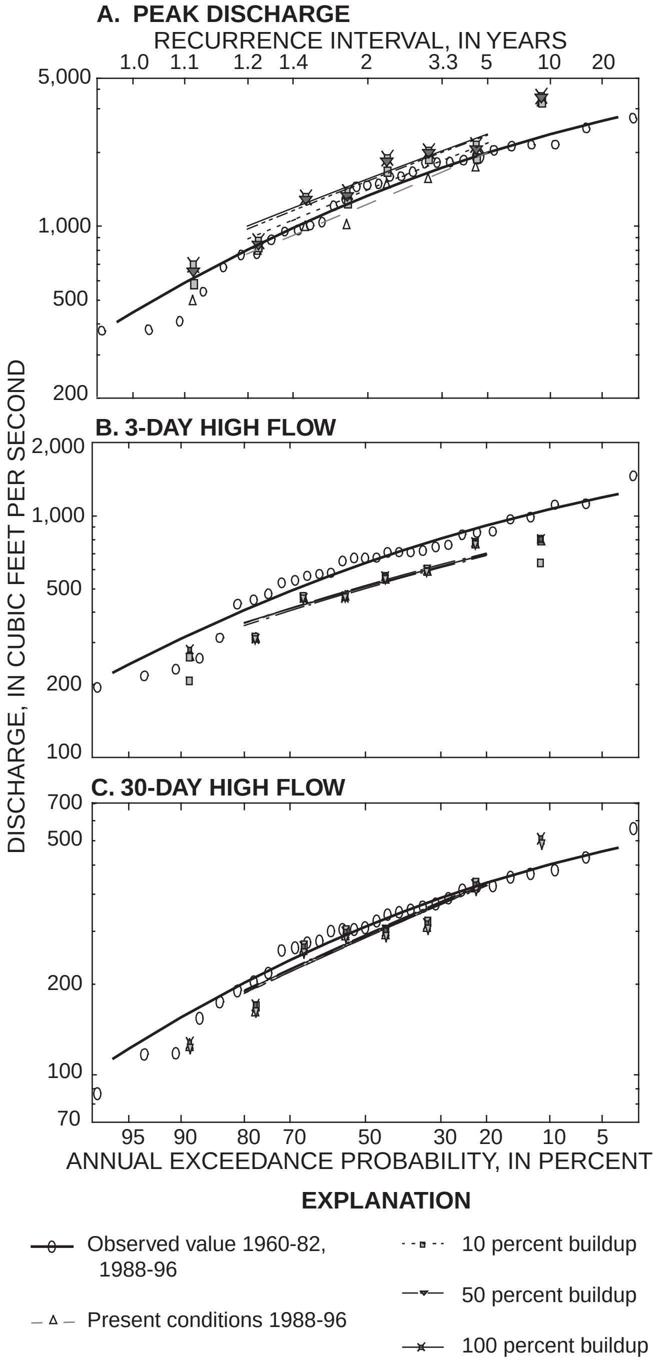


Figure 31. Log Pearson Type-III distribution of observed and simulated peak discharges of Ninemile Creek at Camillus, N.Y., for 100-percent buildup represented as impervious land: (A) Peak discharge. (B) 3-day high flow. (C) 30-day high flow.

Effects of Stormwater Detention on Runoff from a Hypothetical Residential Development

Stormwater-detention basins are commonly used in developing areas to attenuate peak discharges and to control nonpoint-source-pollutants. Such basins could increase downstream flooding, however, if the peak outflow coincides with the peak discharge in the receiving stream (Hawley and others, 1981). The watershed model was used to assess the potential for flooding in Camillus under this condition by simulating the effect of a hypothetical 147-acre medium-density residential development on flows in Ninemile Creek. This was done by adding a RCHRES that receives runoff from the hypothetical development and one that represents its detention basin. The development and its detention basin were scaled to the size of an area in the headwaters of the West Hill tributary (fig. 8) in which future development is expected. Predevelopment conditions were represented as mixed forest and agricultural lands. The effects of stormwater detention on flows in Ninemile Creek at Camillus were examined by routing the basin outflow (1) directly to the creek at Camillus, and (2) to the West Hill Tributary. These simulations allowed assessment of downstream flows when the development and its detention basin were (1) near the main channel, and (2) far from the main channel such that other channel storages can affect the timing of peak discharges.

Detention-Basin Design

The simulated detention basin was designed to State guidelines (New York State Department of Environmental Conservation, 1992). The design criteria for basins to be used for runoff control differ from those for basins to be used for water-quality control; guidelines for runoff-control basins state that peak discharges from a developed area should not exceed the predevelopment peak for a 24-hour storm with a recurrence interval of 2, 10, and 100 years, whereas guidelines for water-quality control basins state that the capacity should retain runoff for a period of 24 to 40 hours after the first 0.5 in. of rainfall, or runoff from a 1-year, 24-hour storm, whichever is greater. The model was used to calculate the pre- and postdevelopment peak discharges and runoff volumes that these design criteria represent.

The amount of runoff produced by the first 0.5 in. of rainfall depends on the antecedent conditions. Simulations of runoff from the hypothetical development for the non-winter storms of 1995-96 (appendix B) indicate that storms with about 0.5 in. of rainfall generate from 0.06 to 0.16 in. of runoff (fig. 32). The storage necessary to capture this runoff would range from 0.73 to 2.0 acre-feet.

Runoff from a 1-year, 24-hour design storm (rainfall of about 2.3 in., Hershfield, 1961) with an SCS (Soil Conservation Service, now known as the Natural Resources Conservation Service) Type-II rainfall distribution also depends on the antecedent conditions (fig. 32). Dry and wet antecedent conditions were represented in the model by setting starting water-storage conditions to values obtained from previous simulations for (1) July 1991 (dry conditions), and (2) April, 1993 (wet conditions).

Simulated peak-discharge and storm-runoff volumes for pre- and postdevelopment conditions for 24-hour storms, of 1-, 2-, 10-, 25-, and 100-year recurrence intervals are summarized in table 12 and plotted in figure 33. Antecedent conditions caused considerable variation among peak discharges in predevelopment (mixed forest and agricultural land)

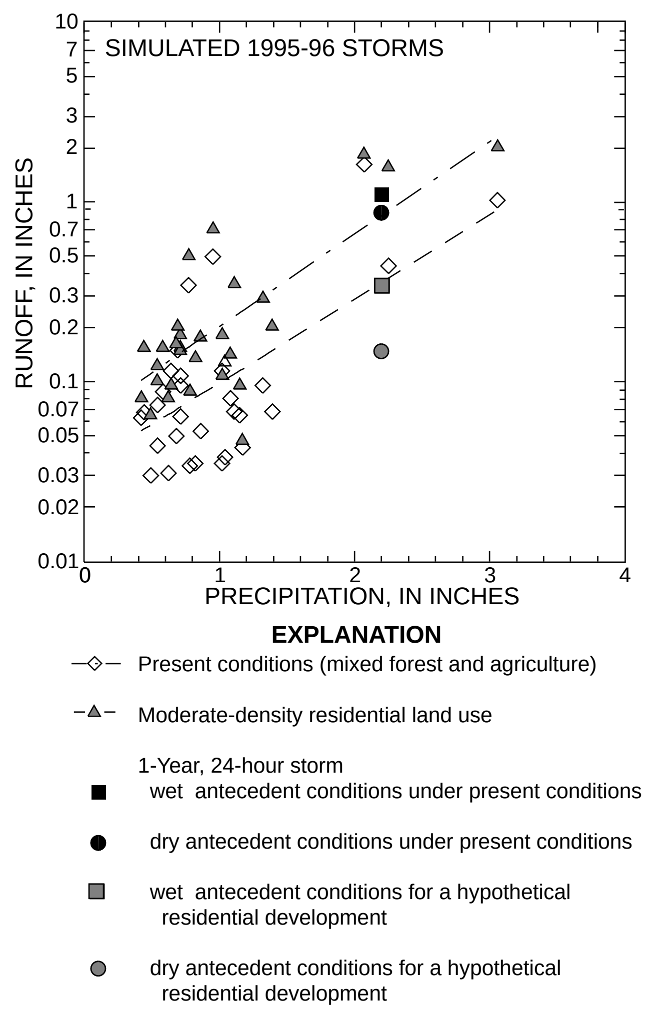


Figure 32. Simulated runoff of Ninemile Creek at Camillus, N.Y., in relation to precipitation in simulations of 1995-96 non-winter storms under present land-use conditions and from a hypothetical moderate-density residential development for a 1-year 24-hour design storm under wet and dry antecedent conditions. (Storm data are given in appendix B.)

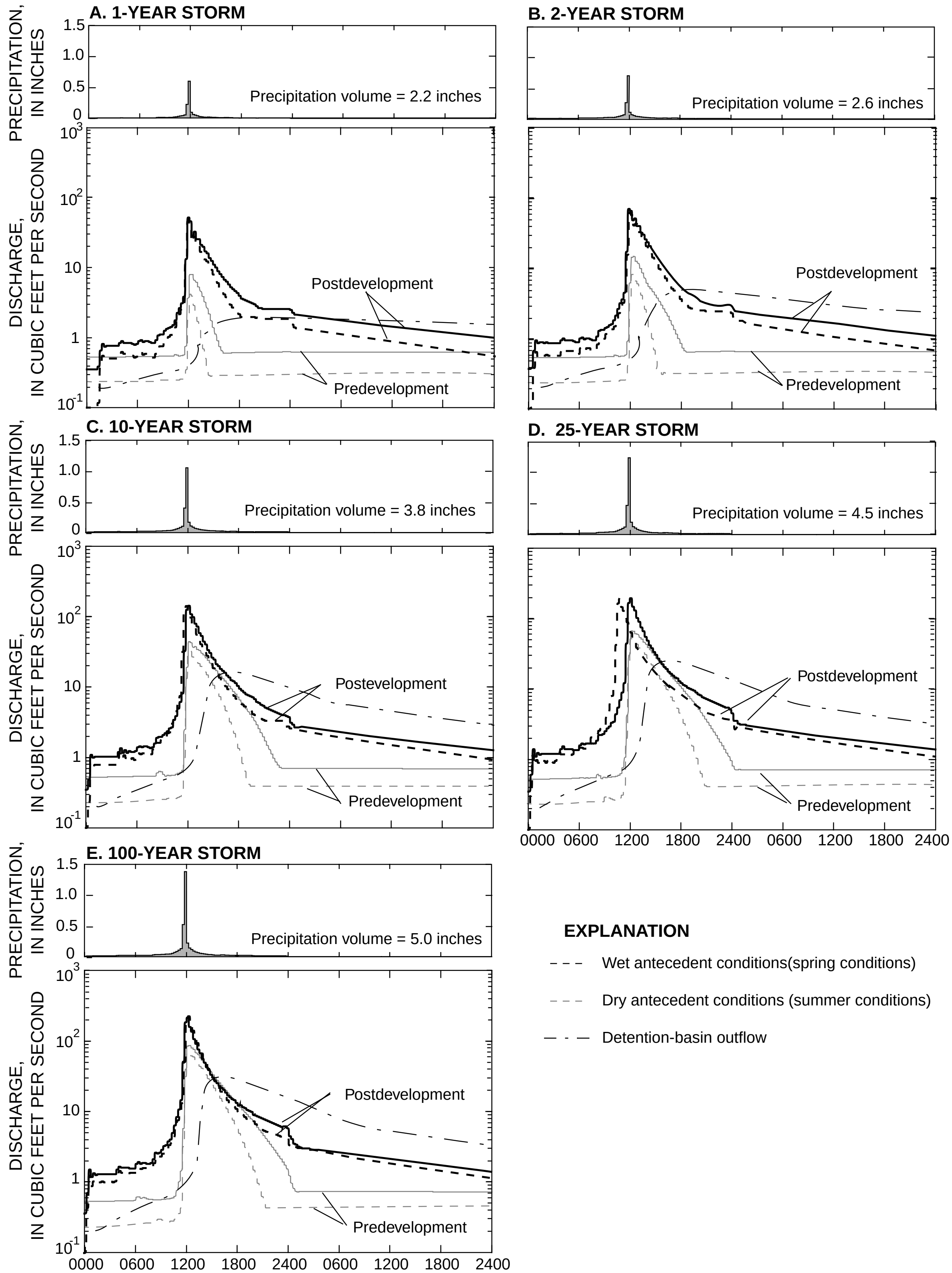


Figure 33. Simulated pre- and postdevelopment discharge in Ninemile Creek at Camillus, N.Y. from a 24-hour design storm of selected recurrence intervals under wet and dry antecedent conditions and from a hypothetical postdevelopment stormwater detention basin under wet antecedent conditions: (A) 1-year storm (B) 2-year storm. (C) 10-year storm. (D) 25-year storm. (E) 100-year storm.

simulations, but not in postdevelopment (moderate-density residential) simulations. The predevelopment variation in peak discharge was more pronounced among small storms than among large storms; for example, peak discharges from the 1- and 2-year storms were about twice as large for wet antecedent conditions than those under dry antecedent conditions, whereas the peak discharge from the 100-year storm under wet antecedent conditions was only about 20 percent greater than that under dry antecedent conditions.

Predicted storm volumes, like peak discharges, varied with antecedent conditions and, again, the differences were more pronounced in predevelopment simulations then in postdevelopment simulations and were greater for small storms than for large storms (table 12). Predevelopment runoff from the 1-year storm was 56 percent smaller under dry antecedent conditions than those under wet antecedent conditions, and runoff from the 100-year storm was 32 percent smaller under dry antecedent conditions than those under wet antecedent conditions. Postdevelopment runoff from the 1-year storm was 25 percent smaller under dry antecedent conditions than those under wet antecedent conditions, and runoff from the 100-year storm was 9 percent smaller under dry antecedent conditions than those under wet antecedent conditions.

The design of a detention basin to meet New York State guidelines will depend on which type of antecedent conditions are used to calculate runoff characteristics before and after development. Once the values for these characteristics are obtained, the basin design can be evaluated by incorporating its storage-to-outflow relations into a model RCHRES. The storage-to-outflow relations can be modified through a trial- and error-approach to optimize the desired stormwater-management objectives.

A detention basin designed to meet the state guidelines to control the quantity and chemical quality of runoff from the hypothetical residential development would require a storage capacity of about 13 acre-ft. for water-quality control and an outlet control that decreases peak discharges by 50 ft^3/s for a 2-year storm and by 150 ft^3/s for a 100-year storm. Assumed design characteristics of the detention basin include an initial surface area of 3 acres, a length-to-width ratio of 3:1, and a side slope of 6:1. The relation of the simulated water stage to surface area, storage capacity, and discharge is shown in figure 34. Predicted outflow from a detention basin designed to serve the hypothetical development for 24-hour storms of 1-, 2-, 10-, 50-, and 100-year recurrence intervals under wet antecedent conditions are plotted in figure 33 and summarized in table 12. Such a detention basin

Table 12. Simulated peak discharge and runoff volume from a hypothetical 147-acre development in Ninemile Creek watershed near Camillus, N.Y. under predevelopment (forest and agricultural) and postdevelopment (moderate-density residential) conditions, for 24-hour storms of, 1-, 2-, 10-, 25-, and 100-year recurrence intervals.

[Peak discharge based on Soil Conservation Service Type-II rainfall distribution (Hershfield, 1961). ft^3/s, cubic feet per second. Dash indicates not simulated].

Storm-recurrence Interval	Antecedent condition	Peak discharge (ft^3/s) Predevel-opment	Peak discharge (ft^3/s) Postdevel-opment	Runoff volume (acre-feet) Predevel-opment	Runoff volume (acre-feet) Postdevel-opment	Detention Basin Peak Outflow (ft3/s)	Detention Basin Delay of Peak (hours)
1 year	Dry	4.0	48	1.50	10.6	--	-
	Wet	7.9	48	3.40	13.3	3.1	9.0
2 years	Dry	7.9	64	2.19	14.7	--	--
	Wet	15	65	4.91	17.7	5.6	5.5
10 year	Dry	31	133	7.77	27.7	--	-
	Wet	45	140	14.5	31.3	18	3.5
25 years	Dry	53	185	13.5	36.0	--	--
	Wet	67	193	21.4	39.8	28	3.0
100 years	Dry	69	223	17.9	41.5	--	--
	Wet	86	232	26.4	45.5	35	2.7

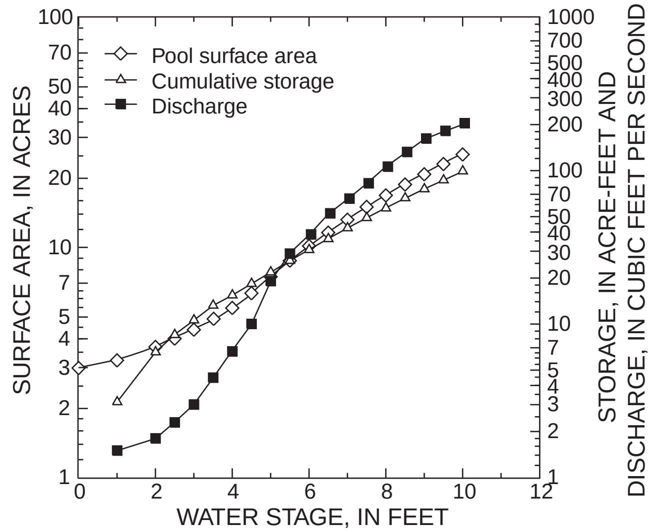


Figure 34. Pool-surface area, storage capacity, and discharge of a stormwater detention basin to serve a hypothetical 147-acre moderate-density development near Camillus, N.Y., in relation to water stage.

would decrease peak discharges by 60 ft^3/s for a 2-year storm and by 200 ft^3/s for a 100-year storms.

Effects of Runoff Detention on Downstream Flooding

Increased flooding can occur downstream from a detention basin if outflow from the basin exceeds the flow that would occur without detention. For simple storms of short duration (such as the 24-hour design storms with a single peak), outflow from the detention basin will generally exceed the flow that would occur otherwise in the late part of the storm or after the storms ends, when water is draining from storage. The effect of detention on downstream flooding from storms with multiple peaks and(or) of long duration are difficult to characterize because the basin outflow depends on the specific storm characteristics relative to the available storage. An assessment of the effects of a detention basin on downstream flooding requires a comparison of (a) the downstream flows that would occur if the basin were absent, with (b) the downstream flows that would occur if the basin were present, over a range of conditions.

Detention basins that drain directly (or nearly so) into Ninemile Creek will generally cause peak discharges in Ninemile Creek to increase when the basins' peak outflow coincides with the creek's peak discharge. Whether the two peaks coincide can be calculated from the basins' and stream's "time of concentration" (the time interval between the center-of-mass of precipitation and the peak discharge). The time-of-concentration of the detention basin's outflow ranged from 9 h for a 1-year storm to 2.7 h for a 100-year storm (table 12) and the time-of-concentration of Ninemile Creek at Camillus ranged from about 3 h for a 1-year storm to 2 h for a 100-year storm (fig. 33). The time-of-concentration of detention-basin outflows for the 10-, 25-, and 100-year storms were similar to those for Ninemile Creek at Camillus; thus, the respective peaks will tend to coincide (fig. 35C, D, E) and thereby cause increased flooding at Camillus. In headwater developments, the time-of-concentration of the basin outflow is roughly equivalent to delay in the time of peak discharge from the basin because the peak discharge from the development is expected to be near in time to the center-of-mass of the precipitation.

Simulations did not include the drainage area above the Marietta gaging station (45.1 mi^2), but this omission does not appear to affect the time and duration of peak discharge of Ninemile Creek at Camillus appreciably; hydrographs of observed flow of Ninemile Creek at Camillus and Marietta during the January 1996 storm, and the hydrograph for the intervening area between streamflow gages (flow values at Camillus minus flow values at Marietta), indicate that the flow in the intervening area and at Camillus peaked at the same time and that the magnitudes of the peak discharges were similar (fig. 35).

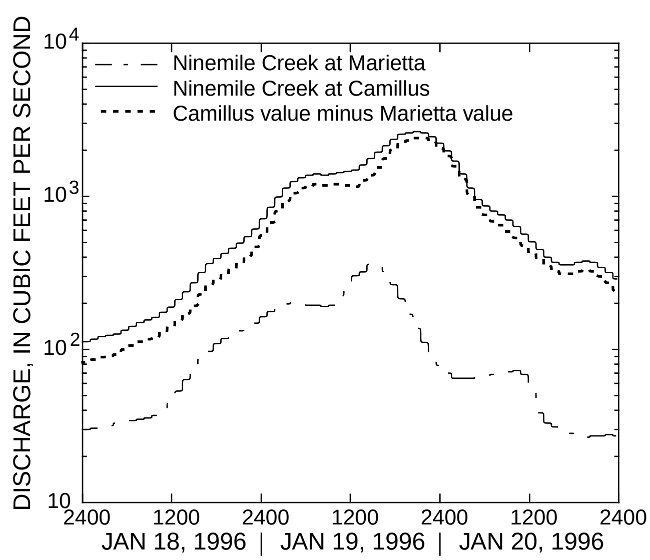


Figure 35. Observed discharge of Ninemile Creek at Camillus and Marietta, N.Y., during the January 1996 storm and the difference between the two flows.

Simulations of runoff from the hypothetical development with and without a detention basin indicate that basin outflow from the development would be less than the uncontrolled runoff (with no basin) during the first 12 hours of the 1-year storm and the first 3 hours of the 100-year storm (fig. 36). Therefore, if the discharge of Ninemile Creek at Camillus were to peak within the early period of the storm, before the basin outflow exceeds the rate of uncontrolled runoff that would occur if the basin were absent, downstream flooding would be diminished. If the creek did not peak until later in the storm, however, when the basin outflow exceeds the rate of uncontrolled runoff that would occur if the basin were absent, downstream flooding would be increased. The magnitude of the stormflow must therefore be considered when the effects of a detention basin on flooding are evaluated.

Although the predicted peak outflow from the detention basin approximately coincides with the peak discharge in Ninemile Creek at Camillus for the 100-year storm, the outflow from the basin at this time is about the same as the uncontrolled flow (fig. 36B). Simulation results indicate that, for a brief period after the peak discharge in Ninemile Creek, basin outflow exceeded the uncontrolled flow that would occur if the basin were absent (heavily shaded area fig. 36C). During this period, the difference between the detention-basin outflow and uncontrolled flow was small relative to flow in Ninemile Creek at Camillus—less than 1 percent during most of the storm, but approached 5 percent near the end of the storm.

Simulation results for a simulated detention basin with the original storage capacity decreased by 50 percent indicate that the difference between the basin outflow and uncontrolled flow is about twice as large as in the previous (full-sized basin) simulation

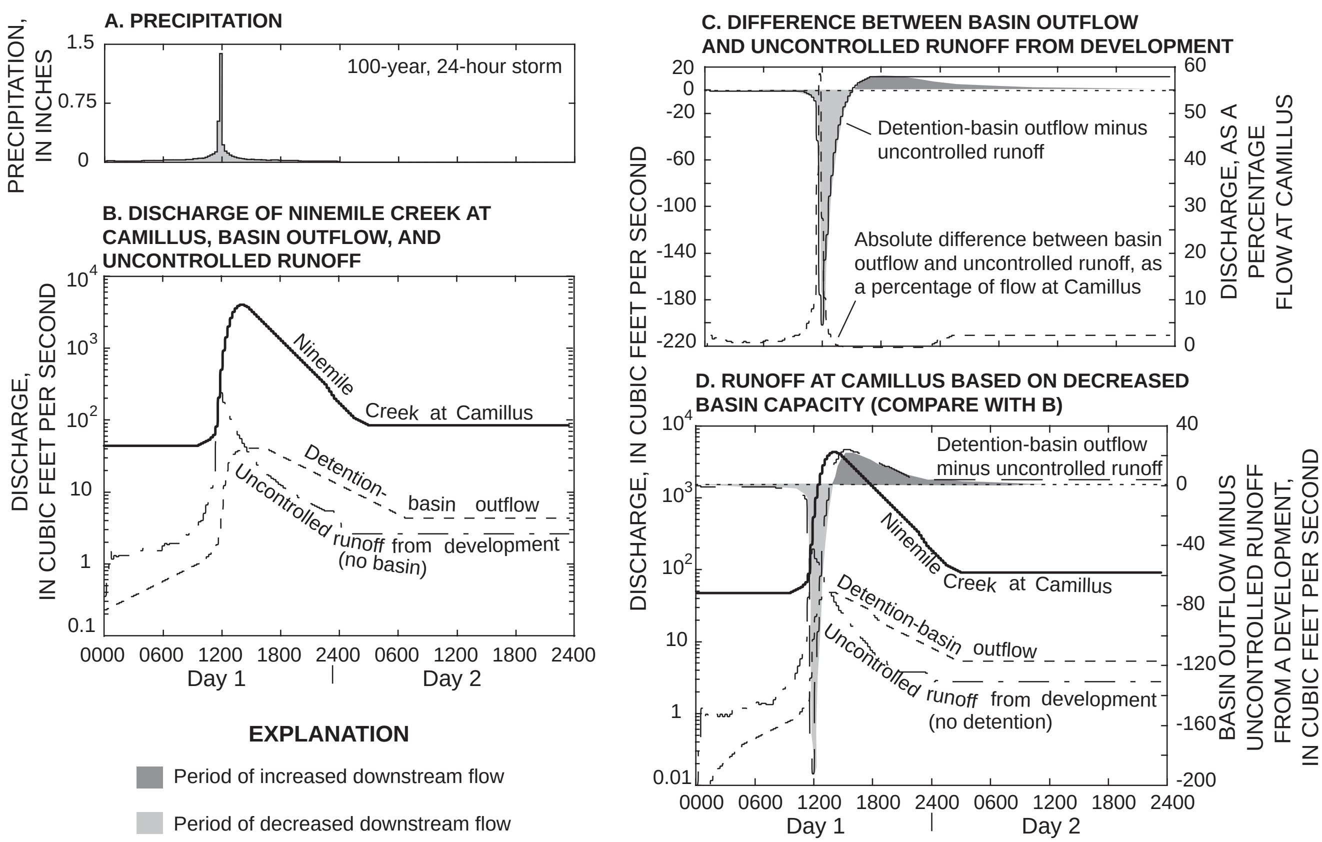


Figure 36. Simulated discharge in Ninemile Creek watershed, Onondaga County, N.Y., resulting from a 100-year, 24-hour storm at a hypothetical 147-acre residential development with and without a stormwater detention basin:
A. Storm precipitation.
B. Discharge of Ninemile Creek at Camillus, outflow from the detention basin, and uncontrolled runoff.
C. Difference between outflow from the detention basin and runoff from the development.
D. Discharge of Ninemile Creek at Camillus, outflow from the detention basin, and uncontrolled runoff from the development with basin capacity decreased by 50 percent.

(heavily shaded area in fig. 36D). Additionally, the maximum difference between basin outflow and uncontrolled runoff occurs closer to the time of peak discharge in the Ninemile Creek. As a result, the smaller basin contributes about 2 percent more flow to Ninemile Creek at Camillus near the peak than would uncontrolled runoff from the development. This again illustrates that (1) the effects of a detention basin on downstream flooding depend on the basins' available storage relative to its inflow, and (2) the effects of a detention basin on downstream flooding must be considered separately for each combination of conditions.

Additional development and runoff detention in the watershed could have a cumulative effect on the flow in Ninemile Creek at Camillus, but the preceding example is based on the assumption that the basin outflow drains directly to Ninemile Creek near Camillus. Many parts of the watershed that are likely to undergo development drain to tributaries, rather than to the main branch of Ninemile Creek, and channel storage along these tributaries, particularly those with extensive wetlands, will further delay the time of peak discharge. Model simulations of the same development but with the detention basin draining to the West Hill tributary (RCHRES 23, fig. 8), rather than to Ninemile Creek, indicated no increase in peak discharge at Camillus under any flow conditions. The predicted time-of-concentration of the West Hill tributary ranged from about 1.5 h for a 2-year storm to 1 h for a 100-year storm and the detention basin would delay the uncontrolled peak discharge from the development by 5.5 h for a 2-year storm to 2.7 hours for a 100-year storm. Thus, the peak outflow from the detention basin occurs sufficiently long enough after the time-of-concentration of the West Hill tributary that the basin would decrease the peak discharge in the tributary (fig. 37).

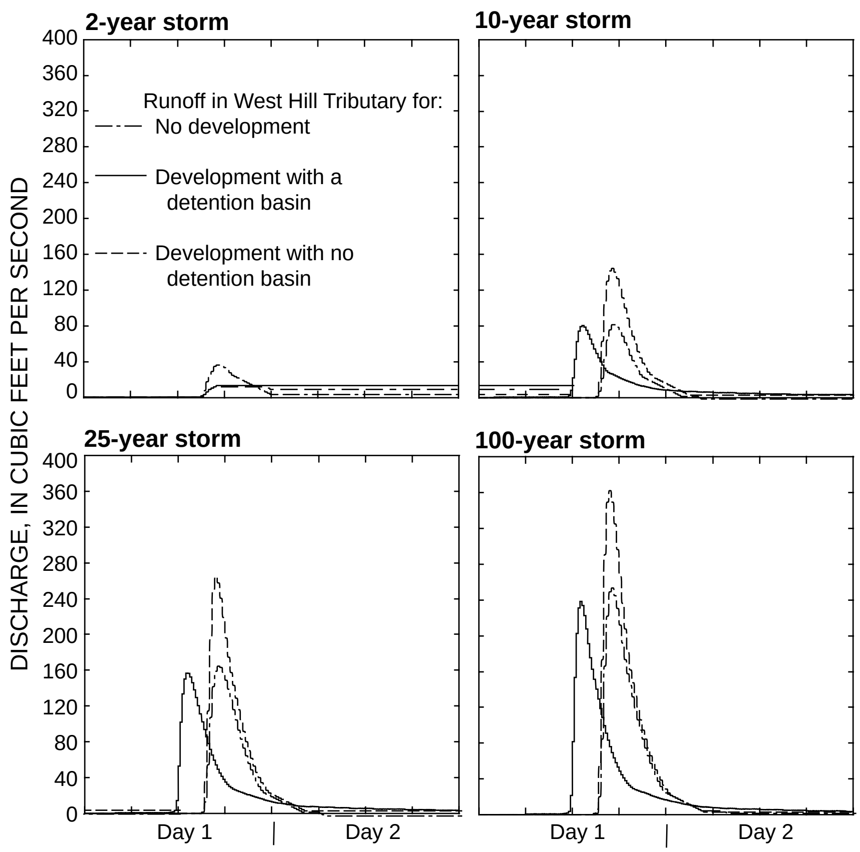


Figure 37. Simulated discharge of West Hill tributary in the Ninemile Creek watershed, Onondaga County, N.Y., resulting from storms of selected recurrence intervals under present conditions (no upstream development) and with a 147-acre moderate-density residential development with and without a stormwater-detention basin. (Location is shown in fig. 8.)

Without the detention basin, runoff from the hypothetical development would significantly increase peak discharge in the West Hill tributary. The predicted peak discharge in the West Hill tributary from the development without a detention basin was more than twice the peak discharge for current undeveloped conditions for a 2-year storm and about a third larger than the peak for current conditions for the 100-year storm (fig. 37). Adding a detention basin caused peak discharge of the West Hill tributary to be about the same as the current peak discharges resulting from 2- to 100-year storms.

As in the simulations in which the basin and uncontrolled runoff discharged directly to Ninemile Creek, the predicted effects of a detention basin that discharges to West Hill Tributary are specific to its (1) storage-to-discharge characteristics, (2) inflows relative to its available storage, and (3) outflow relative to flow in the receiving water body. Conditions other than those simulated may affect flow in Ninemile Creek differently, but alternative conditions could be examined with the precipitation-runoff model used in this study.

SUMMARY AND CONCLUSIONS

A precipitation-runoff model, HSPF (Hydrologic Simulation Program Fortran), was developed and calibrated for a 41.7 mi^2 part of the Ninemile Creek watershed between the streamflow gages at Marietta and Camillus to predict (1) the hydrological effects of future suburban development on streamflow, and (2) the effects of stormwater detention on flooding of Ninemile Creek at Camillus. Streamflow data and meteorologic data, including precipitation, evaporation, dew point, solar radiation, and wind speed, were assembled, checked, and entered into the watershed-data management system (WDMS) for model simulations. The model was calibrated to conditions of water years 1988-96 (October to September).

Changes in runoff volume and peak discharge that would result from development were investigated by representing the amount of land considered suitable for development as (1) open/residential land, and (2) impervious land, then incrementally increasing the percentage of land converted to each. Results were compared with those from simulations of current conditions.

Simulations of 30 non-winter 1995-96 storms with 10-percent and 100-percent buildup of developable land converted to open/residential land indicated that peak discharge in Ninemile Creek at Camillus increased by an average of 10 and 37 percent, respectively, and that converting developable land to an appropriate amount of impervious land (100-percent buildup represents an impervious cover about 7 percent of the watershed area) would increase peak discharges by an average of 13 to 68 percent, respectively. Storm-runoff volume would be increased by a little more than 10 percent for both types of development under 100-percent buildup conditions. The simulated effects of both types of development were most pronounced in the summer, when soil-water storage is low and pervious areas are able to retain storm precipitation: At other times of the year, soil-water storage is near capacity, and little infiltration can occur. Once the available soil-water storage in pervious areas is depleted, the area functions as it were impermeable.

The effects of development as impervious land were also examined through a comparison of log-Pearson Type-III probability curves for peak discharge and for 3-day and 30-day high and low flows. The annual peak discharge for a given log-Pearson Type-III probability distribution increased with increasing impervious land, but the relative increase in peak discharge diminished with decreasing flow probability— that is, as the storm magnitude increases, the increase in peak discharge from development remained constant. Analyses of peak discharge for the 1989-96 water years indicate that under 100-percent buildup conditions as impervious land, stormflows that now occur on average once every 2 years will occur once every 1.5 years, and stormflows that now occur on average once every 5 years will occur once every 3.3 years. Development is not expected to cause significant increases in flooding along Ninemile Creek during large-magnitude (infrequent) storms, but is expected to increase the frequency and magnitude of small storms. Simulations with development represented as impervious land indicated a slight decrease in low flows for 3-day periods.

The second model application examined the potential for a hypothetical moderate-density 147-acre residential development with and without a stormwater-detention basin to cause increased flooding in Ninemile Creek at Camillus by delaying the arrival of the peak flow. The model was used to evaluate the pre- and postdevelopment storm volumes and peak discharges that would result from a 24-hour rainfall with a 1-, 2-, 10-, 25- and 100-year recurrences probability.

When the delayed onset of peak outflow from a detention basin coincides with the peak discharge in the receiving stream, the downstream flow is greater than it would be without the basin. The peak basin outflows are indicated to coincide with the peak discharges in Ninemile Creek at Camillus during large-magnitude (10-, 25-, and 100-year) storms but the effects of a detention basin on downstream flooding depend on the magnitude of the basin outflow. Simulation of the 100-year storm indicated that the additional flow during the time in which the basin outflow exceeds the runoff from the development that would occur without a basin was less than 1 percent of the flow in Ninemile Creek near the time of the peak.

A simulation in which the detention basin's storage capacity was decreased by 50 percent indicated that (1) the difference between controlled and uncontrolled runoff from the residential development is about twice as large as the difference for the large basin, and (2) the maximum difference between outflow from the smaller basin and the runoff with no basin occurs closer to the time of the peak in Ninemile Creek than it would for the large basin. As a result, the smaller detention basin contributes about 2 percent more to the peak discharge in Ninemile Creek at Camillus than would uncontrolled runoff from the development.

Many parts of the watershed that could be developed do not drain directly to the main branch of Ninemile Creek, but to tributary streams. Storage along these tributaries, particularly those with extensive wetlands, will further delay the time of peak discharges. Simulations were run in which runoff from the hypothetical development and detention basin was routed to the West Hill tributary rather than Ninemile Creek; results indicated that the peak outflow from basin is delayed sufficiently that it does not coincide with the peak discharge in the West Hill tributary. Simulations also indicated that peak discharge in the West Hill tributary with no development were about the same as with development and a detention basin. Simulations of the same development without a detention basin indicated that the peak discharge in the West Hill tributary from a 2-year storm was more than twice that obtained with a detention basin, and peak discharge for a 100-year storm was about a third larger than that obtained with a detention basin. The predicted effects of stormflow detention on downstream flooding depend on the basin's storage-to-discharge characteristics, inflows relative to its available storage, and outflow relative to flow in the receiving waters. Conditions other than those discussed here could affect flows in Ninemile Creek differently. The model used in this study could be used to evaluate such conditions.

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APPENDIXES

Appendix A. Ninemile Creek watershed model (HSPF) user control file (uci) for PERLND and IMPLND blocks [three or more asterisks indicate a model comment statment].

```
HSPF model for Ninemile Creek watershed, Onondaga County, N.Y.                                  ***

****************************************************************************************************
***                  PERLND - Pervious land surface block                                       ***
****************************************************************************************************

PERLND
 ACTIVITY
  <PLS >      Active Sections (1=Active, 0=Inactive)                                            ***
 ###   -###    ATMP   SNOW    PWAT   SED    PST  PWG  PQAL    MSTL    PEST    NITR   PHOS  TRAC   ***
  1  1     4         1          1
 END ACTIVITY

 PRINT-INFO
  <PLS > <-*** Print-flags: 2-PIVL, 3-dy, 4-mn, 5-yr, 6-never  ***-> PIVL  PYR                  ***
### -###ATMPSNOW    PWAT     SED    PST  PWG  PQAL  MSTL    PEST    NITR    PHOS    TRAC        ***
   1     14          4          4         1       9
 END PRINT-INFO

 GEN-INFO
  <PLS ><-------Name-------> NBLKS          Unit-systems           Printer                      ***
###-###                              User         in        out     Engl     Metr               ***
       1   Forest poor <5%          1         1         1         1       15        0
       2   Forest poor >5%          1         1         1         1       15        0
       3   Forest mod  <5%          1         1         1         1       15        0
       4   Forest mod  >5%          1         1         1         1       15        0
       5   Forest well <5%          1         1         1         1       15        0
       6   Forest well >5%          1         1         1         1       15        0
       7   Agr poor <5%             1         1         1         1       15        0
       8   Agr poor >5%             1         1         1         1       15        0
       9   Agr mod  <5%             1         1         1         1       15        0
      10   Agr mod  >5%             1         1         1         1       15        0
      11   Agr well <5%             1         1         1         1       15        0
      12   Agr well >5%             1         1         1         1       15        0
      13   Wetland                  1         1         1         1       15        0
      14   Open/residential         1         1         1         1       15        0
 END GEN-INFO
----------------------------------------------------------------------------------------        ***
                    SNOW ACCUMULATION AND MELT                                                  ***
--------------------------------------------------------------                                  ***
 ICE-FLAG
  <PLS >  0= Ice formation not simulated, 1= Simulated                                          ***
 ###       -###         ICEFG                                                                   ***
   1         14                 1
 END ICE-FLAG

 SNOW-PARM1
  <PLS >  Snow input info: Part 1                                                               ***
 ###    -###          LAT         MELEV         SHADE         SNOWCF         COVIND             ***
   1       6           43.          800.          0.30           1.80           0.15
   7      12           43.          800.          0.02           1.70           0.15
  13                   43.          800.          0.10           1.75           0.20
  14                   43.          800.          0.15           1.70           0.25
 END SNOW-PARM1
```

Appendix A. (Continued) Ninemile Creek watershed model (HSPF) user control file (uci) for PERLND and IMPLND blocks

```
SNOW-PARM2
  <PLS >  Snow input info: Part 2                                                    ***
 ###  -###     RDCSN      TSNOW     SNOEVP     CCFACT     MWATER     MGMELT          ***
   1     6      0.20        32.       0.02       0.10       1.00     0.1100
   7    12      0.20        32.       0.03       0.12       1.00     0.1300
  13            0.20        32.       0.03       0.15       1.00     0.1300
  14            0.20        32.       0.04       0.20       1.00     0.1500
 END SNOW-PARM2

---------------------------------------------------------------------------------    ***
                 Section PWATER                                                      ***
------------------------------------------------------------------                   ***

 PWAT-PARM1
***          1=varies monthly 0=does not
*** <PLS > <PWATER flags><monthly parameter value flags>                             ***
 ###   -###    CSNO  RTOP  UZFG  VCS  VUZ  VNN  VIFW  VIRC  VLE                      ***
   1      6    1 0 0    1     1    1    1    1     1
   7     12    1.0 0    1     1    1    1    1     1
         13    1 0 0    1     1    1    1    1     1
         14    1 0 0    1     1    1    1    1     1
 END PWAT-PARM1

 PWAT-PARM2
  <PLS >                                                                             ***
 ###   -###    FOREST     LZSN   INFILT     LSUR    SLSUR    KVARY    AGWRC          ***
               (none)     (in)  (in/hr)     (ft)   (none)   (l/in)   (l/in)          ***
          1     0.850     3.20    0.040    4500.    0.025     0.35    0.996
          2     0.850     3.00    0.030    3500.    0.075     0.37    0.996
          3     0.850     3.10    0.080    4500.    0.025     0.30    0.997
          4     0.850     3.00    0.060    3500.    0.075     0.32    0.997
          5     0.850     3.70    0.180    4500.    0.025     0.24    0.998
          6     0.850     3.00    0.160    3500.    0.075     0.25    0.998
          7     0.030     3.20    0.040    4500.    0.025     0.37    0.995
          8     0.050     3.00    0.030    3500.    0.075     0.40    0.995
          9     0.030     3.10    0.080    4500.    0.025     0.30    0.996
         10     0.050     3.00    0.060    3500.    0.075     0.32    0.996
         11     0.030     3.70    0.180    4500.    0.025     0.22    0.997
         12     0.050     3.00    0.160    3500.    0.075     0.25    0.997
         13     0.200     3.00    0.020     800.    0.002     0.25    0.999
         14     0.100     3.00    0.050    2000.    0.035     0.40    0.995
 END PWAT-PARM2

 PWAT-PARM3
  <PLS >                                                                             ***
 ###   -###   PETMAX   PETMIN   INFEXP   INFILD   DEEPFR   BASETP   AGWETP           ***
   1     14      40.      35.      2.0      1.2     0.00     0.00     0.00
 END PWAT-PARM3
```

Appendix A. (Continued) Ninemile Creek watershed model (HSPF) user control file (uci) for PERLND and IMPLND blocks

PWAT-PARM4

<PLS >								***
Flag	PARM1	VCS	VUZ	VUR	VMN	VIFW	VLE	***
###	-###	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP	***
		(in)	(in)	(none)	(none)	(l/da)	(none)	***
1	2							
3	4							
5	6							
7	8							
9	10							
11	12							
	13							
	14							

END PWAT-PARM4

MON-INTERCEP

Monthly interception storage capacity ***

< PLS > Interception storage capacity at start of month; Required if VCSFG=1 -PARM1 ***

###	-###	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	***
1	6	0.02	0.02	0.02	0.02	0.03	0.07	0.10	0.14	0.17	0.16	0.07	0.03	
7	12	0.02	0.02	0.02	0.02	0.04	0.04	0.08	0.12	0.08	0.06	0.04	0.03	
13		0.02	0.02	0.02	0.02	0.04	0.06	0.09	0.10	0.09	0.08	0.04	0.03	
14		0.05	0.05	0.05	0.05	0.05	0.06	0.09	0.12	0.09	0.07	0.05	0.05	

END MON-INTERCEP

MON-UZSN

Upper zone nominal storage ***

< PLS > Upper zone storage at start of each month;Required if VUZFG=1 -PARM1 ***

###	###	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	***
1	12	0.4	0.4	0.5	0.8	0.8	0.8	1.0	1.0	1.2	1.2	0.9	0.7	
13		0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.5	0.7	0.7	0.5	0.3	
14		0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.5	0.9	0.9	0.7	0.4	

END MON-UZSN

MON-MANNING

Manning’s “n” for overland flow plans ***

<PLS > Manning’s n for overland flow; Required if VNNFG=1 in PWAT-PARM1 ***

###	-###	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	***
1	6	0.25	0.25	0.25	0.25	0.27	0.27	0.27	0.27	0.27	0.25	0.25	0.25	
7	12	0.25	0.25	0.25	0.25	0.27	0.30	0.30	0.30	0.30	0.27	0.25	0.25	
13		0.25	0.25	0.27	0.27	0.30	0.30	0.35	0.35	0.35	0.27	0.25	0.25	
14		0.25	0.25	0.25	0.25	0.30	0.30	0.30	0.30	0.30	0.27	0.25	0.25	

END MON-MANNING

MON-INTERFLW

Monthly interflow parameter at start of each month ***

<PLS > Required if VIFWFG=1 in PARM1 ***

###	-###	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	***
1	6	0.90	0.90	1.30	1.35	1.35	1.30	1.25	1.25	1.20	1.00	1.00	1.00	
7	12	0.80	0.80	1.20	1.35	1.35	1.30	1.25	1.25	1.20	1.00	1.00	1.00	
13		1.30	1.30	2.20	2.30	2.35	2.30	2.20	2.10	2.10	1.80	1.70	1.60	
14		1.05	1.05	1.05	1.10	1.20	1.10	1.05	1.05	1.05	1.05	1.05	1.05	

END MON-INTERFLW

Appendix A. (Continued) Ninemile Creek watershed model (HSPF) user control file (uci) for PERLND and IMPLND blocks

```
MON-IRC
  Monthly interflow recession at start of each month                                                     ***
  <PLS > Required if VIRCFG=1 in PWAT-PARM1 (max < 1.0)                                                  ***
 ###   -###    JAN    FEB    MAR    APR    MAY    JUN    JUL   AUG    SEP    OCT    NOV    DEC           ***
  1      12    0.10   0.10   0.72   0.83   0.88   0.93   0.98  0.98   0.95   0.90   0.90   0.80
 13            0.92   0.92   0.92   0.95   0.96   0.98   0.98  0.98   0.95   0.94   0.93   0.92
 14            0.45   0.45   0.45   0.40   0.40   0.40   0.35  0.35   0.35   0.40   0.45   0.45
 END MON-IRC

 MON-LZETPARM
  Lower zone ET at start of each month                                                                   ***
    <PLS >         Required if VLEFG=1 in PARM1                                                          ***
 ###   -###    JAN    FEB    MAR    APR    MAY    JUN    JUL   AUG    SEP    OCT    NOV    DEC           ***
   1      6    003    .003   .003   0.02   0.05   0.45   0.75  0.85   0.80   0.45   0.03   .003
   7     12   .002    .002   .002   0.01   0.02   0.18   0.45  0.65   0.55   0.15   0.01   .002
  13          .003    .003   .005   0.02   0.04   0.30   0.50  0.60   0.55   0.25   0.03   003
  14          .003    .003   .003   0.01   0.04   0.38   0.55  0.75   0.65   0.35   0.01   003
 END MON-LZETPARM

 PWAT-STATE1
  <PLS > Initial conditions at start of simulation                                                       ***
 ###   -###     CEPS     SURS     UZS     IFWS     LZS     AGWS     GWVS                                 ***
   1      2     0.00     0.00     1.14    0.005    2.48    0.66     0.23
   3      4     0.00     0.00     0.88    0.004    2.55    0.96     0.35
   5      6     0.00     0.00     0.39    0.003    3.00    1.35     0.50
   7      8     0.00     0.00     1.26    0.010    2.72    0.82     0.32
   9     10     0.00     0.00     0.99    0.005    2.92    1.29     0.49
  11     12     0.00     0.00     0.53    0.004    3.35    1.85     0.71
  13            0.00     0.00     0.83    0.095    2.53    0.71     0.24
  14            0.00     0.00     0.88    0.000    2.62    0.96     0.38
 END PWAT-STATE1
END PERLND

****************************************************************************************************
***                                  IMPLND  - Impervious land                                     ***
***                                                                                                ***
****************************************************************************************************

IMPLND
 ACTIVITY
  <ILS >  Active Sections (1-active, 0-inactive)                                                         ***
 ###   -###    ATMP   SNOW   IWAT   SLD   IWG   IQAL                                                   ***
   1      3       1      1
 END ACTIVITY

 PRINT-INFO
       2-PIVL, 3-dy, 4-mn, 5-yr, 6-never                                                                 ***
  <ILS > <------ Print-flags --------> PIVL  PYR                                                         ***
 ###   -###    ATMP   SNOW   IWAT   SLD   IWG   IQAL   ####   ##                                       ***
   1      3       4      4      1     9
 END PRINT-INFO

 GEN-INFO
  <ILS ><-------Name------->          Unit-systems        Printer                                      ***
###-###                       NBKLS     imn     out     Engl    Metr                                   ***
     1    Resident <5%            1       1       1       15       0
     2    Resident >5%            1       1       1       15       0
     3    Commerical              1       1       1       15       0
 END GEN-INFO
```

Appendix A. (Continued) Ninemile Creek watershed model (HSPF) user control file (uci) for PERLND and IMPLND blocks

```
-------------------------------------------------------------------------------------------------------------------------------          ***
                        IMPLND -  Section SNOW                                                                                           ***
---------------------------------------------------------------                                                                          ***

 ICE-FLAG
  <ILS >  0= Ice formation not simulated, 1= Simulated                                                                                   ***
 ###    -###        ICEFG                                                                                                                ***
    1        3              1
 END ICE-FLAG

 SNOW-PARM1
  <ILS >  Snow input info: Part 1                                                                                                        ***
 ###   -###          LAT        MELEV        SHADE      SNOWCF       COVIND                                                              ***
    1       2            43.          800.           0.20           1.30             0.3
    3                    43.          800.           0.15           1.30             0.3
 END SNOW-PARM1

 SNOW-PARM2
  <ILS >  Snow input info: Part 2                                                                                                        ***
 ###    -###      RDCSN        TSNOW      SNOEVP       CCFACT      MWATER        MGMELT                                                  ***
    1        2          0.12            32.          0.05            1.0            0.25          0.0100
    3                   0.12            32.          0.05            1.0            0.25          0.0100
 END SNOW-PARM2

---------------------------------------------------------------------------------------------------------------------------------------  ***
                        IMPLND - Section IWATER input                                                                                    ***
-----------------------------------------------------------------------                                                                  ***

 IWAT-PARM1
  <ILS >                                Flags                                                                                            ***
 ###    -###        CSNO       RTOP         VRS        VNN        RTLI                                                                   ***
    1        3              1            1            1
 END IWAT-PARM1

 IWAT-PARM2
  <ILS >                                                                                                                                 ***
 ###   -###        LSUR      SLSUR          NSUR          RETSC                                                                          ***
    1                   200.         .010            .010               .01
    2                   200.         .025            .010               .01
    3                   400.         .010            .010               .01
 END IWAT-PARM2

 IWAT-PARM3
  <ILS >                                                                                                                                 ***
 ###    -###       PETMAX           PETMIN                                                                                               ***
    1        3              40.                  35.
 END IWAT-PARM3

 IWAT-STATE1
  <ILS >  IWATER state variables                                                                                                         ***
 ###    -###            RETS                SURS                                                                                         ***
   1        3                .00                  .00
 END IWAT-STATE1
END IMPLND
```

Appendix B. Duration, observed and simulated base-flow and peak-flow data with simulation error, precipitation characteristics, and antecedent conditions for 1995-96 nonwinter storms in Ninemile Creek watershed, Onondaga County, N.Y.

[ft^3/s, cubic feet per second; ft^3/s-h, cubic feet per second hour; h, hour; SD, standard deviation, ME, mean error, RMSE, root mean square error; Vol., volume]

Storm period				Streamflow										Precipitation volume and intensity*					Antecedent Rainfall		
Begin		End		Observed				Simulated				Percent Difference		Volume (inches)		Intensity (inches/hour)			Hours since rainfall of		Vol. during past 168hr (inch)
Date mm/dd/yy	Time	Date mm/dd/yy	Time	Base ft^3/s	Vol. ft^3/s-h	Peak ft^3/s	Time of peak	Base ft^3/s	Vol. ft^3/s-h	Peak ft^3/s	Time of peak	Vol.	Peak	Mean inch	SD in	Mean in/hr	SD in/hr	Max. in/hr	0.00 inch	0.10 inch	
06/02/95	17:00	06/04/95	13:00	47	2750	71	02:00	42	2690	70	24:00	-2.1	-1.7	0.71	0.21	0.34	0.20	0.68	76	94	0.46
06/30/95	24:00	07/02/95	13:00	28	1230	43	15:00	31	1180	33	03:00	-3.7	-23	1.17	1.23	0.06	0.03	0.56	76	327	0.18
07/17/95	04:00	07/18/95	18:00	30	1400	51	02:00	29	1170	36	19:00	-17	-29	0.49	0.25	0.06	0.06	0.30	36	52	0.48
07/26/95	04:00	07/27/95	18:00	30	1360	41	21:00	29	1150	35	7:00	-15	-15	0.54	0.22	0.09	0.06	0.24	24	84	0.28
08/03/95	18:00	08/04/95	24:00	30	1320	63	06:00	29	1000	44	20:00	-24	-30	0.82	0.46	0.14	0.10	0.47	132	192	0.04
08/05/95	11:00	08/06/95	18:00	32	2240	150	18:00	31	1110	43	14:00	-50	-72	1.04	0.59	0.19	0.17	0.60	26	33	0.85
08/11/95	15:00	08/13/95	21:00	28	1820	41	20:00	28	1600	33	12:00	-12	-19	0.42	0.25	0.05	0.02	0.21	51	51	1.27
08/15/95	14:00	08/17/95	21:00	30	3360	160	23:00	28	1660	37	21:00	-51	-77	1.15	0.48	0.46	0.34	0.83	70	75	0.67
08/31/95	16:00	09/01/95	24:00	29	1530	72	24:00	26	990	41	18:00	-35	-43	1.02	0.47	0.43	0.27	0.66	257	357	0.00
09/08/95	02:00	09/10/95	24:00	31	2890	68	08:00	26	1990	36	08:00	-31	-47	0.54	0.38	0.05	0.02	0.24	29	41	0.36
09/13/95	07:00	09/14/95	14:00	31	1190	51	24:00	27	900	36	24:00	-25	-30	0.78	0.19	0.04	0.02	0.56	83	89	0.83
09/22/95	12:00	09/23/95	18:00	29	1260	51	23:00	25	890	34	16:00	-29	-33	0.62	0.15	0.11	0.01	0.23	36	131	0.15
10/05/95	12:00	10/07/95	24:00	25	3280	95	05:00	27	2120	44	03:00	-35	-54	1.39	0.17	0.07	0.01	0.36	23	23	0.28
10/14/95	09:00	10/16/95	24:00	22	3360	99	05:00	30	3030	70	02:00	-10	-30	1.32	0.06	0.06	0.02	0.31	161	167	0.02
10/21/95	01:00	10/25/95	24:00	24	23050	840	24:00	38	32900	3210	14:00	43	280	3.06	0.17	0.17	0.03	0.40	111	137	1.34
Summary 1995				**Total**	52030			**Total**	54454		**ME**	-20	-15								
											RMS	30	83								

*. Precipitation values calculated from data from the four gages in, or near, the study area. (Locations are shown in fig. 1.)

Appendix B. Duration, observed and simulated base-flow and peak-flow data with simulation error, precipitation characteristics, and antecedent rainfall conditions, for 1995-96 nonwinter storms in Ninemile Creek watershed, Onondaga County, N.Y. (continued)

Storm period				Streamflow										Precipitation volume and intensity					Antecedent Rainfall		
Begin		End		Observed				Simulated				Percent Difference		Volume (inches)		Intensity (inches/hour)			Hours since rainfall of		Vol. during past 168hr (inch)
Date mm/dd/yy	Time	Date mm/dd/yy	Time	Base ft^3/s	Vol. ft^3/s-h	Peak ft^3/s	Time of peak	Base ft^3/s	Vol. ft^3/s-h	Peak ft^3/s	Time of peak	Vol.	Peak	Mean inch	SD in	Mean in/hr	SD in/hr	Max. in/hr	0.00 inch	0.10 inch	
04/15/96	24:00	04/15/96	24:00	190	22370	270	20:00	190	22660	270	17:00	1.3	0.5	0.44	0.26	0.02	0.03	0.07	30	30	1.18
04/22/96	16:00	04/22/96	16:00	190	17430	300	09:00	190	16210	260	08:00	-7.0	-12	0.77	0.05	0.02	0.00	0.13	47	47	0.75
04/29/96	10:00	04/29/96	10:00	220	25770	460	02:00	230.	24620	330	09:00	-4.4	-27	0.95	0.19	0.08	0.02	0.22	45	45	1.23
05/09/96	04:00	05/09/96	04:00	190	103060	710	20:00	180	89500	440	07:00	-13	-38	2.07	0.13	0.06	0.06	0.24	34	40	0.63
06/07/96	01:00	06/07/96	01:00	77	5830	94	24:00	71	5070	80	20:00	-13	-15	0.69	0.06	0.02	0.00	0.15	122	194	0.14
06/19/96	07:00	06/19/96	07:00	64	1900	83	19:00	54	1710	73	14:00	-10	-13	0.68	0.13	0.11	0.03	0.32	79	154	0.17
07/02/96	23:00	07/02/96	23:00	51	3040	58	10:00	48	2880	57	08:00	-5.3	-2.2	0.71	0.38	0.03	0.01	0.28	67	80	0.73
07/15/96	09:00	07/15/96	09:00	44	2230	78	14:00	44	2560	100	15:00	-15	35	1.11	0.26	0.17	0.03	0.48	221	264	0.00
07/18/96	20:00	07/18/96	20:00	43	1440	71	09:00	46	1690	85	14:00	-17	20	0.86	0.2	0.07	0.04	0.38	69	80	1.12
07/30/96	03:00	07/30/96	03:00	40	3140	74	18:00	44	3020	47	06:00	-3.8	-37	0.64	0.33	0.07	0.03	0.27	65	227	0.12
08/08/96	07:00	08/08/96	07:00	41	9700	410	21:00	41	16880	1400	05:00	74	243	2.25	1.25	0.1	0.05	0.70	155	180	0.08
08/15/96	20:00	08/15/96	20:00	32	1200	53	24:00	62	2200	90	21:00	83	70	0.58	0.34	0.12	0.11	0.45	157	157	0.67
09/08/96	11:00	09/08/96	11:00	38	1690	56	22:00	57	2280	67	21:00	35	19	1.08	0.08	0.05	0.02	0.21	41	394	0.04
09/17/96	08:00	09/17/96	08:00	37	2250	55	07:00	51	3040	69	04:00	35	26	0.71	0.25	0.03	0.01	0.08	25	77	0.52
09/28/96	13:00	09/28/96	13:00	32	2830	73	05:00	51	3950	80	04:00	40	9.4	1.02	0.16	0.04	0.02	0.14	44	44	0.43
Summary 1996				**Total**	203870			**Total**	198250		**ME**	16	18								
											RMS	34	69								
Summary 1995-96				**Total**	255900				252710		**ME**	-1.8	1.9								
											RMS	32	76								