Simulated Effects of a Stormwater-Detention Basin on Peak Flows and Water Quality of East Branch Allen Creek, Monroe County, New York

By Phillip J. Zarriello

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	0.4047	hector
square foot (ft^2)	0.09294	square meter
square mile (mi^2)	2.590	square kilometer
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
inch per year (in/yr)	25.4	millimeter per year
inch per hour (in/h)	25.4	millimeter per hour
	Volume	
acre-foot (acre-ft)	1233.619	cubic meter
	Weight	
pound (lb)	0.4536	kilogram
	Temperature	
degree Fahrenheit (˚F)	5/9 (˚F-32)	degree Celsius (˚C)

Other Abbreviations

milligrams per liter (mg/L)	=	parts per million
micrograms per liter (µg/L)	=	parts per billion
milligrams per kilogram (mg/kg)	=	parts per million
micrograms per kilogram (µg/kg)	=	parts per billion

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 the United States and Canada, formerly called Sea Level Datum of 1929.

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Abstract

A storm-runoff model of the East Branch Allen Creek watershed near Rochester, N.Y., was developed to assess the effects of a stormwater-detention basin on runoff quantity and quality. The model was calibrated with data collected at the East Branch Allen Creek monitoring site during seven storms in 1992 that had a recurrence intervals of 2 years or less. Historical precipitation records from the National Weather Service at Rochester Airport and discharge records from Allen Creek were used to generate storms with a 2-, 10-, 25-, 50-, and 100-year recurrence interval. Peak flows at the outlet of the detention basin for storms with 10- to 100-year recurrence intervals decreased by 93 to 83 percent for a basin with no permanent pool and by 68 to 75 percent for a basin with a permanent pool. The peak flow for the storm with a 2-year recurrence interval decreased by 70 percent for a basin without a permanent pool and by only 55 percent for a basin with a permanent pool because much of the storage capacity of the basin was unused in a storm of this magnitude. The effects of peak-flow attenuation by the basin diminished downstream as a result of uncontrolled inflow from other areas. The peak flow at the gage for a 10 -year and 100-year storm decreased by 27 and 30 percent, respectively, and the decrease for a basin with a permanent pool was only 1 percent less than that for one without.

Suspended-sediment-trap efficiency of a detention basin, estimated from a reservoir-sedimentation model and averaged from simulations of flow with a high clay content and flow with a high sand content, was 55 and 68 percent, respectively, for a basin without a permanent pool; the corresponding trap efficiency for a basin with a permanent pool was 45 and 62, respectively, when dead storage was bypassed, and was 66 and 77 percent, respectively, when dead storage was displaced. The average trap efficiency for storms with a recurrence interval of 2 years or less was 62 percent, ±16, depending on the magnitude of the storm and sediment-particle-size distribution. The total phosphorus retention is estimated to be 41 percent. The 4.5-acre wetland area at the upstream end of the detention basin is expected to cause further decreases in the sediment and nutrient load, but the rate of nutrient retention and uptake by plants is uncertain because the plant species and stormflows are highly variable. The estimated annual nutrient uptake ranged from a maximum of 2.9 tons of nitrogen and 0.5 tons of phosphorus in a *Typha* (cattail)-dominated wetland to a minimum of 0.4 tons of nitrogen and 0.04 tons of phosphorus in a mature *Phragmites* (reed)-dominated wetland.

INTRODUCTION

Developed areas have been shown to undergo more severe flooding than undeveloped areas because the impervious surface areas such as roads and parking lots prevent infiltration of rain and increase the volume of storm runoff (Leopold, 1968; Sauer and others, 1983). Flooding in developed watersheds that lack significant channel storage is more severe than in other watersheds (Malcolm, 1980). One technique that has proved effective in providing flood control is the use of stormwater-detention basins, which also decrease the concentrations of sediment and associated contaminants entrained in runoff through particulate settling (U.S. Environmental Protection Agency, 1986; Schueler, 1987). The use of detention basins to decrease contaminant loads in urban runoff is promulgated by The Federal Clean Water Act (FCWA) (Gallup and Weiss, 1988).

Recent development in the Irondequoit Creek watershed, which drains into Irondequoit Bay, on the south shore of Lake Ontario near Rochester, N.Y. (fig. 1), has resulted in increased flooding and sedimentation. Detention basins have been identified as a potential method of stormflow- and water-quality control in the watershed to decrease sediment and associated nutrient (phosphorus) loads, which have led to eutrophication of Irondequoit Bay (O'Brien and Gere, 1983).

In 1993, the U.S. Geological Survey (USGS), in cooperation with the Monroe County Department of Health, began a 1-year study to investigate the potential effects of a stormwater-detention basin in the East Branch Allen Creek watershed (fig. 1) on runoff quantity and quality. As a part of this study, a watershed model was developed to simulate storm runoff in the watershed and assess the basin's effectiveness in attenuating peak stormflows, and a reservoir-sedimentation model was developed to assess particulate entrapment in the basin and the changes in stormwater quality that occur between the basin inflow and the outflow.

Purpose and Scope

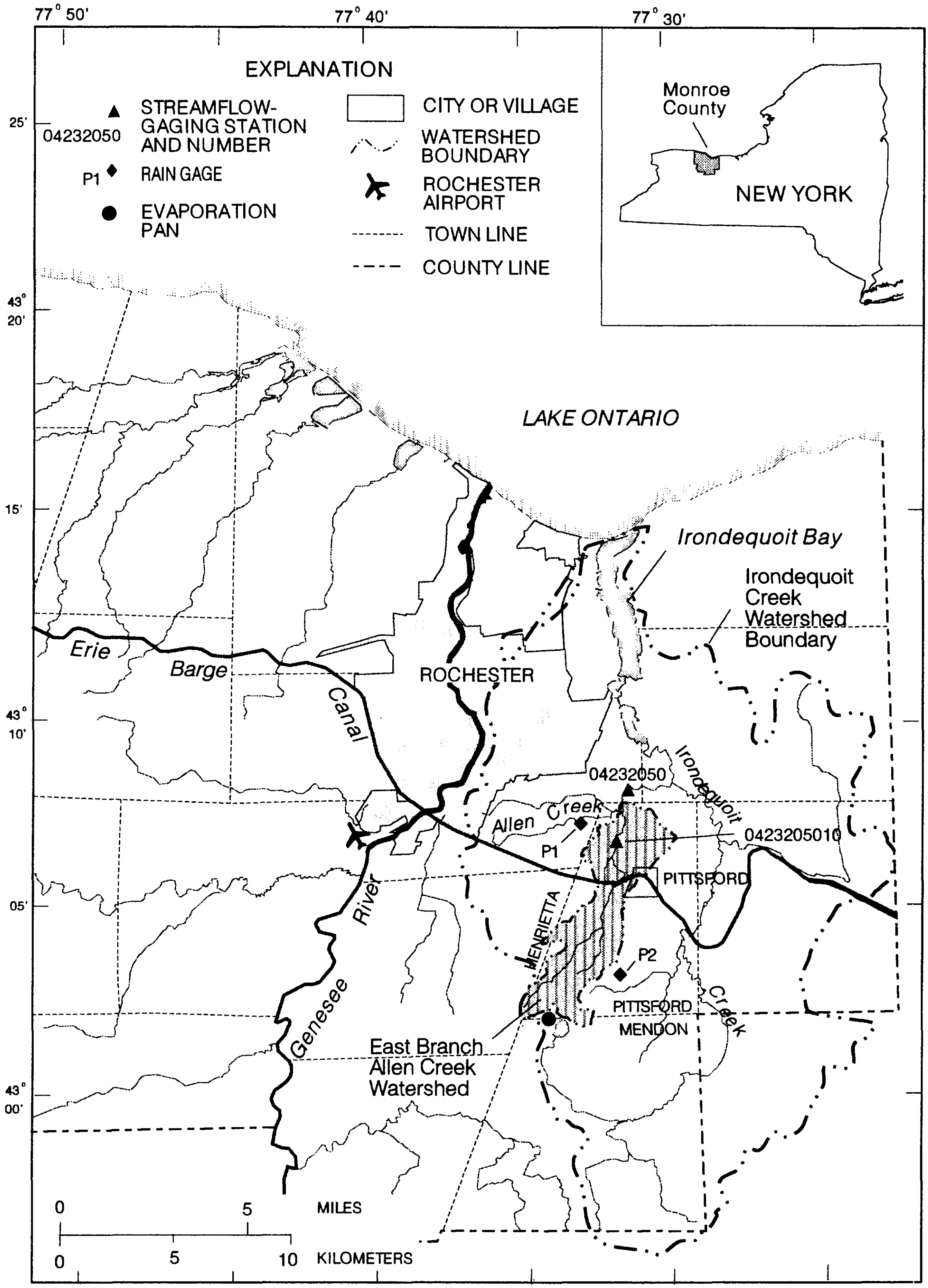
This report describes the hydrology of the East Branch Allen Creek watershed, the rainfall-runoff-simulation model (DR3M), the sedimentation model, and the effects of the detention basin on peak flow and chemical quality of storm runoff from the watershed. It discusses the peak-discharge attenuation for simulated storms with a 2-, 10-, 25-, 50-, and 100-year recurrence interval and presents estimates of (1) the detention basin's trap efficiencies for suspended sediment, and (2) decreases in nutrient concentrations in the detention basin and wetlands, as calculated from the relation of nitrogen and phosphorus concentration to (a) suspended-sediment concentrations, and (b) plant uptake of nitrogen and phosphorus in the wetlands.

Previous Studies

The hydrology and water-quality characteristics of the Irondequoit Creek Basin were studied in detail during the early 1980's as part of the National Urban Runoff Program (NURP). The NURP study indicated that, of the six major Irondequoit Creek subbasins, the Allen Creek watershed contributed the largest load of most constituents per unit area (Kappel and others, 1986; O'Brien and Gere, 1983). As part of the NURP study, a Distributed Routing Rainfall Runoff Routing Model of the Allen Creek watershed was developed (Kappel and others, 1986) and was used to provide initial soil-moisture and runoff parameters as model input for the East Branch watershed. Subsequent work in the Irondequoit Creek basin evaluated the effectiveness of detention basins as a storm-runoff quantity and quality control (Zarriello and Surface, 1989; Zarriello and Sherwood, 1993). Flood mapping was conducted in the basin in 1978 for insurance investigations under the Federal Emergency Management Agency (FEMA) and the Comprehensive Drainage Plan of the a Town of Pittsford (Lozier Engineers, Inc., 1982).

Acknowledgments

Martin Brewster, Town of Pittsford Deputy Commissioner of Public Works, provided detailed hydrologic descriptions and maps of the basin needed for development of the runoff model. Peter Nielsen and Derek Anderson of Lozier Architects/Engineers, the Town's consulting engineer, provided additional information on the watershed characteristics and design of the outlet control structure. The Monroe County Environmental Health Laboratory provided rainfall data for model calibration.



Base from U.S. Geological Survey Digital Line Graph, 1:100,000

Figure 1. Principal geographic features of Monroe County, N.Y. and location of East Branch Allen Creek watershed and streamflow-gaging stations used in this study.

WATERSHED CHARACTERISTICS

The watershed of the East Branch of Allen Creek encompasses 10.2 mi^2 and lies mostly in the Town of Pittsford, near Rochester in Monroe County, N.Y., but extends into in the Towns of Mendon and Henrietta (fig. 1). Allen Creek is a tributary to Irondequiot Creek, which flows into Irondequoit Bay on Lake Ontario. The north-central part of the watershed is traversed along its east-west axis by the Erie-Barge Canal, which is hydraulically separated from the watershed except during periods of low flow, when water is siphoned from the canal to augment flow in the East Branch of Allen Creek.

Land Use, Soils, and Topography

Land use is in transition from open and agricultural to residential. The southern half of the watershed contains mostly open and agricultural land, and the northern half is mainly residential and commercial, except for two golf courses, which together occupy 0.765 mi^2 (fig. 2). Land use in 1992 (Martin Brewster, Town of Pittsford, oral commun., 1994) was as follows: woods, 5.6 percent; agriculture, 24.8 percent; open land, 34.4 percent, of which 7.5 percent is in golf courses; residential, 24.8 percent; transitional from undeveloped to developed, 0.9 percent; commercial, 6.0 percent; wetlands, 3.2 percent; stormwater-detention basins, 0.3 percent (fig. 2). Two major four-lane Interstate highways transverse the basin—the New York State Thruway in the south, and Route 490 in the northeast—along with several State highways (4.5 mi), many town roads (14.3 mi), and county roads (47.3 mi).

Most soils in the watershed have low to moderate permeability associated with till and lake-silt and clay deposits from which they are formed (Heffner and Goodman, 1973; Yager and others, 1985). These soils are predominantly loam, with a potential infiltration rate ranging from less than 0.6 in/h to 2.0 in/h. The Soil Conservation Service (SCS) classifies soils with this infiltration rate into hydrologic group B, which has moderately low runoff potential. Soils of high permeability overlie lake silt and fine sand in a small area in the northeastern part of the watershed; these soils have a potential infiltration rate of at least 6.0 in/h and are classified by the SCS as Group A, which has the lowest runoff potential (fig. 3).

The watershed is characterized by gently rolling hills that range from about 715 ft above sea level in the south to 380 ft above sea level at the mouth to Allen Creek in the north. Slopes between stream channels and valley ridges range from 8 percent to less than 1 percent, with a mean of about 3.3 percent. Stream-channel slopes range from less than 1 percent to about 2 percent and average slightly less than 1 percent. Stream channels are generally steeper in the upper (southern) part of the watershed than in the lower (northern) part.

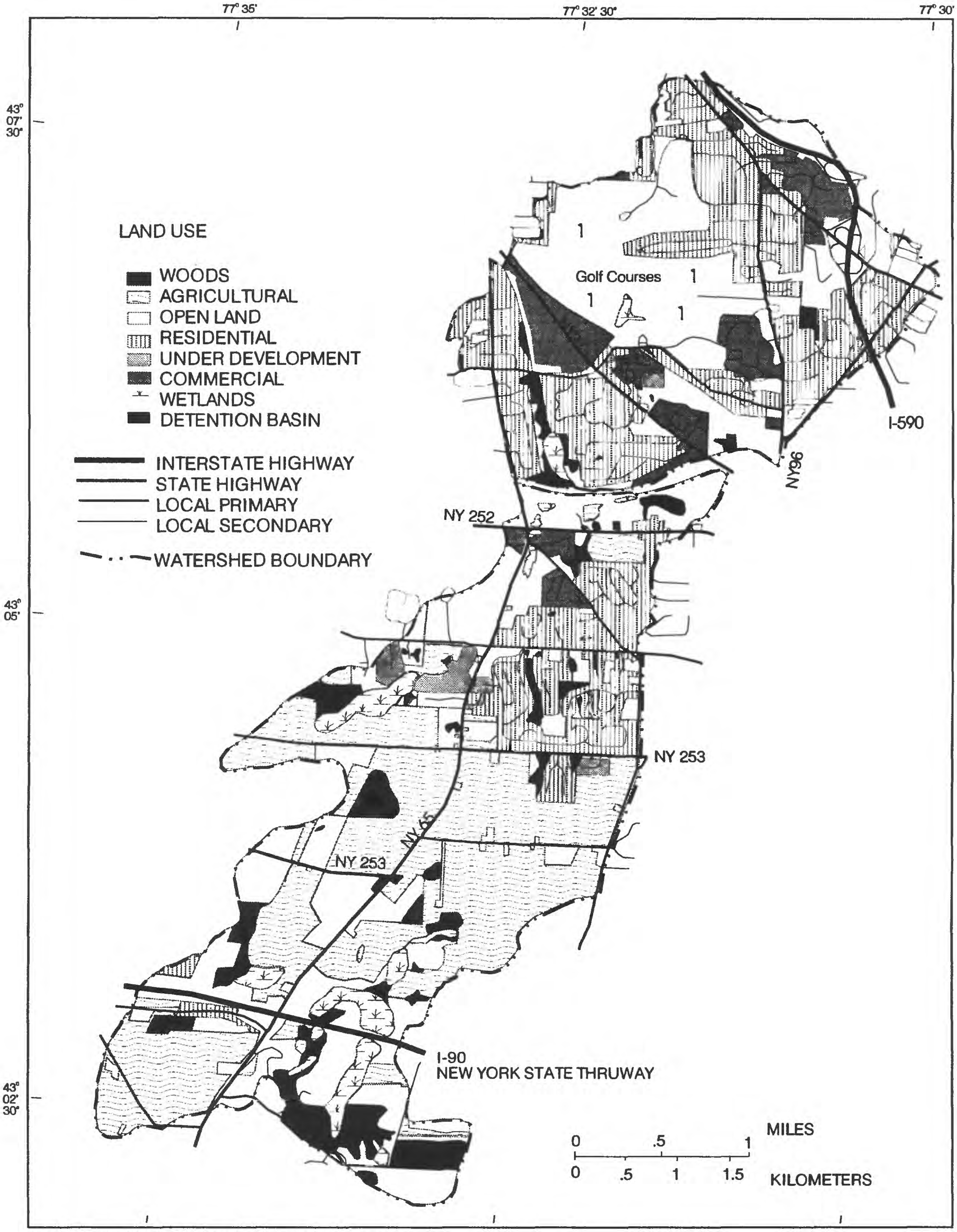
Streamflow and Rainfall

The return frequency and associated magnitude of runoff and precipitation were calculated and used to develop "design" storms to assess the effects of the detention basin on peak flows over a wide range of discharges. This information provided model input for selected storm flows that are expected to occur once every 2, 10, 25, 50, and 100 years.

Peak-Flow Frequency

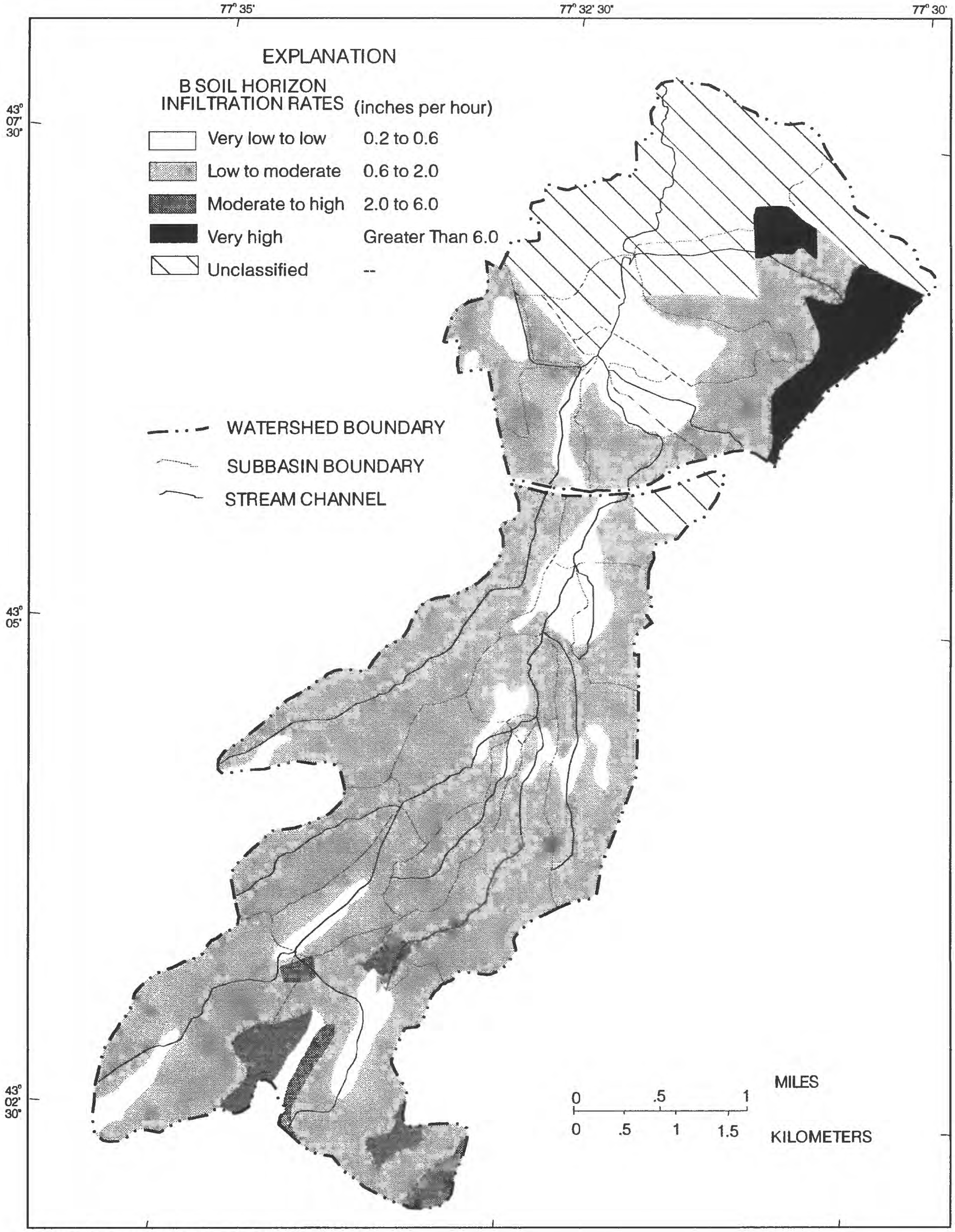
The relation of peak flow to probability of exceedance (or recurrence interval) is referred to as the peak-flow frequency relation. Probability of exceedance is the probability that a peak flow will exceed a specific magnitude in any one year. Recurrence interval is the reciprocal of the probability of exceedance and is the interval, in years, in which a given peak flow is expected to be exceeded. For example, a peak flow having a probability of exceedance of 0.04 has a recurrence interval of 25 years. A peak flow having a recurrence interval of 25 years might not occur in a given 25-year period or might occur more than once in a 25-year period, but will occur every 25 years, on average, over a long period of time.

Long-term discharge data (1960-92) measured at the USGS streamflow-gaging station on the main branch of Allen Creek (04232050) was used to estimate the peak-flow frequency at the gaging station on the East Branch Allen Creek (0423205010), 2.63 mi upstream (fig. 1). A Log-Pearson Type III analysis of peak flows, calculated by USGS flood-frequency program J407 (Kirby, 1982) in accordance with guidelines recommended by the Interagency Advisory Committee on Water Data (U.S. Geological Survey, 1982), is summarized in table 1. Peaks from the Allen Creek gage for selected recurrence intervals were



Base from Town of Pittsford Planning Department land-use maps
1:9600

Figure 2. Land use in East Branch Allen Creek watershed, Monroe County, N.Y. (Location is shown in fig. 1.)



Base from Geohydrology of the Irodequoit Creek Basin
Plate 3, Soil Permeability (Yager and others, 1985)
1:125000

Figure 3. Infiltration rates of soils in the East Branch Allen Creek watershed, Monroe County, N.Y. (Location is shown in fig. 1. Data from Yager and others, 1985, pl. 3.)

adjusted through a method by Wandle (1983) that relates the area of the known downstream discharge to the area at the point where discharge is desired, by the relation

$$Q_u = \left(\frac{A_u}{A_k}\right)^R \cdot Q_k \qquad (1)$$

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,
R = Regional coefficient, and
Q_k = Known discharge at downstream location.

Regional coefficients (0.84) for the study area are given in Lumia (1991). An adjustment factor of 0.315 was applied to computed discharge values for selected recurrence intervals at the Allen Creek gage (drainage area 30.1 mi^2) to estimate floodflow frequencies at the East Branch Allen Creek gage (drainage area 7.61 mi^2). Flow-duration curves at the East Branch Allen Creek gage and the upper and lower 95-percent confidence limits are shown in figure 4 and in table 1. Error associated with the adjustment factor was estimated through a comparison of the six highest daily peak flows at the two sites from May 1990 through April 1993. The absolute error and root mean square error (explained later) of the adjusted downstream peak flow and the observed upstream peak flow were -0.01 and 0.06, respectively.

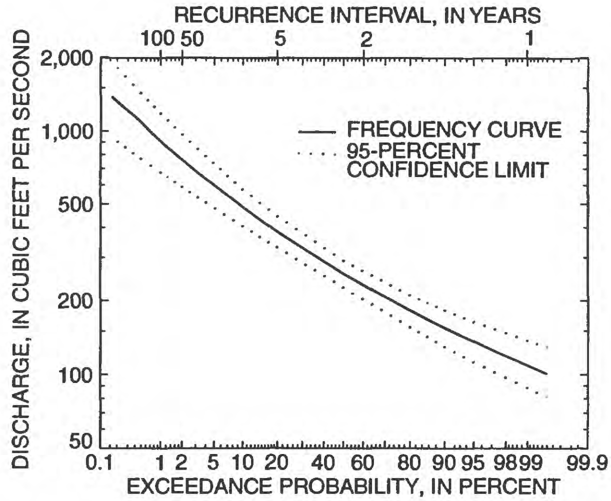


Figure 4. Peak-flow-frequency curve for East Branch Allen Creek, Monroe County, N.Y.

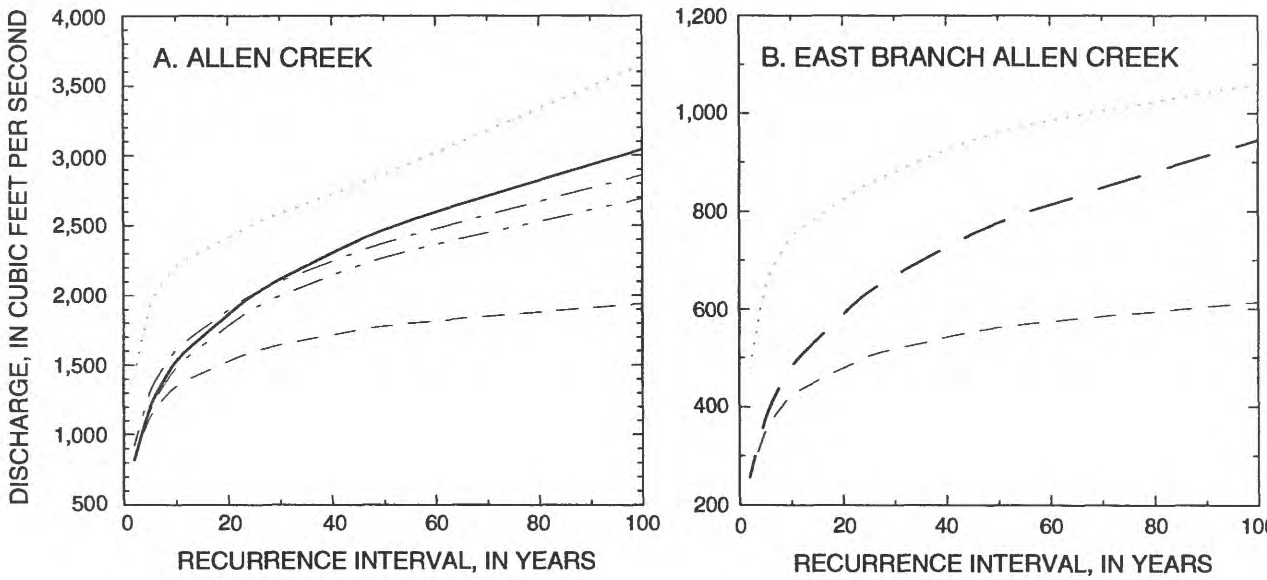
Flood-frequency estimates were also compared to (1) peak flows for selected recurrence intervals calculated from regional regression equations for determining peak flow at ungaged rural sites (Lumia, 1991), and (2) peak flows adjusted for urbanization, as described by Sauer and others (1983). Lumia (1991) also presents a method to improve estimates of flood frequency by a weighted average of peak flows calculated by Log Pearson Type III analysis of gaged data and peak flows calculated from regional regression equations adjusted for urbanization.

Table 1. Estimated peak-discharge frequency at Allen Creek and East Branch Allen Creek, Monroe County, N.Y.
[Discharge is in cubic feet per second]

Annual exceedance probability	Recurrence interval (years)	Allen Creek			East Branch Allen Creek		
		Peak discharge	95-Percent confidence limit		Peak discharge	95-Percent confidence limit	
			Lower	Upper		Lower	Upper
0.500	2	815	717	924	257	226	291
0.200	5	1220	1050	1410	383	331	444
0.100	10	1540	1290	1830	486	405	576
0.040	25	2030	1610	2840	640	506	896
0.020	50	2490	1870	3070	784	588	967
0.010	100	3000	2140	3740	945	675	1180

Continuous flow records at Allen Creek dating from 1960 provided sufficient data for comparison of flood-frequency-estimation methods (fig. 5A). Comparison of regional regression equations and adjusted regional regression equations with Log-Pearson Type III distributions and weighted Log Pearson Type II distributions calculated from 33 years record indicate that: (1) the unadjusted rural peak-discharge estimates underpredict peak flow except for storms with a recurrence interval of 5 years or less, and (2) rural regional regression equations adjusted for urbanization overpredict peak flow for all storms. The weighted flood-frequency estimates are similar to the Log Pearson Type III estimates because the estimate is heavily weighted to these values, and the "expected probability estimate" is similar to the weighted flood-frequency estimate. The expected probability estimate was used to calculate the flood frequencies for the East Branch Allen Creek because (1) the shape of the flood-frequency curve appears to represent peak flow of the East Branch better than other estimates for Allen Creek, and (2) the estimate provides a slightly higher estimate of peak flow at higher flows and, thus, provides a more conservative assessment of the effects of the detention basin on peak flow.

The initial input into the East Branch Allen Creek model was based on storm characteristics that produced actual flows for the selected frequencies in the Allen Creek watershed. Hourly rainfall data from two selected storms that produced peak flows with a recurrence interval of 100 years (3,280 ft^3/s on May 17, 1974) and 10 years (1,590 ft^3/s on June 8, 1980) in the Allen Creek watershed were obtained from the National Oceanic and Atmospheric Administration station at the Rochester Airport. The intensity and volume of rainfall were modified slightly to produce a simulated peak flow that was within the estimated ranges given in table 1.



EXPLANATION

- WRC (Water Resource Council) Log Pearson Type III distribution Bulletin 17B (U.S. Geological Survey, 1982)
- Lumia (1991) regional regression equations for peak flow at rural ungaged sites
- Sauer and others (1983) adjusted with a basin-development factor of 4 for urbanization
- Weighted WRC & Lumia (1991) adjusted for urbanizaton
- WRC "Expected Probability Estimate" (U.S. Geological Survey, 1982)
- Wandle (983) weighted area applied to Allen Creek WRC "Expected Probability Estimate"

Note: Bold line indicates method used in this report for estimating flood-frequency

Figure 5. Discharge as a function of recurrence interval,as calculated by six published methods.

Historical Rainfall Characteristics

Long-term (1948-83) hourly rainfall data from the National Oceanic and Atmospheric Administration station at the Rochester Airport were used to define recurrence-probability curves for storm duration, volume, average intensity, and maximum intensity (fig. 6A), and antecedent rainfall volumes in the last 1, 2, 3, and 7 days before the storm (fig. 6B). This information was compiled through SYNOP, a program developed for NURP (U.S. Environmental Protection Agency, 1976). These probability curves can be used to select other storm and antecedent conditions to evaluate detention-basin effectiveness.

A dry period of at least 12 hours was used to define independent storms. For the 35 years of record, the SYNOP program selected 4,020 storms for analysis–slightly fewer than 115 storms per year on average. The recurrence interval for a storm represents the period of record (35 years) divided by the number of storms (4,020), divided by 1 minus the percent probability:

$$T = \frac{M/N}{1 - Pr} \tag{2}$$

where T = Recurrence interval, in years,
M = Number of years in the record,
N = Number of storms in the record, and
Pr = Probability of occurrence.

Thus, storms with recurrence intervals of 2, 5, 10, 25, 50, and 100 years have probabilities of 99.565, 99.825, 99.913, 99.965, 99.982, and 99.991 percent, respectively.

Probability distributions computed for peak flow are related to precipitation characteristics, but a storm that produces a 100-year peak flow does not necessarily reflect a precipitation intensity with a 100-year recurrence probability because peak flows reflect the combined effects of precipitation intensity, duration, and volume, as well as antecedent soil conditions. For example, the two storms that were used as initial input for generating peak flows with a recurrence interval of 100 years and 10 years (May 17, 1974 and June 8, 1980) represent rainfall volumes with recurrence intervals of about 20 and 2 years, and a maximum intensity of 100 and 3 years, respectively. Therefore, a design flow calculated from long-term flow records or related to long-term flow records is more representative of expected return flows than a design storm generated from rainfall characteristics alone. For this reason, if long-term flow data are unavailable, flow-probability distributions can be developed from flow records generated from long-term rainfall records by a watershed-runoff model.

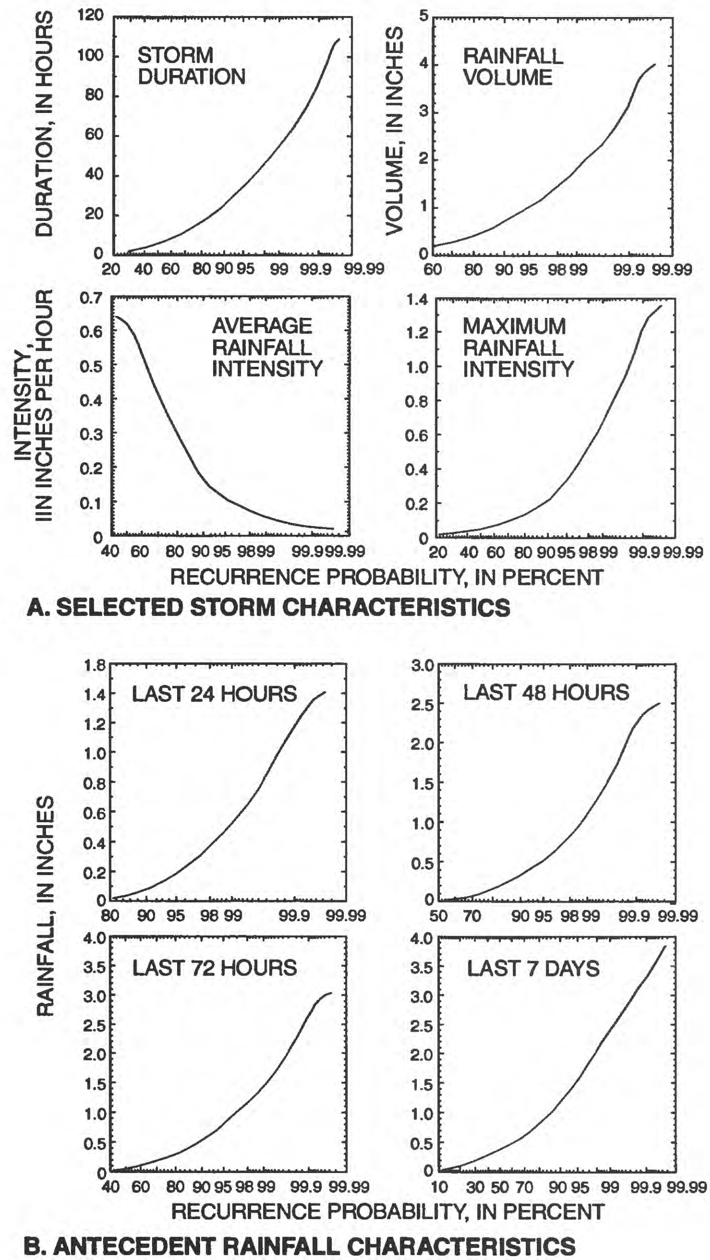


Figure 6. Probability curves based on National Oceanic and Atmospheric Administration hourly rainfall data at the Rochester, N.Y., Airport, 1948-83: A. Selected storm characteristics. B. Antecendent rainfall characteristics.

WATERSHED RAINFALL-RUNOFF MODEL

The Distributed Routing Rainfall Runoff Model (DR3M) developed by the USGS (Alley and Smith, 1982a) was chosen to simulate the relation of rainfall to runoff in the East Branch watershed because the central part is highly urbanized and because the model had been previously used to simulate runoff in the Allen Creek watershed (Kappel and others, 1986).

DR3M is a continuous deterministic simulation model that uses rainfall as the primary input to provide detailed storm routing of rainfall through a series of land segments into a series of stream-channel segments. Thus, the watershed can be conceptualized as a series of land segments connected to stream-channel segments that interconnect to represent the watershed. Channel segments can be routed into reservoir segments that represent either manmade or natural storage.

Land segments consist of impervious and pervious surfaces. Runoff from impervious surfaces is classified into two categories—hydrologically effective area (HEA), which routes precipitation directly into channel segments, and hydrologically ineffective area (HIA), which routes precipitation onto adjacent pervious areas. Runoff from pervious areas is governed by the Green-Ampt equation (Green and Ampt, 1911), which calculates the antecedent soil-moisture conditions from daily rainfall and evaporation. Runoff from adjacent HIA's is added to the soil moisture of the pervious area into which it flows, and once the infiltration capacity of the soil is exceeded, the runoff is routed into an adjacent channel segment. Precipitation from as many as three rain gages can be represented in the model and distributed over land segments by Thiessen polygon coefficients. Thus, the amount of runoff generated from pervious surfaces is controlled by (1) a set of calibrated soil parameters, (2) antecedent precipitation and evaporation, and (3) the storm characteristics such as intensity, duration, and volume.

Channel segments represent natural or manmade conveyances that receive water from adjacent land segments or from upstream channel or reservoir segments. Channel segments are described in terms of their geometry (circular or triangular), length, slope, and a roughness coefficient or a set of kinematic wave-routing parameters. Alley and Smith (1982a) describe the limitations and assumptions of kinematic wave equations used for overland flow and channel routing.

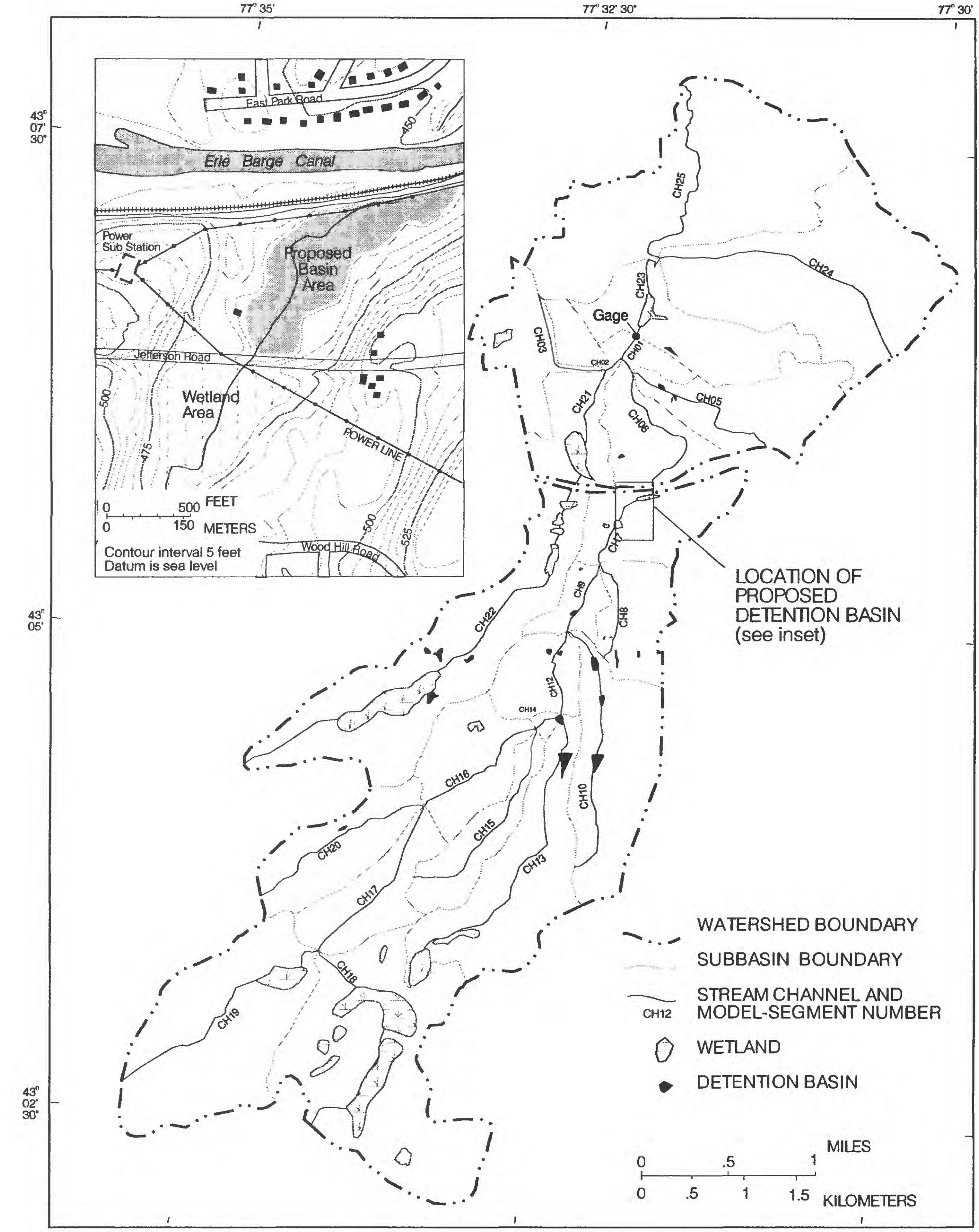
Reservoir segments represent wetlands, storm-flow-detention basins, or undersized culverts that act as storage basins. The Modified-Puls method is used to describe reservoir segments in terms of an inflow hydrograph and the outflow-to-storage relation of the reservoir.

Segmentation

The East Branch Allen Creek watershed was divided into 27 overland-flow segments, 25 channel segments, and 10 reservoir segments, excluding the detention basin (fig. 7). Segmentation of the watershed was based on natural topographic divides, augmented by information on the storm-sewer system, natural intersections of channels, and areas of similar land use. The hydrologic characteristics of the individual subbasins were obtained by compiling the spatial characteristics of the watershed and preparing coverages for Geographic Information System (GIS) analysis.

For each land segment, the areas of HEA and HIA were initially calculated from the land-use characteristics of the watershed. Agricultural, open, and wooded lands were initially estimated to have an HIA of 1 percent; residential areas had an estimated HIA of 20 percent, and commercial areas had an estimated HIA of 20 percent and an HEA of 40 percent. Additional areas of HIA and HEA were added to the land segments according to the type and length of roads within the segment. The final values of HIA and HEA applied to each land segment were adjusted through the model calibration procedure discussed later. The adjusted HIA and HEA represent 34 and 6 percent of the total watershed area, respectively; the remaining 60 percent of the watershed is pervious area.

Most channel segments use one lateral-inflow (land) segment twice to approximate the geometry of the subbasin (fig. 7). This decreases the number of segments needed to represent the basin while preserving the approximate length of the flow path along which water must flow to reach a stream-channel segment. This is an important consideration during flow routing because the time of the peak in each channel segment will be controlled in part by the geometry of the lateral inflow segments. A second set of land segments was used to represent lateral inflows in the northeastern part of the basin because this area is defined by a second set of soil-moisture parameters (table 2) to simulate the permeable soils in this part of the watershed (fig. 3).



Base from Town of Pittsford Planning Department land-use maps, 1993
1:9600

Figure 7. Segmentation and hydrologic features of the East Branch Allen Creek watershed, Monroe County, N.Y. (Location is shown in fig. 1.)

Table 2. Optimized parameter values for soil-moisture and runoff terms

[in., inches: in/h, inches per hour]

Term*	Soil Permeability	
	Low to moderate	Moderate to high
SOIL-MOISTURE TERMS		
PSP (in.)	5.005	5.005
KSAT (in/h)	0.224	6.300
RFG	17.820	17.820
BMSN (in.)	4.84	4.84
RUNOFF TERMS (same for both soil types)		
EVC	0.77	
RR	0.95	
IMP (in.)	0.05	

* PSP - Suction at the wetting front for soil moisture at field capacity.

KSAT - Effective hydraulic conductivity of saturated soil.

RGF - Ratio of suction at the wetting front for soil moisture at wilting point to that of field capacity.

BMSN - Available soil water at field capacity.

EVC - Evaporation-pan coefficient to convert to potential evapotranspiration

RR - Percentage of daily rainfall that infiltrates into the soil.

IMP - Maximum impervious retention.

Ten reservoir segments were used to simulate wetlands in the western and southern (upper) part of the watershed and the manmade detention facilities in the east-central part (fig. 7). Reservoir segments generally represent several wetlands and (or) detention basins because these were too numerous to simulate individually and because information on the storage-to-outflow relation for all the wetlands and some of the detention basins was lacking. The reservoir segments used in the model approximate the combined effect of these wetlands and detention basins on the streamflow in the watershed. The storage-to-outflow relations for the simulated detention basins were obtained from engineering details of a constructed detention basin. Where this information was unavailable, estimates of storage were made from topographic maps, and outflows were estimated from model calibration of peak flow and time of peak.

Calibration

Model calibration is necessary to obtain parameter values that adequately represent the runoff process. The calibration procedure involved matching simulated storm volume, peaks, and time of peak to the measured values. Seven storms that occurred from April through September 1992 were selected for model calibration; these storms represented a wide range of storm volume, duration, and intensity. The streamflows used for calibration had been measured at 15-min time steps during these storms at the USGS gaging station in the East Branch about 3 mi upstream from the mouth. The measured discharge does not include the lower part of the East Branch Allen Creek watershed; thus, the calibrated model represents only the 7.61-mi^2 drainage area upstream from the gage (about 75 percent of the watershed). Daily and unit (5-min) precipitation data used in the model were recorded by the two weighing-bucket rain gages closest to the watershed; these sites are operated by the Monroe County Environmental Health Laboratory and are just outside the northwest and southeast borders of the watershed (fig. 1). Rainfall values were distributed within the watershed through Thiessen polygon coefficients. Daily evaporation data were also obtained from Monroe County Environmental Health Laboratory, which operates a Class A evaporation pan just outside the southern boundary of the watershed (fig. 1).

Storm-runoff volumes were initially calibrated by an optimization routine (Rosenbrock, 1960) provided as part of DR3M. During optimization of storm-runoff volumes, the watershed is treated as a lumped parameter, and no routing is performed, but runoff volumes are calculated. A adjustment parameter (EAC) for the hydrologically effective impervious area (HEA) is calibrated first for small storms that are assumed to generate runoff predominantly from these areas. Optimization is performed next for soil parameters, which control runoff from pervious areas during larger storms. Optimized parameter values for soil moisture and runoff are summarized in table 2.

Once the model is calibrated for storm volumes in the lumped-parameter mode, the model is run in a distributed-parameter mode to calibrate peaks and the time of peaks. In the distributed-parameter mode, the model calculates runoff from each land segment into the adjacent stream-channel and reservoir segments over a series of time steps. The timing and magnitude of peak runoff from each land segment and stream-channel segment is varied by manually adjusting the length, slope, and roughness coefficients of the associated segment. Because the timing and magnitude of peak runoff are affected by wetlands (3.2 percent of the watershed) and at least 18 known detention basins, 10 reservoir segments representing these areas were added to the model to reduce peak flows once the other parameters were adjusted.

Error

After calibration, the absolute error (AE) and the root mean-square error (RMS) of the percent difference between the observed and predicted values were computed (table 3). These tests provide a measure of the model accuracy within the range of storm conditions used to calibrate the model. AE indicates model bias as the difference from zero, and RMS weights the error to outlier values. AE and RMS are calculated by

$$AE = \sum \frac{r}{n} \qquad RMS = \sqrt{\sum \frac{r^2}{n}}\ , \tag{3}$$

where $r = \dfrac{\text{observed value - predicted value}}{\text{observed value}}$

n = number of storms.

Accuracy, as determined by these tests, is only a measure of the model's representativeness of the system at the point of known flow. Although the model is capable of producing information on flow at any point defined by a model segment, no information is available to assess the accuracy of the simulated flows except at the model segment corresponding to the East Branch Allen Creek gage. Similarly, no information is available to verify the representativeness of about 25 percent of the model area downstream from the gage (2.63 mi^2). Simulated flows at these points are subject to uncertainty because no data are available for comparison against simulated results.

Rainfall-runoff models are highly sensitive to rainfall variability, particularly in large watersheds, because the amount and intensity of rainfall can differ appreciably over small areas. Although DR3M can incorporate data from up to three rain gages, data were available from only two sites (P1 and P2 in fig. 1) and might not adequately describe the distribution of rainfall over the entire watershed. Furthermore, DR3M distributes inputs from multiple gages equally for every storm; hence, local variation in rainfall could be a significant source of error between the simulated and observed values.

One of the purposes of a watershed model is to simulate large storms from historical rainfall data that occur infrequently. A watershed model is especially useful for assessing effects of this type of storm because flow measurements for storms of this

Table 3. Rainfall volume, runoff volume, peak flow, and model error for simulated East Branch Allen Creek discharges, Monroe County, N.Y.

[Locations of rain gages (P1 and P2) are shown in fig. 1]

	Rainfall volume (inches)		Runoff volume (inches)			Peak flow (cubic feet per second)		
Storm date	P1	P2	Observed	Predicted	Percent Difference	Observed	Predicted	Percent Difference
92-04-11	1.2	0.8	0.353	0.408	-15.6	124	84	32.2
92-04-16	1.2	1.4	0.753	0.472	37.3	133	70	47.4
92-05-02	1.2	1.2	0.527	0.545	-3.4	149	168	-12.8
92-07-12	3.1	2.7	0.571	0.842	-47.5	119	109	8.4
92-08-03	2.4	2.1	0.728	0.850	-16.7	158	138	12.6
92-08-27	3.6	2.8	1.868	1.554	16.8	316	346	-9.5
92-09-03	1.0	0.8	0.322	0.249	22.7	93	78	16.1
			Absolute error (percent)		-0.9			13.5
			RMS error (percent)		26.6			22.9

magnitude are typically not available. This technique should be used with caution, however, because the model is calibrated to discharges from relatively small storms; these data could give inaccurate results when extended far beyond the model's calibrated range.

Another potential source of error in simulating large, infrequent storms is that the storage-to-outflow relations defined for wetlands could differ at high flows from the flows used for model calibration. For example, the predicted recession hydrograph for three of the calibration storms (April 11, July 12, and August 3) indicate that the storage-to-outflow relations defined for reservoir segments overpredict the duration of water retention, although the recession hydrographs for the other four calibration storms closely match the observed data. Thus, the uncertainty in the storage-to-outflow relations for natural impoundments can increase the error in predicted flows of large storms.

DESIGN OF SIMULATED DETENTION BASIN

The detention basin, referred to as Schuyler Pond, would control runoff from the southeastern part of the East Branch Allen Creek watershed south of the Erie-Barge Canal and railroad (inset, fig. 7). The drainage area above the detention basin is 5.29 mi^2, or about half of the East Branch watershed.

The purpose of the detention basin is to provide (1) stormwater detention for downstream flood control, (2) streamflow augmentation during periods of low flow, and (3) improved stormwater quality through settling of particulate matter. Basin size and control structure was designed by Lozier Engineers to obtain maximum flow attenuation (Lozier Architects and Engineers, 1993). Most of the detention-basin site lies within the 100-year flood plain (fig. 7 inset).

Structure and Capacity

The railroad embankment is used as part of the control structure along with a constructed outlet to regulate outflows and allow free drainage through the present arched box culvert under the railroad and the box invert under the Erie-Barge Canal. Jefferson Road (elevation 467.5 ft) limits the pool elevation for the structure to a maximum of 466 ft. The storage capacity of the basin at this elevation is about 160 acre-feet (about 0.56 inches of runoff) and covers about 20 acres (fig. 8). The maximum storage would retain about 1.5 in of rainfall according to the log-transformed mean rainfall-runoff coefficient calculated from the calibration storms.

Outlet Control

The outlet control-structure was designed to (1) allow base flow to pass through the detention basin unimpeded, (2) attenuate peaks of small storms that cause localized flooding at the two golf courses (fig. 2), and (3) preserve sufficient storage to attenuate peaks of large storms or successive small storms.

The original control design uses a combination of a relatively small, 1-ft-diameter pipe at the base of the control, three 2-ft-diameter openings at an intermediate

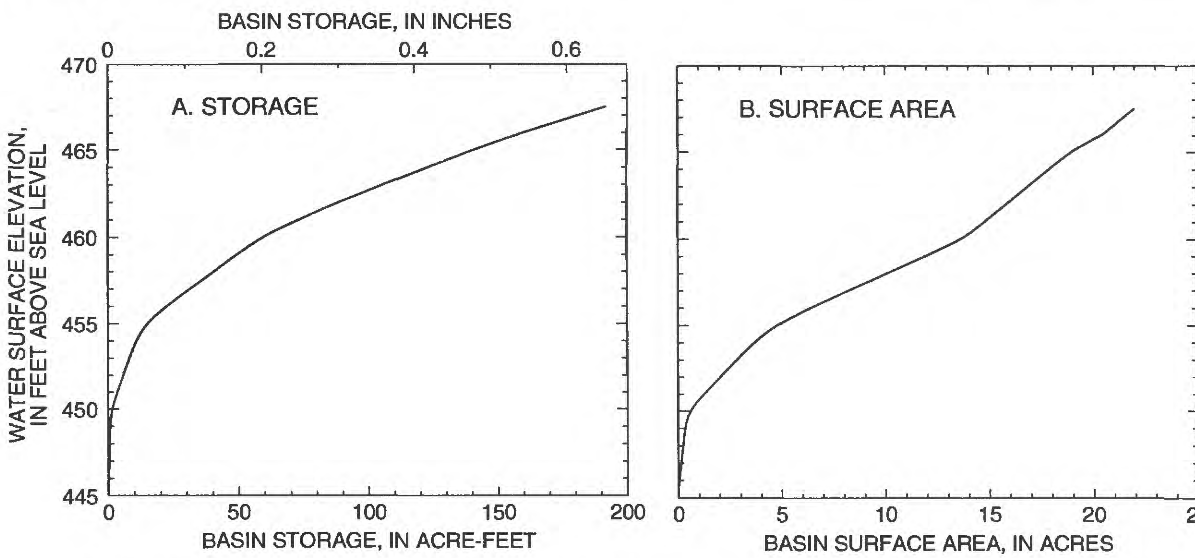


Figure 8. Relation of water-surface elevation to (A) storage, and (B) surface area in the simulated detention basin on East Branch Allen Creek, Monroe County, N.Y. (Location is shown in fig. 7.)

control, three 2-ft-diameter openings at an intermediate level, and a emergency spillway 1.5 ft below the elevation of Jefferson Road (Lozier Architects and Engineers, 1993). A second outlet-control design was developed by the same designers after initial model results indicated sufficient storage to incorporate a permanent pool that could be used to augment low flows. The revised control incorporates a 14-ft broad-flat weir at an elevation of 457.0 ft inside a box structure. The box structure drains water from the bottom of the detention pond except during large storms, during which the rising water will drain through rectangular openings in the structure at an elevation of 463.3 ft.

Configuration with No Permanent Pool

The outlet structure for the basin configuration with no permanent pool (original control design) allows water to drain through the bottom opening, which has a capacity of discharging 2.7 ft^3/s before overtopping. This allows daily flows to pass through the basin unimpeded about 20 percent of the time, as determined from flow-duration analysis of average daily mean flows at the East Branch Allen Creek gage. Once discharge exceeds 2.7 ft^3/s, however, storm runoff will back up, and the outflow discharge will increase at a relatively slow, uniform rate (fig. 9) until it reaches about 14 ft^3/s, whereupon water will spill into the intermediate openings at an elevation of 460 ft. The daily mean discharge exceeds this capacity only 15 percent of the time. At this discharge, about 58 acre-feet of storage, or about 36 percent of the total storage capacity of the basin, will be filled. The water-surface area of the basin at this elevation would be about 13 acres, and the basin would take about 2 days to empty without additional inflow.

High flows that cause ponding above the basin's primary storage (above 460 ft) will begin to use the secondary storage and will discharge through the three 2-ft openings as well as the 1-ft base opening.

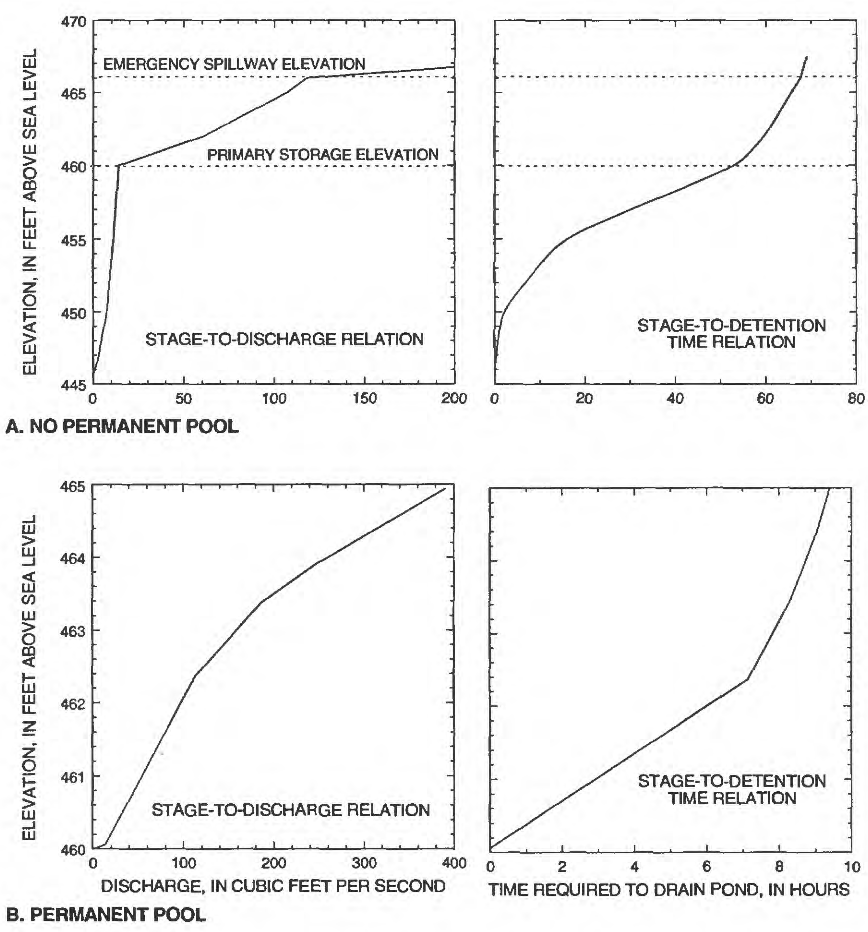


Figure 9. Water-surface elevation in relation to discharge and detention time for two outlet configurations of the simulated detention basin on East Branch Allen Creek, Monroe County, N.Y. (A) No permanent pool. (B) Permanent pool.

Discharge from the basin increases rapidly as the pond rises above the level of the intermediate openings (460 ft), and the rate of water-level rise decreases as a result of the increased discharge and storage. The rate of discharge and rate of water-level rise remain relatively uniform until the level of the emergency spillway (466 ft) is reached. At this stage, about 87 percent of the total storage is used, and the water-surface area approaches 20 acres. Daily discharge exceeds the outlet-control discharge just below the emergency spillway (107 ft^3/s) only about 1 percent of the time. The time required for the basin to drain 5 ft to the level of primary storage (460 ft) is about 18 hours (fig. 9A).

Configuration with a Permanent Pool

The detention basin has sufficient storage to maintain a permanent pool (dead storage) that could be drained during periods of low flow to augment streamflow in the East Branch for irrigation. This design incorporates the primary storage discussed above (58 acre-feet) as a permanent pool that could be released to an elevation of 452.0 ft to augment low flows by about 1 ft^3/s for nearly 30 days. The lowest sustained flow for a 30-day period (1991-93 water year), calculated from daily mean flows at the East Branch gage, was 2.23 ft^3/s. Additional information would be needed to determine whether the amount of available storage is sufficient to meet irrigation requirements during low-flow periods. The decrease in storage that would result from maintaining a permanent pool would cause some decrease in the basin's ability to accommodate large storms, however, as discussed later.

The outlet control structure consists of a 5-ft-diameter opening at the base of the box structure at an invert elevation of 446.0 ft (this configuration requires excavation), but the water level in the pond is controlled by a internal 14-ft broad-crested weir that has a invert elevation of 460.0 ft. Unlike the original design, the weir allows relatively rapid increases in discharge over small changes in the pool elevation (fig. 9B). Additional 1.7-ft-high box openings in the external control structure at an invert elevation of 463.3 ft allow discharge as large as the 100-year storm to pass before overtopping into the top opening of the control at 466.0 ft. A 1.0-ft-diameter pipe controls water level in the permanent pool to a depth 452.0 ft.

EFFECTS OF SIMULATED DETENTION BASIN ON EAST BRANCH ALLEN CREEK

This section summarizes the effect of the basin on peak flows as predicted by the flow model, and on water quality (suspended-sediment and phosphorus concentration), as predicted by the sedimentation model.

Peak Flows

Simulated peak flows for storms with a 2-, 10-, 25-, 50-, and 100-year recurrence interval at the outflow from channel 7 (location of the detention basin) and channel 25 (mouth of East Branch) are plotted in figure 10. Peak flow from a storm with a 2-year recurrence interval is smaller than expected (the actual peak is probably less than a 2-year peak), but this storm was chosen because (1) measured flow data from the East Branch Allen Creek gage were available, and (2) it demonstrates the response of the detention basin to a storm having a second peak. All storms with 25- and 50-year peak-flow records at Allen Creek occurred during the spring runoff period and reflect a combination of rainfall and snowmelt. The model does not support a snowmelt routine; consequently, the 25- and 50-year storms were generated by modifying the input rainfall from the 100-year storm of May 16, 1974 and, thus, produced similarly shaped hydrographs that differ in magnitude. Typical spring runoff produces sustained high flow; thus, the effectiveness of the detention basin during this period would likely be less than indicated for storms of similar size at other times, as discussed below.

Peak flow at the detention-basin outlet for storms with recurrence intervals of 10 to 100 years decreased by 93 to 83 percent in simulations with no permanent pool and by 68 to 75 percent in simulations with a permanent pool (fig. 11 and table 4). The slightly greater peak-flow attenuation for large storms than for small storms in simulations with a permanent pool indicates that basin storage is used more effectively in the larger storms. Initial peak flows of the 2-year storm decreased by 70 percent with no permanent pool and by 55 percent in simulations with a permanent pool, indicating that the available storage is underutilized. Attenuation of the second peak during the 2-year storm was similar (about 55 percent) for both configurations because the initial peak filled the basin to the intermediate openings level, which has an outflow

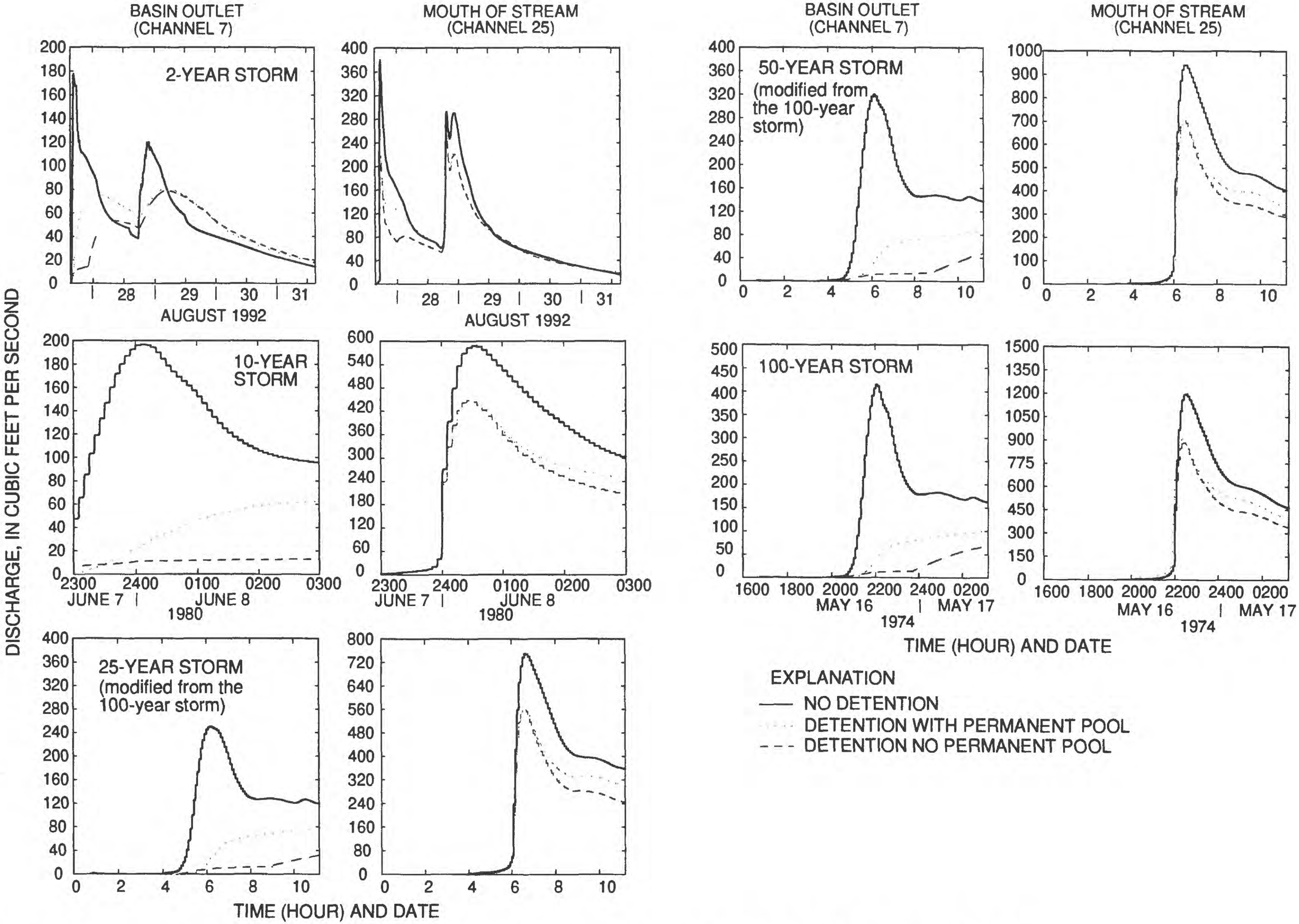


Figure 10. Discharge of East Branch Allen Creek, Monroe County, N.Y. during simulated storms with 2-, 10-, 25-, 50-, and 100-year recurrence intervals at detention basin (channel 7) and at mouth (channel 25), for three types of outflow controls.

Table 4. Peak flow for selected storm-recurrence intervals for simulations with no detention, with detention and no permanent pool, and with detention and a permanent pool in East Branch Allen Creek, Monroe County, N.Y.

[Values are in cubic feet per second. Locations are shown in fig. 7]

Location and configuration	Recurrence interval, in years				
	2	10	25	50	100
CHANNEL 7 — BASIN OUTLET (5.29 mi^2)					
No detention	180	200	250	320	410
No Permanent Pool	79	13	30	48	67
Permanent Pool	81	62	77	86	100
CHANNEL 1 — GAGE (7.61 mi^2)					
No detention	350	500	630	790	980
No Permanent Pool	2000	360	450	560	680
Permanent Pool	200	360	450	560	680
CHANNEL 25 — MOUTH (10.2 mi^2)					
No detention	380	590	750	940	1200
No Permanent Pool	250	450	560	700	880
Permanent Pool	260	440	560	710	890

capacity similar to that of the broad-crested weir that controls flow from the basin with a permanent pool.

For all configurations, the effect of peak-flow attenuation diminished downstream from the basin. Peak-flow attenuation with a permanent pool was only 1 percent less than in simulations without a permanent pool, and the timing of the peak changed only slightly in both (fig. 10). Simulated peak flows of a 10-year storm at channel 1 (gage location) decreased by about 27 percent, and those of a 100-year storm decreased 30 percent; the effect at the mouth (channel 25) was even less as a result of inflows from the additional contributing areas—peak flows of a 10-year storm at the mouth decreased by 24 percent, and those of a 100-year storm decreased by 26 percent.

Peak flows of small, frequent storms (2-year storm) in the lower part of the watershed were attenuated more than the peak flows of larger, less frequent storms that occur once every 10 years or more. Peak flows of a 2-year storm in simulations with no permanent pool decreased by 45 and 35 percent in channels 1 and 25, respectively, whereas peak flows of a 10-year storm decreased by 27 and 24 percent, respectively. Attenuation of peak flows of a 2-year storm in simulations with a permanent pool were similar. The decrease in discharge at these locations for the 2-year and 10-year storms was about the same (from 130 to 150 ft^3/s), indicating that, as the storm magnitude increases, the effect of the basin is diminished by runoff from other areas.

The delay in the arrival of the peak flow was less pronounced in simulations with a permanent pool than in those without, and was more pronounced in small storms than in large storms (fig. 1). The peak flow from a basin with no permanent pool generally occurred 2 to 3 hours later than the peak from a basin with a permanent pool and peak flow from a basin with a permanent pool was only slightly later than the peak with no detention basin. Initial peak flow of the 2-year storm was delayed about 12 hours in simulations with permanent pool and about 16 hours in simulations without. Delays for the second peak were less—about 10 hours—because the normally empty storage available in a basin with no permanent pool was filled with runoff from the earlier part of the storm.

The time required for a basin with no permanent pool to fill to the height of the intermediate outlets is indicated by the inflection of the hydrographs (channel 7 in fig. 10). The available storage below the intermediate opening was filled within about 5 hours after the start of the 25-year storm, after about 4 hours in the 50- year storm, and after about 3 hours in the 100-year storm. This indicates that the available storage above the intermediate outlets is insufficient to cause an appreciable change in the outflow hydrograph for large storms.

Peak flows in the lower part of the watershed occurred slightly sooner in simulations with and without a permanent pool than the peak in simulations with no detention (channel 25, fig. 10) as a result of uncontrolled runoff from the intervening contributing area. The intervening area contains most of the hydrologically effective impervious area in the watershed and, therefore, is expected to produce runoff sooner than the relatively undeveloped upstream area.

Water Quality

The objective of stormwater-quality management is to decrease the mass or concentration of contaminants entrained in storm runoff. Detention of stormwater in the basin will provide several important functions that decrease the mass or concentration of pollutants; one of these functions is the dissipation of kinetic energy, which causes a decrease in sediment load and associated suspended constituents through coagulation and settling. Stormwater detention also provides, to a lesser extent, contact time for dissolved constituents to be adsorbed by organic material. Incorporating and enhancing the wetland areas upstream from and adjacent to the basin will provide the additional functions of (1) physical filtering and sedimentation, (2) biochemical processes such as reduction of nitrates to gaseous nitrogen in anaerobic soils, (3) direct nutrient uptake by wetland vegetation, and (4) adsorption and chelation of dissolved constituents by organic material.

The transport and deposition of total phosphorus in the basin was estimated from the basin's suspended-sediment trap efficiency, calculated by the reservoir subroutine from the Distributed Rainfall Runoff Routing Quality Model (DR3M-QUAL) of Alley and Smith (1982b). Decreases in total phosphorus were estimated from the relation to suspended-sediment concentration measured at the East Branch Allen Creek gage and basin-trap efficiency measured in a previous detention-basin study near Rochester (Zarriello and Sherwood, 1993). Total Phosphorus and nitrogen removal in the adjacent wetlands was estimated from published values of stormwater-quality change in wetlands. Data from stormwater-related wetland studies are sparse, however, and their interpretation is complicated by variation in stormwater quality and quantity and differences in wetland plant species.

Sedimentation Model

Particle entrapment in the detention-basin simulations is based on the "plug flow" concept, in which discrete volumes, or "plugs," of water are routed through a basin, and settling of particulate matter is calculated according to Stokes' Law. The time required for a plug of water to move through the basin (the detention time) is calculated as the time between centroids of the cumulative inflow and an equal cumulative outflow volume (fig. 11). The average pond depth for the period during which the plug moves through the basin is also calculated; this represents the depth through which a particle must fall to be considered trapped.

Settling velocity of a particle is a function of (1) the square of the size and specific gravity of the particle, (2) the fluid viscosity, and (3) an adjustment for nonspherical particles. The range of particle sizes is supplied to the model through a cumulative frequency distribution. Particles that settle through the average depth within the time required for the plug to move through the basin are considered trapped.

Trap efficiency is computed by 1 minus the ratio of the predicted outflow load to the inflow load, expressed in percent. Several simplifying assumptions are made that could affect the model accuracy, among which are: (1) water flows in discrete plugs from a single inflow point to a single outflow point at the opposite end of a basin, (2) flow within the basin is laminar, and (3) no mixing occurs between plugs. The model also does not account for resuspension or movement of settled particles along the basin bottom, nor for chemical reactions such as adsorption, coagulation, or mobilization.

Suspended-Sediment Characteristics

The change in suspended-sediment concentration as water passes through a basin determines trap efficiency and, thus, its effectiveness as a water-quality control on downstream receiving waters. Although many factors determine the effectiveness of a detention basin as a water-quality control, model simulations of trap efficiency are still based on the principle of Stokes' Law, which is strongly dependent on particle-size distribution and the concentration of suspended sediment entering the basin.

Particle-Size Distribution

Particle-size distribution is one of the main factors that control trap efficiency of the suspended sediment. The particle-size distribution in the East Branch Allen Creek watershed was estimated from data collected during the 1980-81 NURP at the Allen Creek gage (fig. 1), about 2.7 mi downstream from the basin (Zarriello and others, 1985). The discharge-weighted mean particle-size distribution, based on only a few samples, ranged from 3 to 12 percent sand, 45 to 62 percent silt, and 38 to 55 percent clay. Two different cumulative-frequency distributions were simulated to bracket this particle-size range—those consisting mostly of coarse-grained particles (high sand content) and those consisting mostly of fine-grained particles (high clay content).

Particle-size distribution was shown in a previous basin-simulation study (Zarriello and Surface, 1989) to vary with discharge—as discharge increases, the proportion of coarse-grained particles increases. This pattern suggest that, because the simulation model uses a constant particle-size distribution throughout the storm, it probably underpredicts particulate settling. Also, because the size-distribution data were scant, the range in the particle-size distribution used for model simulations carries a degree of uncertainty.

Suspend-Sediment Concentration

Suspended-sediment concentrations measured at the East Branch Allen Creek gage from April 1992 through April 1993 were used to define a relation between discharge and suspended-sediment concentration and to develop a continuous inflow-to-concentration relation for the simulation model. Discharge (the independent variable) ranged from 3 to 256 ft^3/s, and suspended-sediment concentration (the dependent variable) ranged from 11 to 683 mg/L in 27 samples. Least-squares regression (fig. 12) was used to calculate inflow concentrations for model input for the seven simulated storms. Suspended-sediment data referred to in this report were measurements of suspended solids, about 85 percent of which are nonvolatile; thus, the suspended solids consist predominantly of the mineral fraction (sand, silt, and clay).

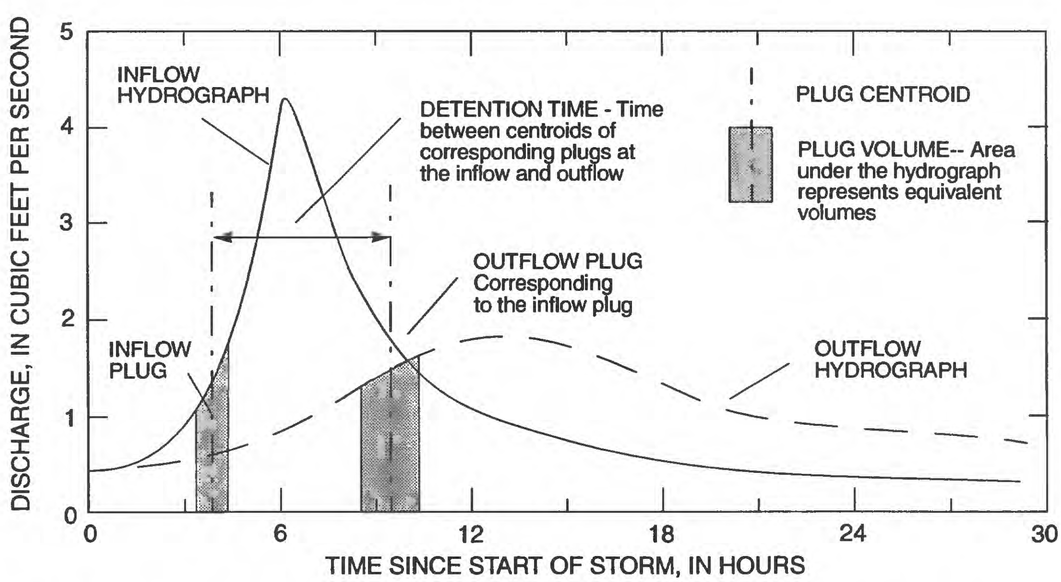


Figure 11. Time elapsed between start of flow plugs at inflow and exit at outflow of detention basin, for use in calculating particle-settling time. (Modified from Alley and Smith, 1982b, fig. 8.)

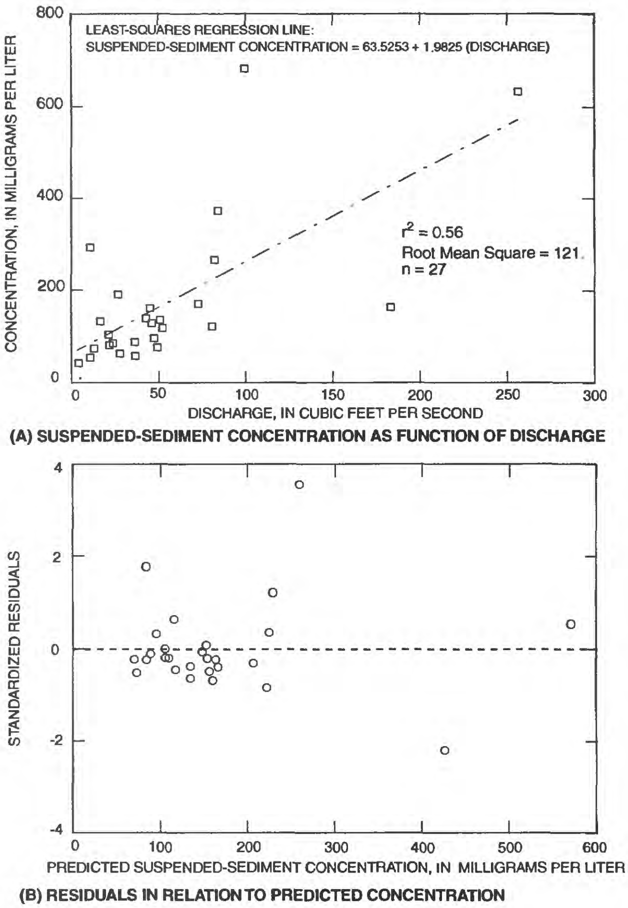


Figure 12. Relation of suspended-sediment concentration to discharge in East Branch Allen Creek, Monroe County, N.Y.: (A) Concentration as a function of discharge. (B) Residuals in relation to predicted concentration.

Predicted Changes In Suspended-Sediment Concentration

Simulations were run for basin-outlet configurations with and without a permanent pool; the resulting changes in discharge and ponding depth for the configuration without a permanent pool during the seven selected storms are plotted in figure 13; those for the configuration with a permanent pool are plotted in figure 14. Both include suspended-sediment concentrations with high sand content and high clay content. Figure 14 represents basins with a permanent pool in which (1) water in storage (dead-storage) is bypassed, and (2) water in storage is displaced. The plots indicate that (1) that the best trap efficiency is provided by the basin with a permanent pool in which water in dead storage is displaced (fig. 14), and (2) the basin with no permanent pool (fig. 13) has a slightly better trap efficiency than the basin with a permanent pool in which dead storage is bypassed (fig. 14).

The slightly better trap efficiency of a basin without a permanent pool than of a basin with a permanent pool when dead storage is bypassed was unexpected because dry detention basins typically are only half as effective as predominantly wet basins as a water-quality control (Wanielista and Yousef, 1993). Two possible reasons for this are: (1) all other factors being equal, the modeled basin with a permanent pool is less effective than one without because it has a greater depth through which the particles must fall to be considered trapped, and (2) basins without a permanent pool have a high potential for resuspension of settled material during storms, and the model is unable to incorporate this. Therefore, the trap efficiency of the configuration without a permanent pool was probably overestimated.

Simulations of a basin with a permanent pool in which water from dead storage is displaced also reflect model limitations and assumptions that are not typically realistic. For example, the model assumes no mixing between inflow and dead storage as stormflow moves through the system; thus, when water in dead storage, which is assumed to be "clean," is displaced, effluent concentrations of suspended-sediment remain zero until the volume of water in dead storage is displaced from the pond. Consequently, initial trap efficiencies are high as a result of the displacement of "clean" water from storage and bias the overall trap efficiency for the basin. Also, even if water displaced from storage did not mix with storm runoff, its quality would depend on several mechanical, biological, and chemical factors, including residence time in the basin and whether it had become anoxic. Therefore, the trap efficiency of a detention basin is probably somewhere between that which would result from displacing water from storage and that which would result from bypassing it.

The sediment-concentration curves (figs. 13 and 14) indicate that the time between peak concentration at the inflow and peak concentration at the outflow is greater in a basin without a permanent pool than in one with a permanent pool when dead storage is bypassed and that the lag time between peak concentrations at

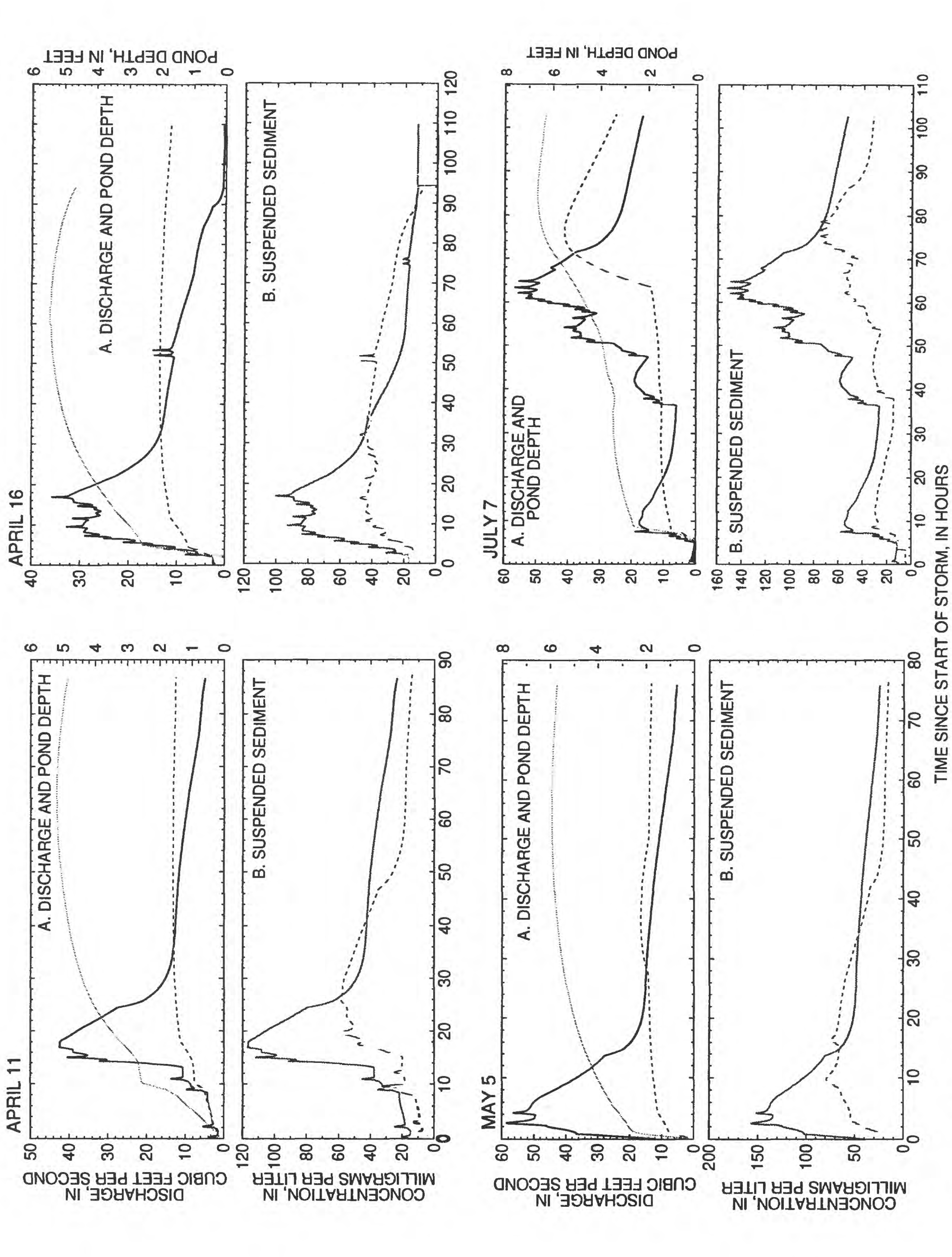


Figure 13. Simulated results for a basin with a permanent pool during seven selected storms of 1992 in the East Branch Allen Creek, Monroe County, N.Y.: (A) Discharge and depth ponding. (B) Suspended-sediment concentration

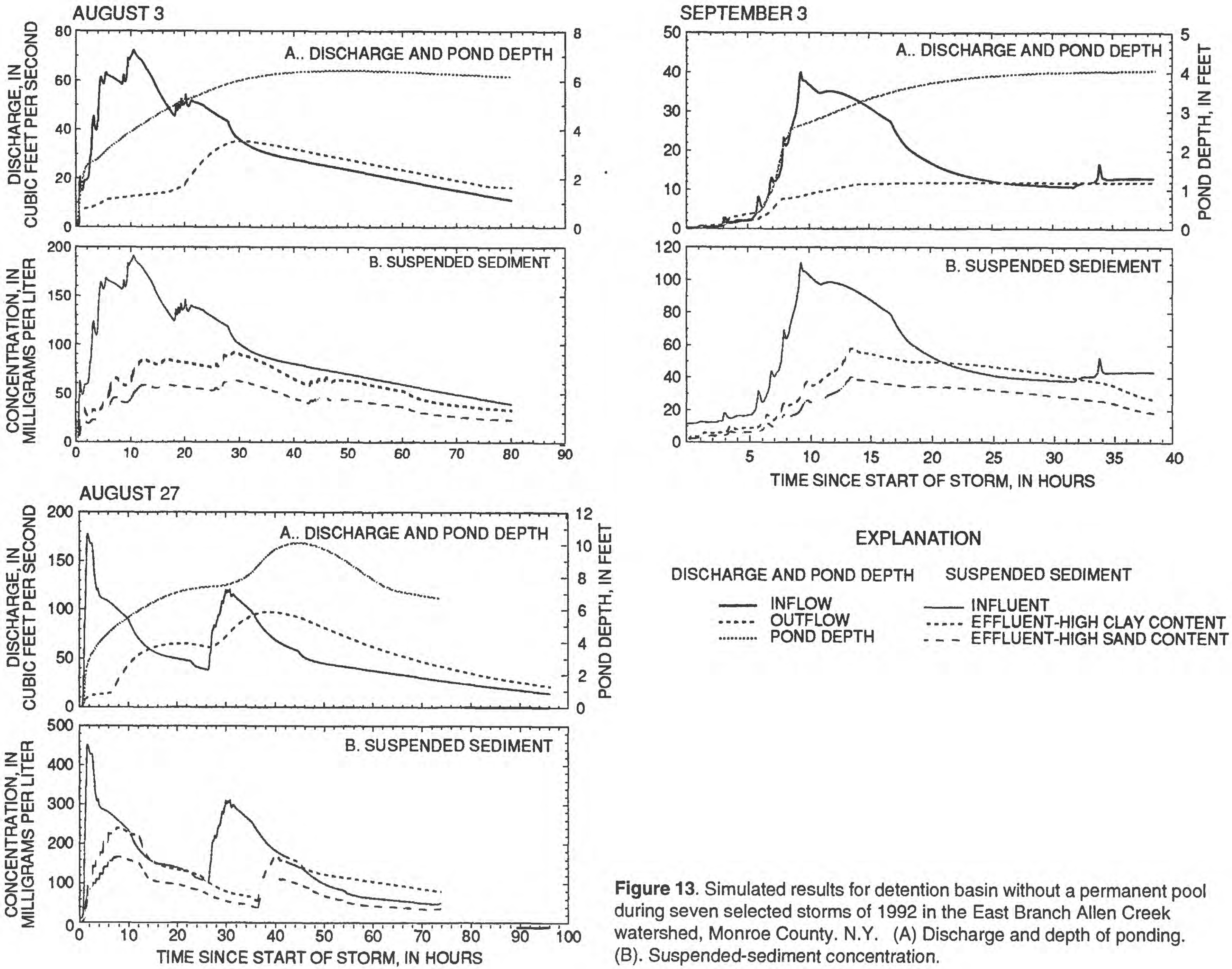


Figure 13. Simulated results for detention basin without a permanent pool during seven selected storms of 1992 in the East Branch Allen Creek watershed, Monroe County. N.Y. (A) Discharge and depth of ponding. (B). Suspended-sediment concentration.

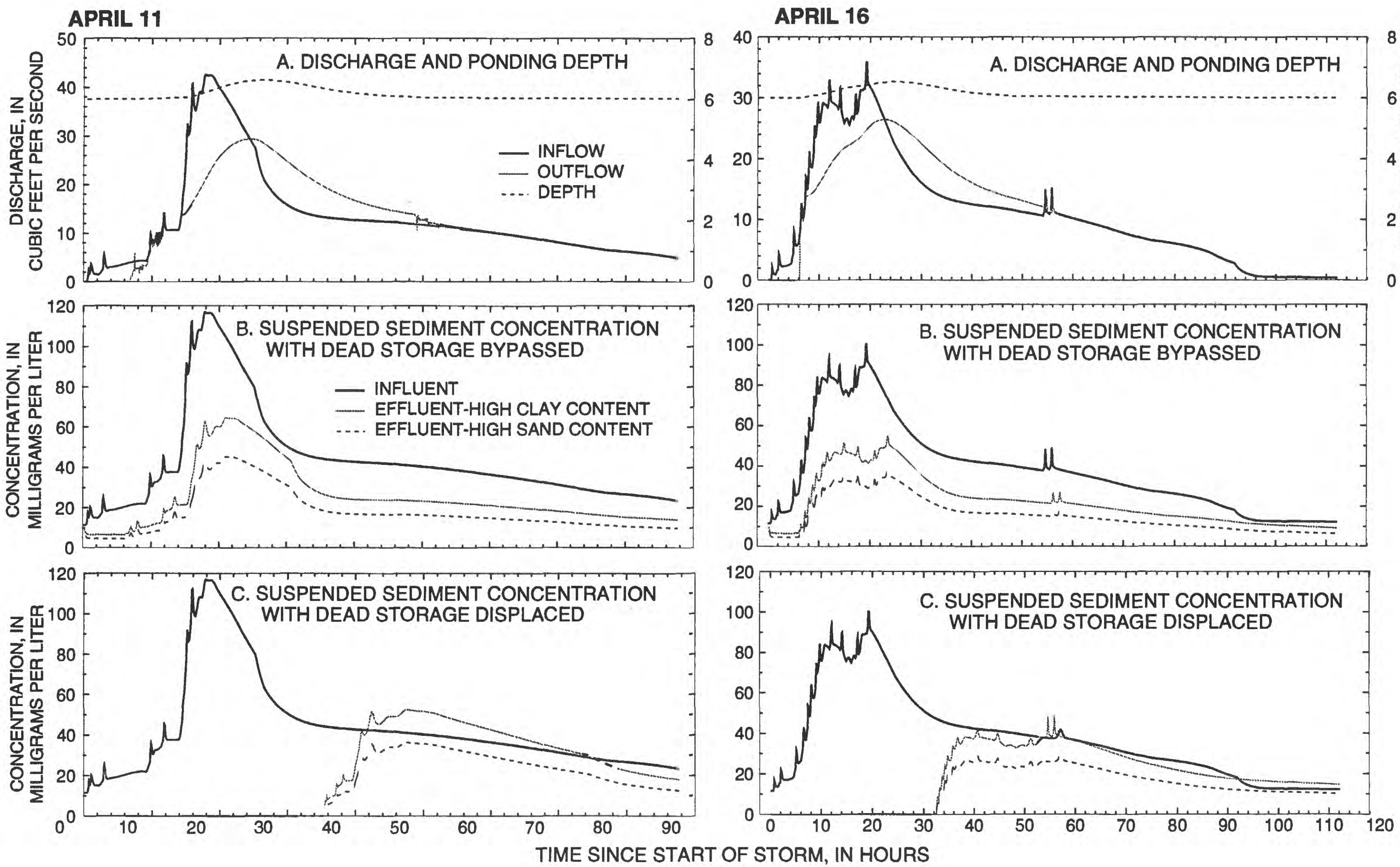


Figure 14. Simulated results for detention basin with a permanent pool during seven selected storms of 1992 in the East Branch Allen Creek watershed, Monroe County, N.Y.: (A) Discharge and depth of ponding. (B) Suspended-sediment concentration with dead storage bypassed. (C) Suspended-sediment concentration with dead-storage displaced.

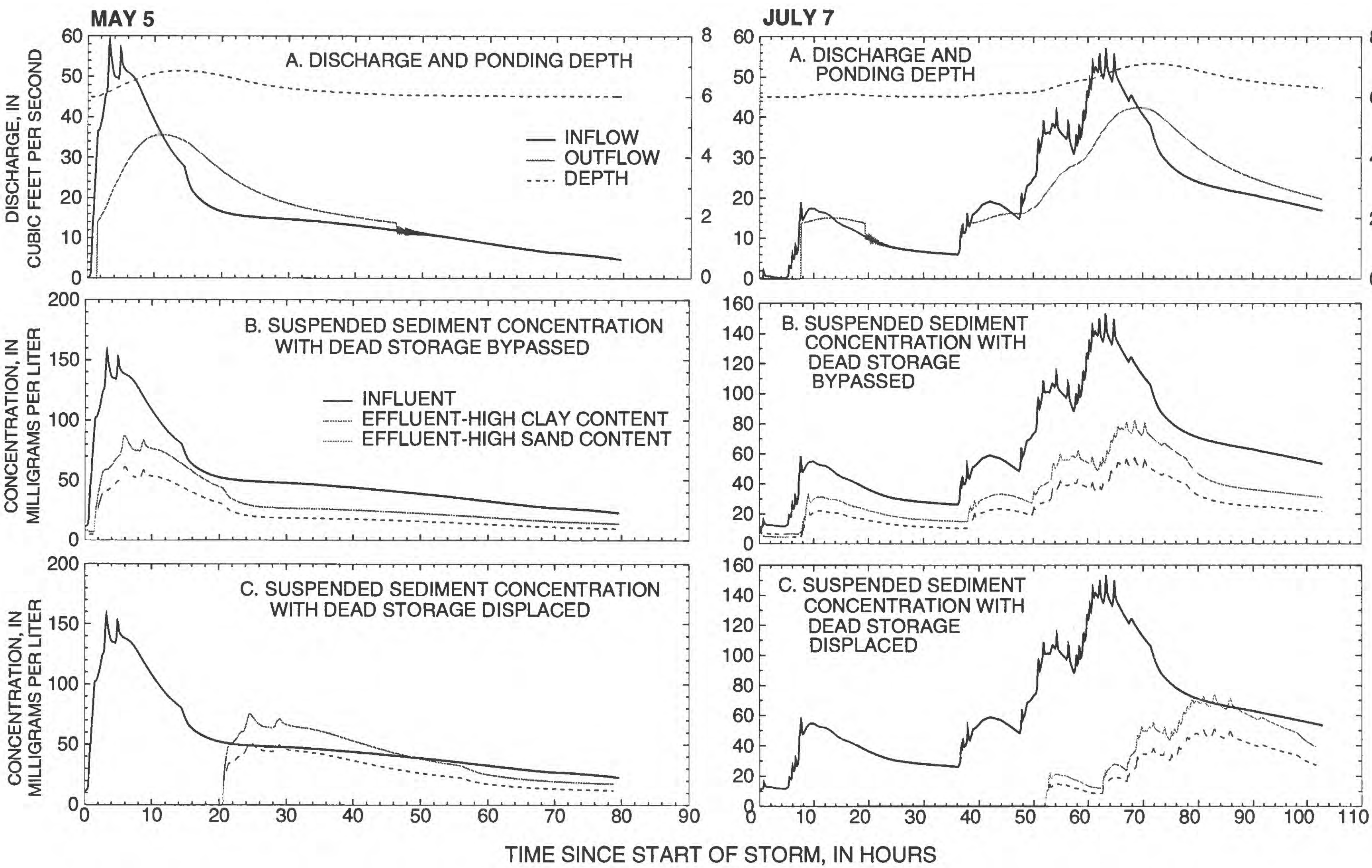


Figure 14. Simulated results for detention basin with a permanent pool during seven selected storms of 1992 in the East Branch Allen Creek watershed, Monroe County, N.Y (continued): (A) Discharge and depth of ponding. (B) Suspended-sediment concentration with dead storage bypassed.(C) Suspended-sediment concentration with dead-storage displaced.

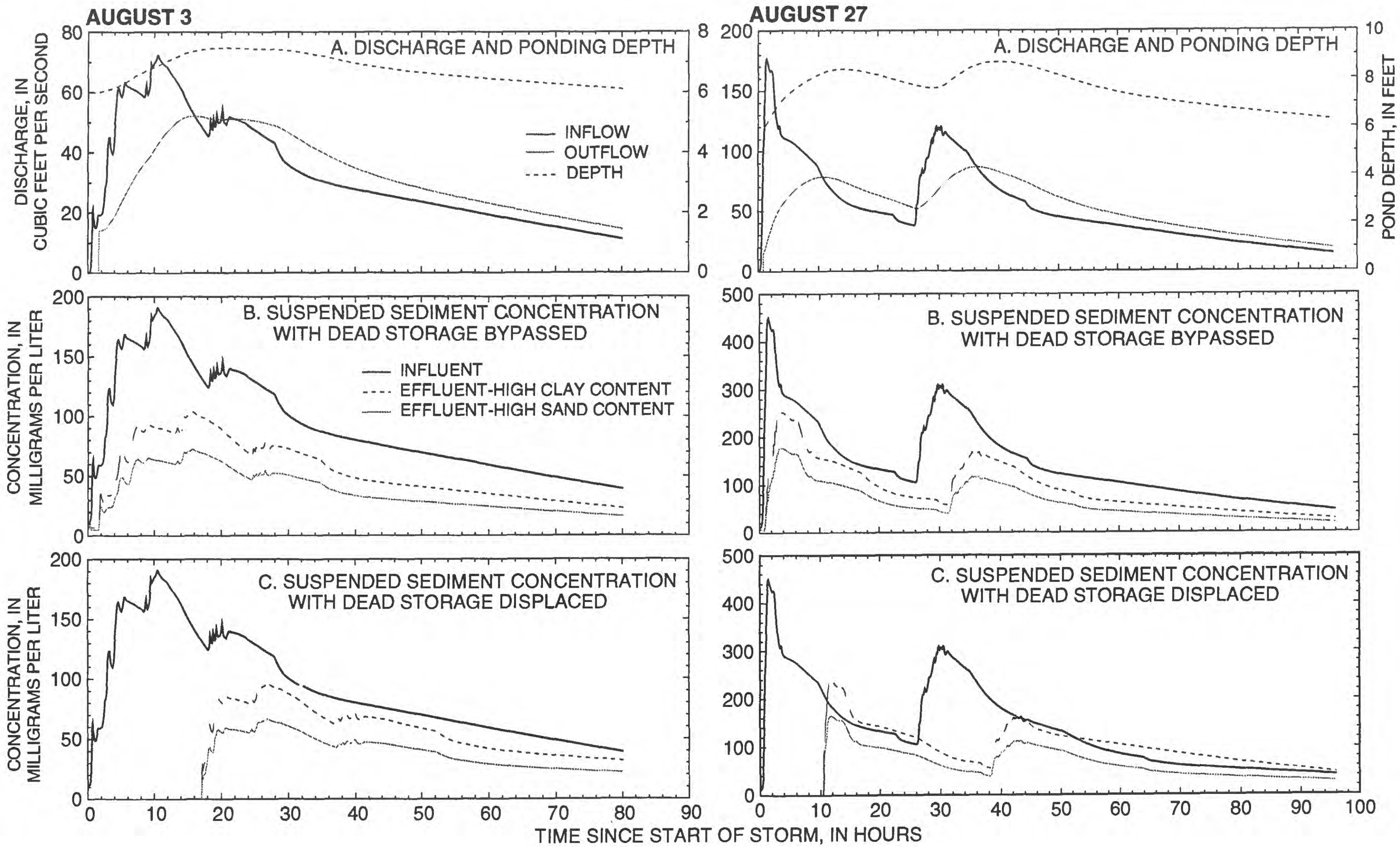


Figure 14. Simulated results for detention basin with a permanent pool during seven selected storms of 1992 in the East Branch Allen Creek watershed, Monroe County, N.Y (continued): (A) Discharge and depth of ponding. (B) Suspended-sediment concentration with dead storage bypassed.(C) Suspended-sediment concentration with dead-storage displaced.

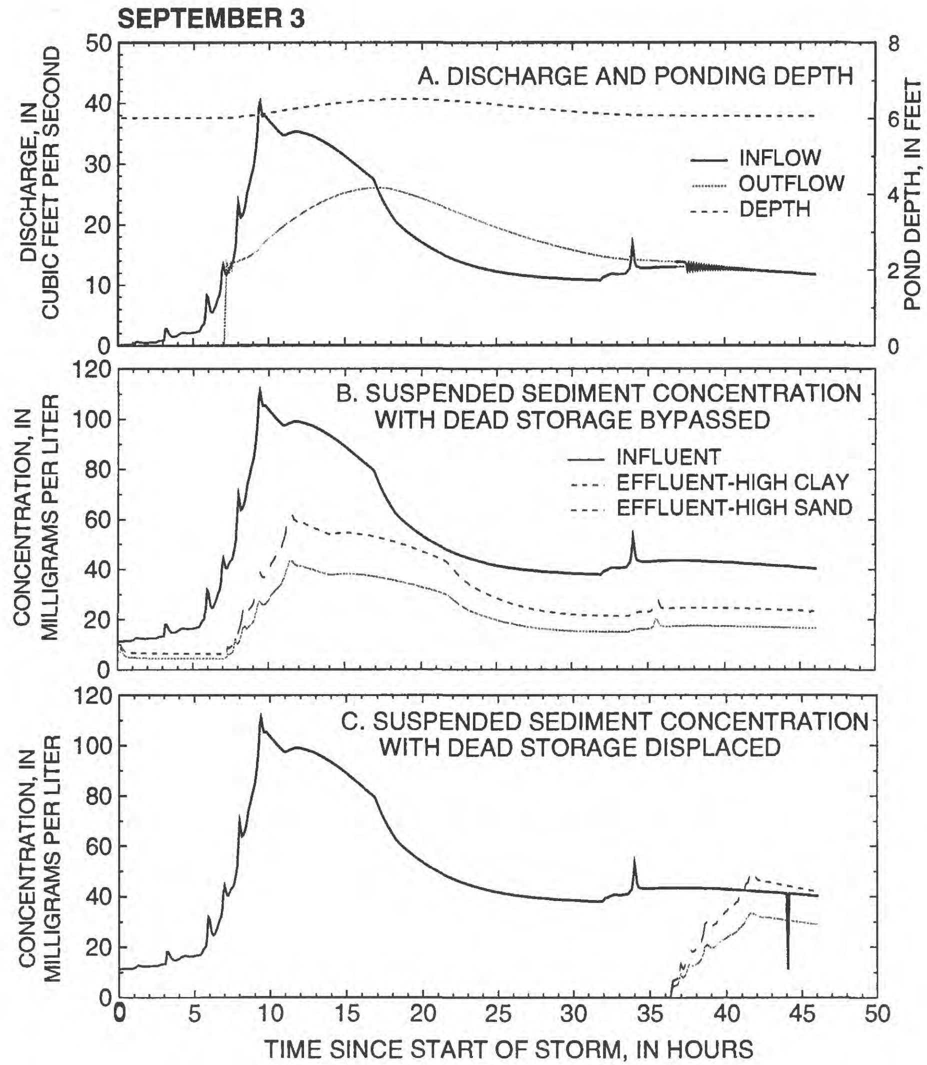


Figure 14. Simulated results for detention basin with a permanent pool during seven selected storms of 1992 in the East Branch Allen Creek watershed, Monroe County, N.Y (continued): (A) Discharge and depth of ponding. (B) Suspended-sediment concentration with dead storage bypassed.(C) Suspended-sediment concentration with dead-storage displaced.

the basin inflow and outflow increases considerably when dead storage is displaced. The peak-outflow concentration lagged behind the peak-inflow concentration by as much as 20 hours in simulations without a permanent pool (fig. 13); in simulations with a permanent pool it lagged by only a few hours when dead storage was bypassed (fig. 14) and by 20 or more hours when dead storage was displaced (fig. 14). The lag time in peak concentration reflects the detention time of "plugs" of water as stormflow moves through the basin. Plug-detention time averaged 14 hours in the basin without a permanent pool; in the basin with a permanent pool it averaged 4 hours with dead storage bypassed, and about 26 hours with dead storage displaced.

Trap-efficiency values for the seven storms (table 5) reflect the estimated detention times of stormflow for the three basin configurations and the two particle-size distributions simulated. Trap efficiency for simulations with no permanent pool averaged 55 percent for stormflows carrying mostly clay-size particles and 68 percent for stormflow carrying mostly sand-size particles. Trap efficiency for a permanent pool averaged 45 and 62 percent for clay- and sand-size particles, respectively, when dead storage was bypassed, and 66 and 77 percent, respectively, when dead storage was displaced (table 5).The widest range of trap efficiencies for both particle-size distributions were in simulations with a permanent pool in which dead storage is displaced (table 5). This is attributed to the range in discharge and volume among the storms; the storm with the largest peak and volume (8-3-92) displaced water from dead storage the most rapidly and for the longest period of time and, thus, produced a relatively low trap efficiency (57 percent for clay, and 70 percent for sand). Conversely, the storm with one of the lowest peaks and the shortest duration (9-3-92) only partly displaced dead storage and produced a relatively high trap efficiency (91 percent for clay, 94 percent for sand). The trap efficiency for simulations in which dead storage was displaced was greater than the trap efficiency for most configurations, however. Changes in the suspended-sediment load for the various basin configurations are illustrated in figure 15.

The average trap efficiency for simulations in which dead storage was bypassed and when it was displaced are nearly identical to the average trap efficiency of simulations without a permanent pool. Therefore, the trap efficiency for storms within the recurrence interval of those simulated is estimated to be about 62 percent ±16.

In general, trap efficiencies for basins in which dead storage is bypassed remain similar among storms except for variation within each particle-size group simulated (table 5). This suggests that the difference between trap efficiencies (about 45 percent for clay and about 62 percent for sand) for storms of this magnitude is determined by the particle-size distribution of incoming

Table 5. Trap efficiency for three basin configurations and two particle-size distributions during selected storms at the simulated detention basin in the East Branch Allen Creek watershed, Monroe County, N.Y.

[All values are in percent unless noted; ft^3/s, cubic feet per second].

		Mostly Clay			Mostly Sand		
			Permanent pool			Permanent pool	
Storm Date	Peak flow to basin (ft^3/s)	No pool	Dead storage bypassed	Dead storage displaced	No pool	Dead storage bypassed	Dead storage displaced
4-11-92	54	54	45	72	68	62	80
4-16-92	40	52	45	72	67	61	80
5-3-92	75	56	45	66	70	62	76
7-12-92	57	52	46	64	67	63	75
8-3-92	72	61	46	57	73	62	70
8-27-92	179	46	46	51	61	62	66
9-3-92	41	65	45	91	75	62	94

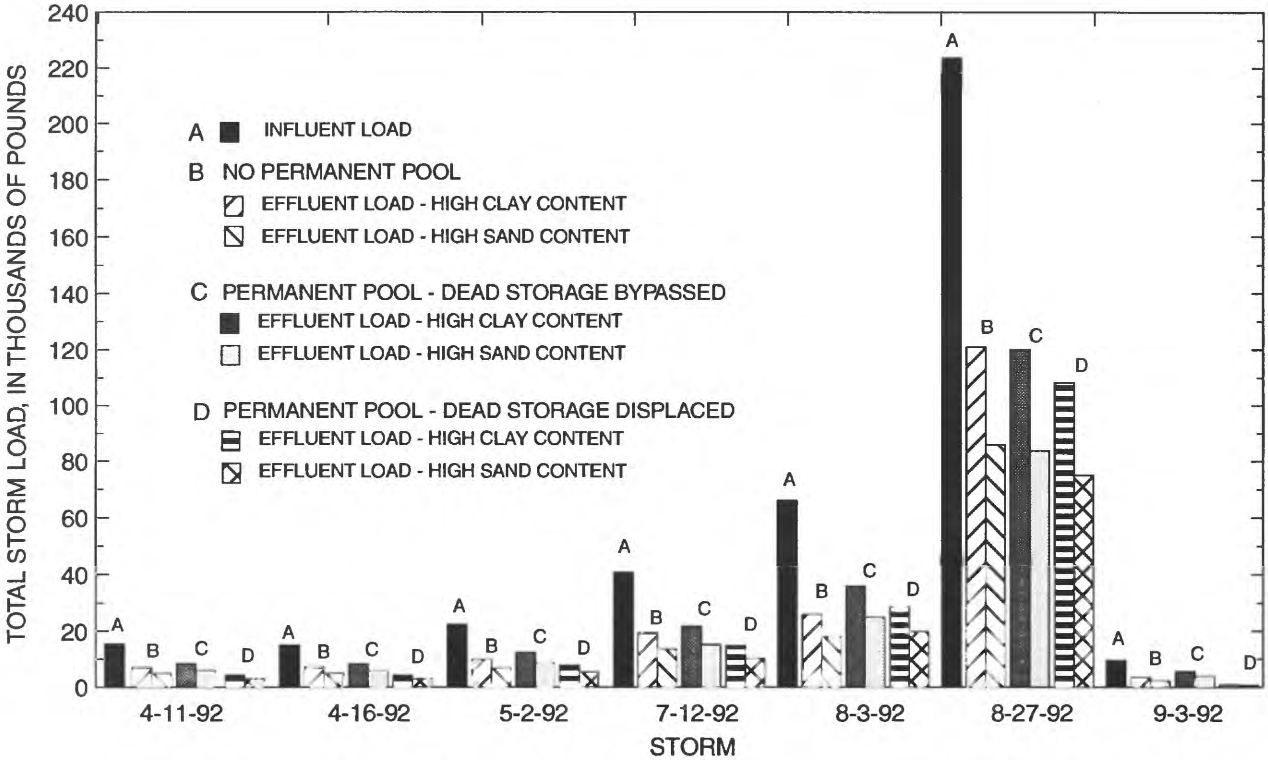


Figure 15. Suspended-sediment loads for three outlet configurations of the simulated detention basin on East Branch Allen Creek, Monroe County, N.Y.

sediments. Because the model is sensitive to this factor, additional data on particle-size distribution of storm runoff in the East Branch Allen Creek watershed would be needed to refine estimates of runoff-quality changes in the detention basin.

Relation Of Suspended Sediment To Total Phosphorus

Regression analysis of total-phosphorus concentration as a function of suspended-sediment concentration (fig. 16) indicates these constituents to be highly correlated (correlation coefficient 93 percent). Applying this relation as a simple adjustment to the trap-efficiency estimates obtained for suspended sediment indicated that the basin would trap about 57 percent of the total phosphorus load. Phosphorus retention is controlled by other factors as well, such as biological uptake and release, and unequal adsorption to various particle sizes. Estimates of the total phosphorus retention can be refined from information available on the relation between total phosphorus and suspended-sediment concentration.

The difference between total-phosphorus concentration and dissolved-orthophosphate concentration at the gage indicates that 80 to 90 percent of the total phosphorus in the East Branch Allen Creek is in suspension. Although this percentage suggests that the basin could capture much of the total phosphorus load, the efficiency of phosphorus removal depends on its adsorption over the range in particle sizes and its chemical behavior, which determines the degree to which it binds to metal ions and colloidal material.

Fine-grained sediments provide the main bonding sites for adsorption, and the amount of phosphorus sorbed to clay minerals will depend on the phosphorus concentrations and the number of available cation-exchange sites (White, 1981). Thus, most of the phosphorus in water with a high concentration of fine-grained sediments and low concentrations of phosphorus will likely bond to the fine-grained sediments, whereas waters with a low concentration of fine-grained sediments and high concentrations of phosphorus, have fewer bonding sites, and only a small amount of the total phosphorus load will be adsorbed. Raush and Schreiber (1981), in a study of phosphorus distribution over several sediment-particle sizes, found that clay-size particles made up 15 percent of the suspended-sediment load but contained 23 percent of the particulate phosphorus load. Similarly, Carter and others (1974), in a study of an Idaho drainage pond, found twice as much phosphorus associated with clay-size particles as with sand-size particles. Brown and others (1981) reported about 60 percent less phosphorus retention than sediment retention in the same pond; this percentage corresponds to the ratio of phosphorus concentration on sand-size particles to the concentration on clay-size particles.

These previous studies provide a general indication of the relation between the grain-size distribution and the sorbed phosphorus concentration, but to accurately define the relation of phosphorus concentration to grain size would require a chemical analysis of each size fraction over a wide range of flow conditions. From this information, the cumulative particle-size distribution could be adjusted in the sedimentation model to reflect the amount of sorbed phosphorus used to calculate the trap efficiency. In the absence of this information, the best estimate of phosphorus retention, based on the relation of total phosphorus concentration to suspended sediment concentration (57 percent), and weighting the trap efficiency for the sediment-size distribution with a high clay content (-16 as determined from suspended-sediment trap efficiencies with high clay content) is about 41 percent.

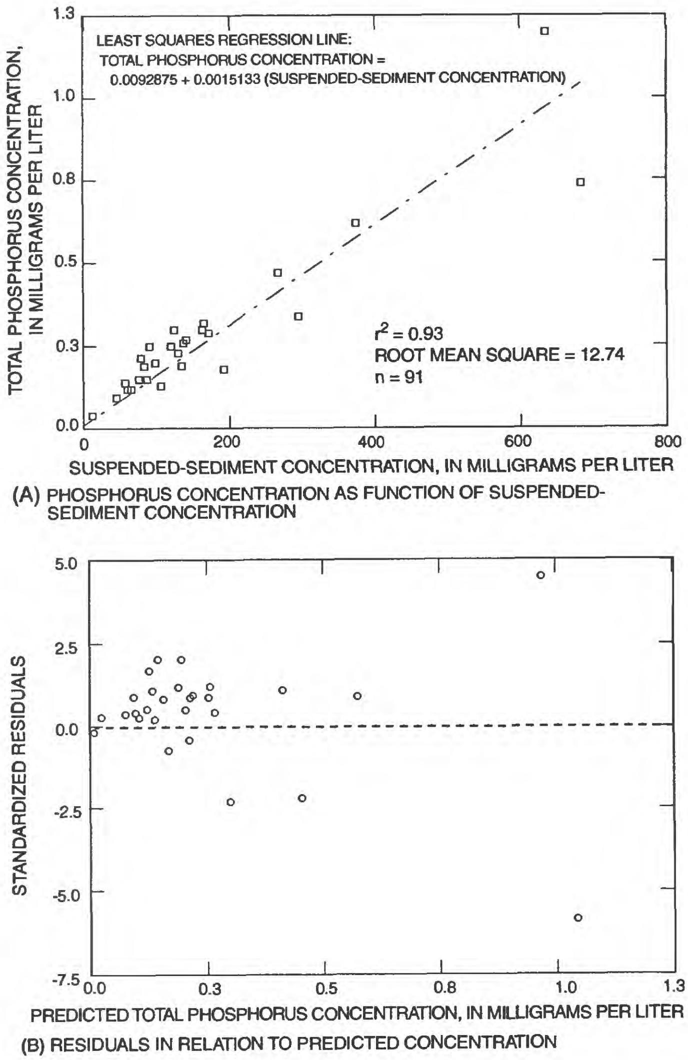


Figure 16. Relation of total phosphorus to suspend-sediment concentration in East Branch Allen Creek, Monroe County, N.Y.: (A) Phosphorus concentration as a function of suspend-sediment concentration. (B) Residuals in relation to predicted concentration.

Potential for Contaminant Removal By Wetlands

Wetlands have been recognized as an effective means of stormwater control (Livingston, 1988), and incorporating natural or constructed wetlands into stormwater-management systems is a topic of growing interest. Little information is available on wetland effectiveness as a stormwater-quality control, however, and inference from the literature is complicated by the wide variety of wetlands and the temporal variability of storm runoff. Thus, the ability of wetlands to remove contaminants entrained in storm runoff cannot be determined with certainty without detailed field investigations.

Although wetlands differ widely in size and in type, they function much as a detention basins in attenuating peak flows and removing suspended matter from stormwater, and their effectiveness is largely determined by the residence time of the storm runoff within the wetland. In addition to providing physical filtering and settling, wetlands have a capacity to uptake nutrients and metals through (1) biofiltering by the vegetation, and (2) adsorption and chelation onto the organic-rich bottom material (Daukas and others, 1989). Also, roots of marsh plants provide a substrate for growth of bacteria that take up soluble nutrients.

Efficiency of contaminant removal appears to be a function of the wetland size in relation to the contaminant loading in storm runoff (Schueler, 1987). Wetlands are most effective when stormwater enters at a relatively uniform rate and the constituents are in low concentrations. Data on nutrient removal in wetlands in the Maryland (Schueler, 1987) suggest that the maximum benefit is achieved when phosphorus loadings do not exceed 45 lb/acre and nitrogen loadings do not exceed 225 lb/acre.

Uptake by wetland plants typically removes 16 to 75 percent of the total nitrogen and 12 to 73 percent of the total phosphorus (Reddy and DeBusk, 1987). Emergent macrophytes such as cattails (*Typha*) and bulrush (*Scirpus*) show potential for rapid nutrient uptake and locking the nutrients into the biomass until it decays, after which it can be mobilized back into the system. Stormwater loads in a detention basin-and-wetland system consisting of sawgrass, bulrush, and pickerelweed in Tallahassee, Fla., were decreased as follows: suspended sediment, 95 percent; total nitrogen,75 percent; ammonia, 37 percent; nitrate, 70 percent; and total phosphorus, 53 percent (Livingston, 1989). Martin (1988) also reported decreases in constituent load at an urban combined detention-basin-and-wetland system in central Florida as follows: suspended solids, 83 percent; total nitrogen, 36 percent; and total phosphorus, 43 percent. Efficiencies for wetlands alone were: suspended solids, 54 percent; total nitrogen, 20 percent; and total phosphorus, 15 percent.

The wetland area available for the detention basin consists of about 4.5 acres of shallow-water cattail and bulrush (Martin Brewster, Pittsford Deputy Commissioner of Public Works, written commun., 1994), mostly at the upstream end of the detention pond. This system will probably be less effective than those in Florida because (1) the effectiveness declines seasonally in the Northeast (Surface and others, 1993; Ferlow, 1993), and (2) the storm-water enters the wetland before passing through the detention basin, whereas in the Florida studies, the detention basin provided primary treatment of storm runoff and allowed flow into the wetland at a relatively controlled rate. Wetlands in temperate climates such as the Northeast are most effective during spring and summer and are least effective during the fall and winter, when plant decay releases nutrients that were bound into the biomass (Ferlow, 1993). Even though the location of the wetland upstream of the detention basin is less effective than if it were downstream from the basin, its surface area and vegetation will still provide some nutrient uptake.

Guidelines for constructing or enhancing wetlands for storm-runoff management in the State of Maryland include the following (Schueler, 1987):

- 25 percent of the wetland area should be 2 to 3 ft deep, and 75 percent should be less than 1 ft deep.
- The discharge outlet should be in the area of deep water,
- The inlet should flow into the shallow, vegetated area,
- The length-to-width ratio should be at least 2:1, and
- The wetland should have the capacity to detain a storm with a 1-year recurrence frequency for a least 24 hours.

The wetland associated with the detention basin in this study is significantly undersized in relation to the Maryland Department of Natural Resources guidelines (Schueler, 1987). A storm with a 1-year recurrence interval (storm of August 27, 1992) had a volume of about 6.7 million ft^3 during a 24-hour period; this volume would require the wetland to be inundated a depth of 34 ft to detain runoff for a 24-hour period. Although this wetland is undersized by Maryland guidelines and is upstream, rather than downstream, from the detention basin, future monitoring could determine its effectiveness.

Uptake of nitrogen and phosphorus by emergent macrophytes can be estimated from the concentration of these constituents in the wetland biomass. Nutrient concentrations in the plant tissue are low in nutrient-poor environments, but the wetland-and-detention system probably represents a nutrient-rich environment because the wetland area is small relative to the potential storm volume. In a nutrient-rich environment, plant-tissue concentrations are relatively high in the early stages of plant development. Typical nutrient concentration for emergent macrophyte species are given in table 6.

Given the wide range of nutrient concentrations in plant tissue, the maximum annual uptake in a 4.5-acre young *Typha* (cattail)-dominated wetland would be about 2.9 tons of nitrogen and 0.5 tons of phosphorus, and the minimum annual uptake in a mature *Phragmites* (reed)-dominated wetland would be about 0.4 tons of nitrogen and 0.04 tons of phosphorus. Improved estimates of the annual nutrient uptake could be obtained from data in table 6 after an inventory of wetland-plant species.

Table 6. Plant biomass and nutrient-concentration ranges in emergent macrophytes
[Data from Reddy and DeBusk, 1987. Dash indicates data are unavailable]

Plant Species	Standing- crop biomass (tons per acre)	Annual biomass yield (tons per acre)	Nitrogen in biomass (pounds per ton)	Phosphorus in biomass (pounds perr ton)
Typha (cattail)	1.9 - 10.0	3.6 - 27.2	10 - 48	1 - 8
Juncus (rush)	9.8	23.8	30	4
Scirpus (bulrush)	--	--	16 - 54	2 - 6
Phragmites (reed)	2.7 - 15.6	4.5 - 26.8	36 - 42	4 - 6
Eleocharis (spike rush)	3.9	11.4	18 - 36	2 - 6

SUMMARY AND CONCLUSIONS

Simulations of the effects of a detention basin on stormwater quantity and quality in the East Branch Allen Creek watershed indicate attenuation of peak flows and improved chemical quality of runoff. A deterministic rainfall runoff model (DR3M) of the East Branch Allen Creek watershed was developed to generate and route storms with a 2-, 10-, 25-, 50-, and 100-year recurrence frequency and assess the effects of the detention basin on peak flows from storms with these recurrence intervals. Transport and deposition of suspended sediment in the basin was calculated with the reservoir subroutine of the DR3M Quality model for seven storms used in the runoff-model calibration with two particle-size distributions (based on the range of measured particle sizes) and two outlet configurations–one that maintains a permanent pool and one that does not. Changes in phosphorus load were estimated from the relation of phosphorus concentration to suspended-sediment concentration and the trap-efficiency results from the DR3M Quality model. Nitrogen and phosphorus retention and uptake in the adjacent wetland were estimated from values reported in the literature.

The runoff model was calibrated to seven storm discharges measured at the East Branch Allen Creek gage between April and September 1992. The volume and peak flow of these storms generally recur several times per year; the largest recurs once every 2 years. The difference between simulated and observed values ranged from -37.3 to 47.5 percent for runoff volume and from -47.4 to 9.5 percent for peak flow. The overall root mean square error was 8.9 percent for runoff volume and 16.0 percent for peak flow.

Long-term flow records from Allen Creek were used to calculate peak-flow frequency for the East Branch, and long term National Oceanic and Atmospheric Administration rainfall records were used to select storms with 2-, 10-, 25-, 50-, and 100-year recurrence intervals. Peak flows for storms with these recurrence intervals were generated to determine the attenuation of peak flows downstream of the detention basin. The basin has a potential storage capacity of 160 acre-feet and captures runoff from about half of the East Branch watershed. Two outlet control designs were considered— one that allows base flow to pass unimpeded, and one that maintains a permanent pool.

Simulated peak-discharge attenuation for 10- to 100-year storms ranged from 93 to 83 percent, respectively, for a basin with no permanent pool, and from 68 to 75 percent, respectively, for a basin with a permanent pool. Peak-flow attenuation for a 2-year storm for a basin with no permanent pool was 70 percent for the initial peak, but only 55 percent for the second peak, which was similar to the attenuation for the configuration with a permanent pool. The relatively small peak-flow attenuation for the 2-year storm indicates that the available storage is underutilized in storms of this size. The attenuation of peak flow diminished downstream in response to the addition of runoff from other contributing areas and differed by less than 1 percent between simulations with a permanent pool and those without. Peak-flow attenuation for the 10- to 100-year storms ranged from 27 to 30 percent, respectively, at the gage and from 24 to 26 percent, respectively, at the mouth of the watershed. Delay in the arrival of the peak was more pronounced in simulations with a permanent pool and in small storms than in those without a permanent pool and in large storms, but the change in the peak at the mouth was only slight for both pool configurations.

The detention basin and wetland are expected to provide sediment settling and to decrease concentrations of nutrients through biochemical processes, such as direct uptake by wetland vegetation and adsorption and chelation by organic material.The suspended-sediment trap efficiencies were estimated from a sedimentation model of the basin. Simulations were made over a suspended-sediment particle-size distribution representing the measured range of fine and coarse-grained particles. Estimated trap efficiencies for simulations with mostly fine-grained sediment and with mostly course-grained sediments ranged from 55 to 68 percent, respectively, with no permanent pool; from 45 to 62 percent, respectively, for a permanent pool with dead storage bypassed; and from 66 to77 percent, respectively, for a permanent pool with dead storage displaced. The average trap efficiency for simulations in which water in dead storage was bypassed and displaced are nearly identical to the average trap efficiency of simulations with no permanent pool. Therefore, the estimated trap efficiency for suspended sediment in storms with a 2-year recurrence interval or less is expected to be about 62 percent ±16.

From 80 to 90 percent of the total phosphorus in the East Branch Allen Creek is in suspension and, thus, can be decreased through settling. Published literature and previous work in the Rochester area indicate that the fine-grained materials are the principal bonding sites for the suspended fraction; therefore, even though the concentration of total phosphorus is highly correlated with concentration of suspended sediment, fine-grained sediments (clay and silt) are trapped less efficiently than coarse sediments (sand), and trap efficiencies must be weighted toward the efficiencies of fine-grain-sediment removal. The relation of total phosphorus concentration to suspended sediment concentration and the trap efficiency for suspended sediments with a high clay content indicate that 41 percent of the total phosphorus is removed. This could be calculated with increased certainty through a chemical analysis of each size fraction over a wide range of conditions.

The function of a wetland as a stormwater-quality control is similar to that of a detention basin in that the effectiveness is largely determined by the residence time of storm runoff in the wetland. Vegetation in the 4.5-acre wetland near the upstream end of the detention basin consists predominantly of cattails (*Typha*) and bulrush (*Scirpus*). Published data indicate that the annual maximum uptake of nutrients by a wetland of this type would be 2.9 tons of nitrogen and 0.5 tons of phosphorus in a new, young *Typha*-dominated wetland, and the minimum annual uptake would be about 0.4 tons of nitrogen and 0.04 tons phosphorus in a mature *Phragmites*-dominated wetland. Published data indicate a wide range in the effectiveness of wetlands, depending on the vegetation species, storm magnitude, and nutrient concentration. An inventory of wetland species could provide improved estimates of wetland effectiveness in nutrient removal.

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