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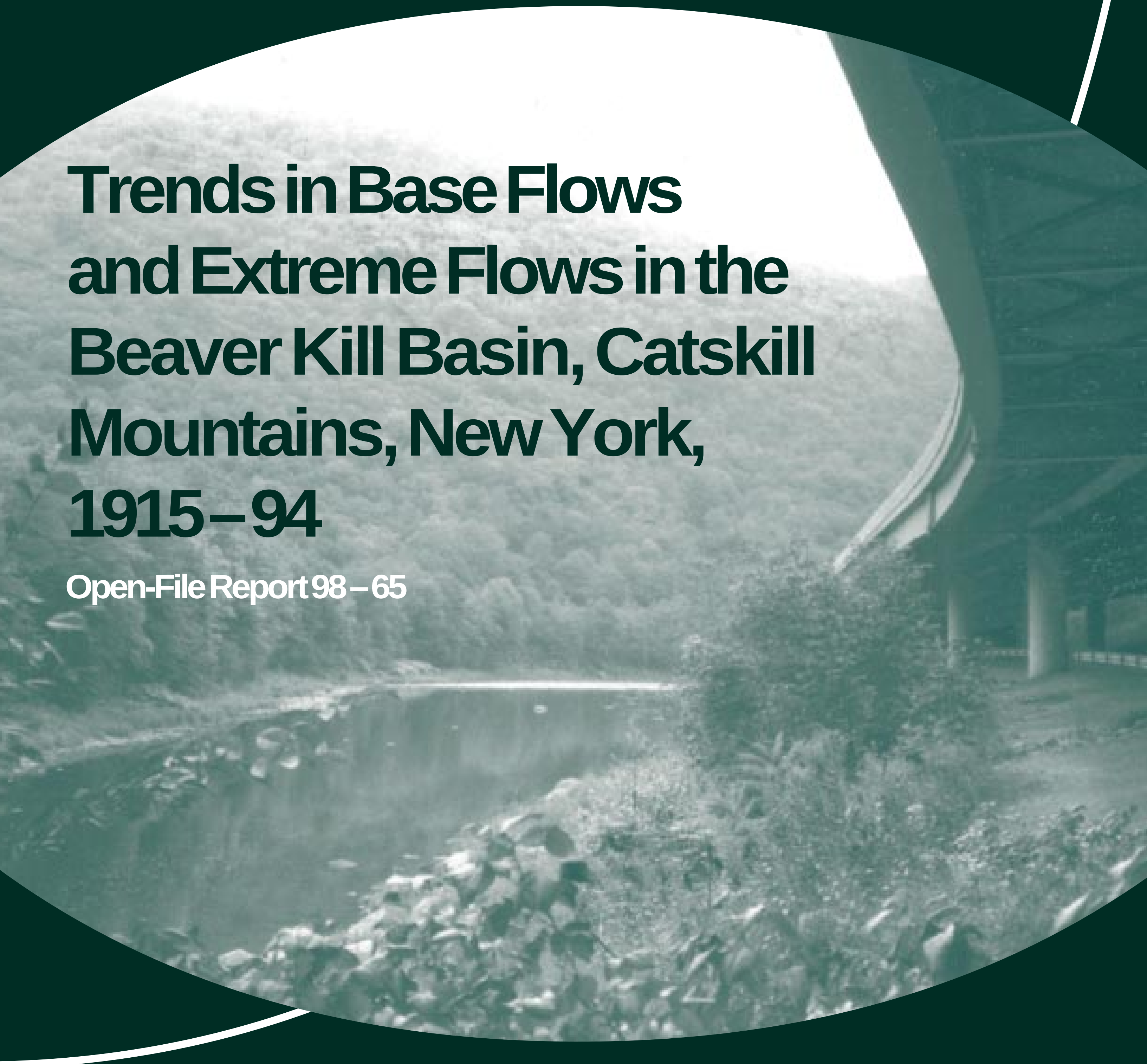
Trends in Base Flows and Extreme Flows in the Beaver Kill Basin, Catskill Mountains, New York, 1915–94

Open-File Report 98–65



U.S. Department of the Interior
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Cover Photo:
Beaver Kill and elevated Route 17,
by Jock Conyngham

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By Barry P. Baldigo

U.S. GEOLOGICAL SURVEY

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USGS

science for a changing world

Troy, New York
1999

U.S. DEPARTMENT OF THE INTERIOR
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U.S. GEOLOGICAL SURVEY
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For additional information write to:

U.S. Geological Survey
425 Jordan Road
Troy, NY 12180-8349
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CONVERSION FACTORS

Multiply	By	To Obtain
	Length	
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	2.590	square kilometer
	Volume	
cubic feet (ft^3)	0.02832	cubic meter
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

Trends in Base Flows and Extreme Flows in the Beaver Kill Basin, Catskill Mountains, New York, 1915-94

By Barry P. Baldigo

ABSTRACT

Long-term records from five streamflow-gaging stations within and near the 300-square mile Beaver Kill Basin were analyzed to determine whether construction and presence of New York State Route 17 (NY 17), which was completed in the late 1960’s, could have altered hydrologic processes in the basin and thereby adversely affected the basin’s trout populations. The hypothesis investigated is that NY 17 has altered surface-water and shallow ground-water flowpaths where it parallels the stream and has increased runoff rates and thereby (1) increased the range in stream discharge (prolonged the base flows, decreased the low flows, and increased the high flows), and (2) altered stream-channel morphology through increased volume and velocity of stormflows.

Analyses of base flows, discharge-duration curves, stage-to-discharge relations, peak and bankfull discharges, and flow extremes at a downstream (Beaver Kill at Cooks Falls) and a small tributary (Little Beaver Kill at Livingston Manor) site provide only limited evidence that NY 17 affected hydrologic processes within the basin. These effects are best indicated by significant increases in the magnitude and (or) the frequency of moderate to large discharges (exceedence probabilities) on an instantaneous basis at the Beaver Kill at Cooks Falls site after 1965. Increases in stormflows can not be attributed solely to NY 17, however, because the trend was evident long before NY 17 was constructed. Changes in land use in parts of the watershed may have contributed to gradual and continuous increases in stormflows throughout the entire 80 (plus) years of record.

Changes in most base-flow and low-flow statistics for the downstream (Beaver Kill at Cooks Falls) site after 1965 are not statistically significant, but, changes in flow-duration curves and annual peak flows are evident. Flow-duration curves at this site indicate that there is a 16 percent increase in average daily flows after 1965. Annual peak flow data indicate that peak flows from storms recurring at 2-year (and longer) intervals after 1965 are significantly larger than those that recur at the same frequencies before 1965. The lack of comparable increases in peak flows from several nearby reference sites after 1965 indicate that the observed increases in peak flows may be unique to the Beaver Kill Basin.

Flow-duration curves and many base-flow and high-flow statistics for the small tributary paralleled by NY 17 in the in the upper reaches of the basin (Little Beaver Kill at Livingston Manor) appear to be considerably altered since NY 17 was constructed. Flow-duration curves at this site indicate that there is about a 54 percent increase in average daily flows after 1965. Increases in the ratio of average annual base flow to average annual flow until 1965 then subsequent decreases suggest an extreme affect of NY 17 on hydrology of the subbasin. The effect of NY 17 on hydrology of the Little Beaver Kill subbasin cannot be defined with certainty, however, because the flow record after 1965 is too short; discharge monitoring was discontinued in 1981.

The increases in peak stormflows in the lower Beaver Kill basin through the period of record may have increased the rates of bed-sediment erosion (degradation) and deposition and accelerated changes in stream-channel morphology, however, these possible effects were not examined. Suggestions for further investigation of the effects of NY 17 and of other factors on hydrology, channel morphology, fish

habitat, and fish populations in the Beaver Kill Basin include (1) addition of streamflow gages or a crest-stage gage network at critical locations, (2) a review of engineering records and other aerial photographs for indications of changes in channel morphology, (3) compilation of temperature data and modeling spatial extent and magnitude of stressful summer temperatures (to selected trout species), and (4) confirming the extent and severity of toxic thermal episodes using in-situ fish toxicity tests.

INTRODUCTION

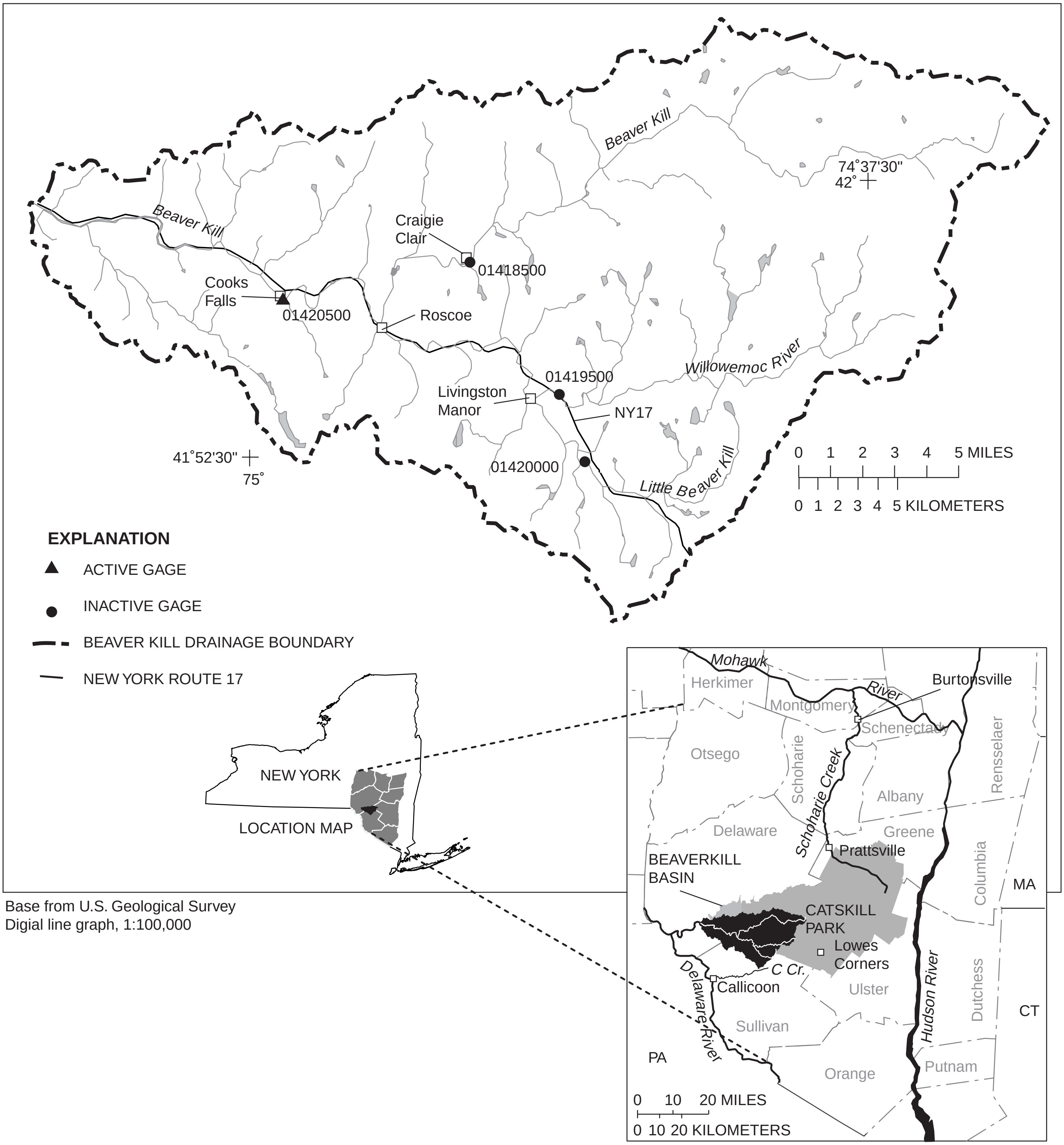
Trout fishing in the Beaver Kill, in the southwestern Catskill Mountains of New York (fig. 1), has long been a major source of income to the region (Francis, 1983). Concern has increased recently over the hydrologic and thermal effects that recent development and a four-lane State highway (NY 17), may have had on fish habitat and trout productivity in the Beaver Kill since its construction in the 1960’s (J. Conyngham, Trout Unlimited, oral commun., 1996). Potential hydrologic changes within the basin that could be associated with NY 17, such as decreased base flow (dry-weather flow) and increased and prolonged extremes in low- and high-flow conditions, are suspected to have altered the aerial extent (quantity) and stability of physical habitat within the Beaver Kill and, thereby, adversely affected resident fish populations. "Habitat area" refers to the wetted surface area of the streambed or channel that resident fish populations inhabit at any given time, and "habitat stability" refers to the propensity of habitat characteristics such as streambed sediment, water depth and velocity, channel width, stream discharge, cover for fish, bank-erosion rates, and related factors, to change or to fluctuate through time.

NY 17 is a four-lane largely elevated highway that was built during the 1960’s and traverses about 26 mi of the Beaver Kill Basin (J. Conyngham, oral commun., 1996), where in it parallels the Little Beaver Kill, the lower Willowemoc Creek, and the lower reaches of the Beaver Kill (fig. 1). The actual construction period spanned much of the 1960’s and completion dates for various sections range from about 1965 to 1969 (J. Conyngham, oral commun., 1996). Parts of the valley floor along many streams in the Beaver Kill Basin are paved or covered by fill associated with the highway’s construction. Sixteen bridges over main channels, numerous channel truncations and armoring (rip-rap), and an extensive drainage-culvert system that directs runoff from NY 17, were also built during the period (J. Conyngham, oral commun., 1996). Features and structures such as these have been shown to alter shallow ground-water flow paths and flow rates, channel storage and recharge, and base flow of nearby streams, and these changes, in turn, can alter the elevation and slope of the water table and diminish the ground-water contribution to streams, thereby decreasing base flows and increasing the range of discharge fluctuations (reducing flow stability) (Blackport and others, 1995). Decreased channel sinuosity and roughness, and increased channel gradient (through channel truncation and armoring), can increase the velocity, power, and magnitude of stormflows and thereby alter streambed morphology and decrease the overall area and stability of stream-channel habitat available to resident fish (Binns, 1979; Fausch and others, 1988). If changes in habitat are extensive, rates of fish survival and reproduction can decline, and the density of their populations may decrease (Simonson and others, 1993).

Purpose and Scope

In 1996, the U.S. Geological Survey (USGS), in cooperation with the Town of Rockland in Sullivan County, began a study to determine whether completion of NY 17 in the 1960’s could have affected hydrologic processes and, thereby adversely affected the trout fishery in the Beaver Kill Basin. The major objective of the study was to evaluate the hypothesis that changes in surface-water and shallow ground-water flowpaths and increased runoff rates due to the presence of NY 17 in the Beaver Kill watershed have (1) widened the range in stream discharge (prolonged the base flows, decreased the low flows, and increased the high flows), and (2) altered stream-channel morphology through increased volume and velocity of stormflows. All analyses (except for peak flows) were based on historical average-daily discharge records from one active and three inactive USGS streamflow-gaging stations within the basin.

This report (1) describes the four sites studied in the Beaver Kill Basin and one reference (unaffected) site in the adjacent Schoharie Creek Basin, (2) presents results of selected analyses of historical surface-water data and discusses significant findings and trends, (3) identifies limitations of the information used in the analyses, and (4) suggests additional areas of study



Base from U.S. Geological Survey
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Figure 1. Principal hydrologic features of study area in southeastern New York State.

and the surface-water monitoring needs that could help establish whether NY 17 has affected fish habitat and trout populations of the Beaver Kill Basin.

Acknowledgments

Thanks are extended to Jock Conyngham for his technical reviews of this document and the analyses, and to The Town of Rockland and Trout Unlimited for support of this work.

STUDY AREA

Four sites in the Beaver Kill Basin (Delaware River system) and one control site in the nearby Schoharie Creek basin (Mohawk River system) were selected for study (fig. 1). Annual average daily discharge, total annual runoff, drainage area, USGS station number, and period of record for each site are given in table 1. The Beaver Kill at Cooks Falls (Cooks Falls site), the downstream site, is the only active stream-flow gaging station in the basin. The upstream site, the Little Beaver Kill at Livingston Manor (Little Beaver Kill site) was discontinued in 1981. Water flowpaths and runoff at these two sites could potentially be affected by NY 17. The two other sites in the basin -- the Beaver Kill at Craigie Clair (Beaver Kill site) and the Willowemoc Creek at Livingston Manor (Willowemoc site), were operated during about 1937-70.

Stream-flow records from 1902-94 are available from Schoharie Creek at Prattsville, about 35 mi northeast of Roscoe (see fig. 1 inset map); Schoharie Creek flows into the Mohawk River, a tributary to the Hudson River (U.S. Geological Survey, 1996). Although the Schoharie Creek watershed also underwent development and road construction sometime during the period of study, the hydrologic effects were probably similar to those occurring in the Beaver Kill, except for the construction of NY 17. No other site in the Catskill region was so close and as similar to the Beaver Kill in drainage area, nor did any other sites have the lengthy period of flow records needed to separate the effects of annual precipitation on flows in the Beaver Kill before 1965 from those thereafter.

Total annual wet precipitation during 1941-94 at rain gages maintained by several cooperators for the National Oceanic and Atmospheric Administration (NOAA) averaged 43.1 in. at eight sites in the northern part of the upper Delaware basin and 46.9

Table 1. Period of record, drainage area, annual average daily discharge, and average total annual runoff of streams at study sites in the Beaver Kill Basin and at the control site in the Schoharie Creek Basin, N.Y. [Locations are shown in fig. 1]

Site name, informal name, and data source	USGS station number	Period of record	Drainage area (square miles)	Annual average daily discharge (cubic feet per second)	Average total annual runoff (inches)
Study sites (Beaver Kill Basin)					
Beaver Kill at Cooks Falls[1] (Cooks Falls site)	01420500	1915-94	241	555	31.27
Little Beaver Kill at Livingston Manor[2] (Little Beaver Kill site)	01420000	1924-81	20	45	30.79
Beaver Kill at Craigie Clair [3] (Beaver Kill site)	01418500	1937-70	82	191	31.63
Willowemoc Creek at Livingston Manor[3] (Willowemoc site)	01419500	1937-70	63	143	30.82
Reference site (Schoharie Creek Basin)					
Schoharie Creek at Prattsville[1] (Prattsville site)	0135000	1902-94	237	460	26.36

[1] U.S. Geological Survey (1996)

[2] U.S. Geological Survey (1982)

[3] U.S. Geological Survey (1972)

in. at the rain gage in the study area at Roscoe, (fig. 1) (B.E. Krejmas, U.S. Geological Survey, unpublished data, 1996).

METHODS

The hypothesis that overland-water flow, shallow ground-water flow, and stream discharge in the Beaver Kill Basin changed after construction of NY 17 was evaluated through analyses of temporal trends in (1) the relation of stream stage to discharge, (2) discharge-duration curves, (3) peak and estimated bankfull discharges, (4) annual and monthly discharges and base flows, and (5) annual and monthly flow extremes (1-, 3-, and 7-day high and low discharges), primarily at the two sites that were most likely to have been affected by NY 17 -- the downstream (Cooks Falls) and the upstream (Little Beaver Kill) sites (fig. 1). Though construction of NY 17 extended through the 1960’s, the year 1965 was selected as the focal point because it was approximately midway in the construction period, any hydrologic changes should have begun to occur, and no definite completion date could be ascertained.

Values for 13 indices for the Cooks Falls and the Little Beaver Kill sites were calculated, and the temporal trends of these indices were compared with (1) precipitation trends, and (2) corresponding trends at three reference sites (the Willowemoc and Beaver Kill sites and the Prattsville site), both before and after 1965, to detect signs of downcutting (incising) and filling of stream channels and for signs of change in related hydrologic processes after construction of NY 17. The 13 indices listed and explained below were:

(a) Relation of stream stage to discharge; this describes the association between the shape of the channel, stream stage, and stream discharge.

(b) Discharge-duration curves; these are cumulative frequency curves that show the percentage of time that specified daily discharges were equalled or exceeded during a given period (Searcy, 1959).

(c) Peak and bankfull discharge; bankfull flows are peak instantaneous flows that recur with a interval of about 1.5 years (exceedence probability of 1/1.5 or 0.67) (Powell, 1995). Larger stormflows that recur every 2-100 years (exceedence probabilities of 0.5-0.01) are estimated with the same peak flow information. Discharge values were calculated by special USGS data-retrieval applications.

(d) annual average daily discharge; estimates for each site and year were obtained from USGS records maintained in Troy, N.Y., and are reported in cubic feet per second or inches of runoff (normalized to subbasin area).

(e) monthly average daily discharge; estimates for each site and each month were obtained from USGS records maintained in Troy, N.Y., and are reported in cubic feet per second or inches of runoff (normalized to subbasin area).

(f) annual average base flow; estimates for each site and year were calculated from USGS records using flow-separation models of Rutledge (1993), and are reported in inches of runoff (normalized to subbasin area).

(g) monthly average base flow; estimates for each site and month were calculated from USGS records using flow-separation models of Rutledge (1993), and are reported in inches of runoff (normalized to subbasin area).

(h) ratio of annual average base flow to annual average flow (annual B/A ratio); calculated for each site and year from estimates of annual average base flow (f) and annual average flow (d).

(i) ratio of monthly average base flow to monthly average flow (monthly B/A ratio); calculated for each site and month from estimates of monthly average base flow (g) and monthly average flow (e).

(j) annual 1-day high flow; highest 1-day average discharge for each site each year.

(k) annual 1-day low flow; lowest 1-day average discharge for each site each year.

(l) monthly 1-day high flow; highest 1-day average discharge at each site each month.

(m) monthly 1-day low flow; lowest 1-day average discharge at each site each month.

Other indices (e.g., 3- and 7-day low and high flows) were examined, but, are not discussed because their temporal trends were similar to, and their associations were less statistically significant (lower *p* values), than those of the 1-day low and high flows. Precipitation was used as an independent variable where appropriate. Similar analyses were also done for the three reference sites (Prattsville, Willowemoc, and Beaver Kill) to help evaluate whether hydrologic changes at the sites potentially affected by NY 17 (Cooks Falls and the Little Beaver Kill sites) might have occurred normally due to regional and temporal variations in precipitation and stream hydrologic conditions.

Total annual wet precipitation data (reported in inches) for each year during the period 1941-94 were estimated by summing provisional monthly accumulations from 8 NOAA rain gages (see study area section) and averaging data from all sites. Annual variations and long-term trends in precipitation were compared to hydrologic changes and trends at potentially affected sites (and at unaffected sites) to determine whether temporal variations in precipitation might have contributed to variations in hydrologic indices and whether any changes after 1965 could be attributed solely to NY 17, or to a combination of natural and man-made factors.

TRENDS IN BASE FLOWS AND EXTREME FLOWS

Changes in monthly and annual discharge, base flow, and several other hydrologic indices were observed at the three reference sites and the two possibly affected sites in the Beaver Kill Basin during their respective periods of record. These changes are presented in terms of significant trends (increasing or decreasing) through time and as changes in the slope of these trends after the construction of NY 17. Although the temporal trends in these indices reflect the streams' response to a multitude of factors, and although differences among time periods represented account for some of the variability of a given index, time (year) is not responsible for these trends; the potential causes of observed variability include fluctuations in precipitation, shifts in land uses and predominant forest cover, and changes in hydrologic flowpaths related to increased development within the basin. Precipitation generally accounts for much of the long-term variability in most of the hydrologic indices evaluated. A significant change in the slope of an index trend after 1965 does not necessarily mean that NY 17 was the reason for the shift -- many other factors (most of which were not assessed) could have contributed to the response.

Hundreds of relations among the 13 indices were evaluated, but only those few found to be significant ($p \leq 0.05$ unless otherwise noted) are discussed. The small amounts of variability in each index accounted for by factors other than precipitation does not mean that these factors are inconsequential, but that their effect on hydrologic processes within the basin was largely overshadowed by the effect of precipitation. These other factors warrant further study because, unlike precipitation, many can be altered through informed watershed management.

Although the slopes of several regression lines that describe relations between indices and time before 1965 differed significantly from the slopes after 1965, the wide range of values for most indices produce large standard errors and confidence limits for the best-fit lines.

Relation of Stream Stage to Discharge

Relations between stream stage and discharge at all four Beaver Kill Basin sites after 1965 differed from those before 1965 as illustrated in examples for the Cooks Falls and Little Beaver Kill sites in figures 2, in which low-flow discharges (base flows) at both sites were associated with slightly lower stages after 1965 than before. Although the slopes of the regression lines for both sites (simple best-fit regression lines for the Little Beaver Kill site are not a true representation of the relation and are not shown) are significantly different after 1965, the standard errors for each line (not shown) overlap considerably; thus, predictions of stream discharge from stage using both lines would not differ significantly. The small but significant decrease in the slope for the Cooks Falls site (fig. 2a) indicates that the control was lowered slightly (by 0.05 to 0.1 ft.), probably through dislodgment of the sediments that typically form a small part of the mostly bedrock control. This lowering would imply increased transport of sediment and(or) increased water velocities after 1965 at this site. A small increase in discharge for a given stage at the Little Beaver Kill site after 1965 (fig. 2B) (regression line not shown) could be attributed to increased approach velocities at the control structure as a result of gradual filling of the control pool by sediment; the control structure itself could not have been altered because a concrete weir was installed in 1933 (U.S. Geological Survey, 1982).

The small shifts in stage-to-discharge relations at both sites after 1965 could be loosely interpreted as circumstantial evidence of increased stormflows, decreased flow stability, increased water velocities, increased sediment transport (in the Little Beaver Kill), and of minor changes in stream-channel morphology after NY 17 was built. The small magnitude of the changes in slopes, however, indicate extremely stable channel geometry and control structures at both locations, as might be expected at bedrock and weir-controlled sites. Comparable changes in stage-to-discharge relations at the three sites unaffected by NY 17 (not shown) suggest that changes in channel morphology were due to natural or human-related processes that occurred throughout the Beaver Kill Basin (for example, deforestation, forest regeneration, and changes in farming methods or intensity). Study of historical changes in stream-channel morphology at other locations would be needed (see Suggestions for Additional Study, further on) to characterize any changes in stream channels and in sediment mobilization in the Beaver Kill Basin.

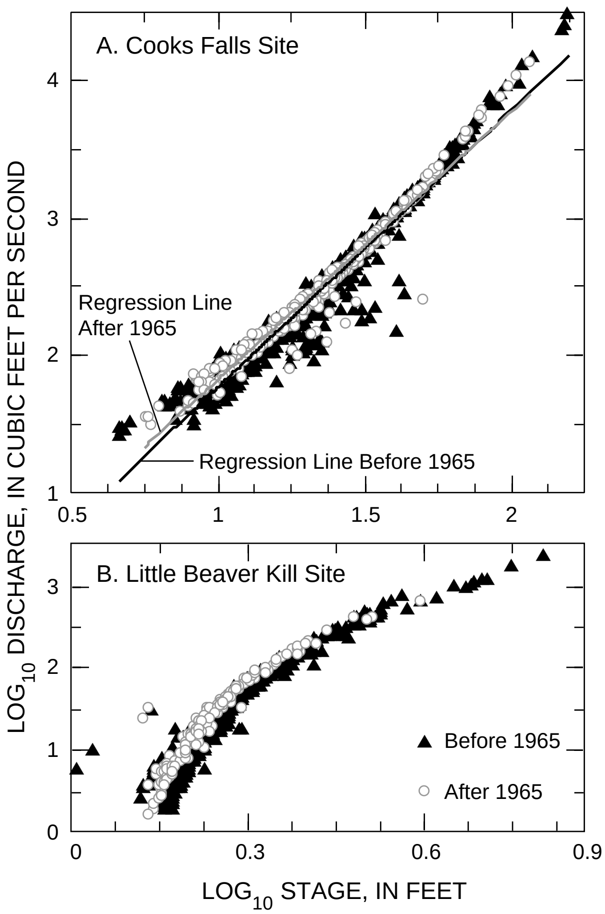

Figure 2. Discharge as a function of stage before and after 1965 for the Beaver Kill at Cooks Falls and for the Little Beaver Kill at Livinston Manor, N.Y., (Locations are shown in fig. 1.)

Discharge-Duration Curves

Comparison of daily flow-duration frequencies for the 14 years before and after 1965 at the Little Beaver Kill site (fig. 3) and for the 29 years before 1965 and the 29 years thereafter at the Cooks Falls site (not shown) indicates either that (1) the average daily flows underwent a significant (16-54 percent) increase after 1965, or (2) a large percentage of flows before 1965 were exceptionally low, and a larger percentage of those after 1965 were exceptionally high. Increased average daily flows (or increased frequency of large flows) in the basin after 1965 would shift the flow-duration curve upward and (or) to the right, as depicted in figure 3. The recurrence of droughts (during the late 1930's, early 1940's, and early 1960's), and the above-average flows during most of the 1970's (Gravlee and others, 1991), suggest that temporal fluctuations in regional precipitation could be the reason for the shifts indicated in figure 3. Analyses that exclude data from the initial highway-construction period (1961-66, which was a time of severe drought) indicate no significant differences between average daily flows before 1965 and those thereafter. The recurrence of several short drought periods in the 1980's and 1990's suggests that the number, and (or) the duration, of moderate to high flows (expressed as average daily flows) may have actually increased at these two sites, but additional flow records would need to be evaluated to confirm or refute this.

If overland and surface-water runoff and stream-water velocities did increase in response to regional increases in precipitation and to the presence of NY 17 and other land-use changes in the basin, the ability of the streams to erode and transport bank and channel sediments, and thereby alter channel morphology, would have also increased after 1965. This possibility was evaluated only at the Little Beaver Kill and Cooks Falls sites, which had very stable control structures; additional channel-geometry information from other sites would be needed to determine the effects of increased flows, or of increased frequency of large flows, on stream channels and sediment transport and deposition throughout the basin.

Peak and Bankfull Discharges

Bankfull discharges at the Cooks Falls and Little Beaver Kill sites, and at the Prattsville (reference) site were estimated from the largest instantaneous flows recorded each year during equivalent periods before and after 1965. Peak discharges that recur every 1.5 years on average (0.67 probability of occurrence each year) were considered (1) to be the bankfull discharge for each site and record period, and (2) to produce

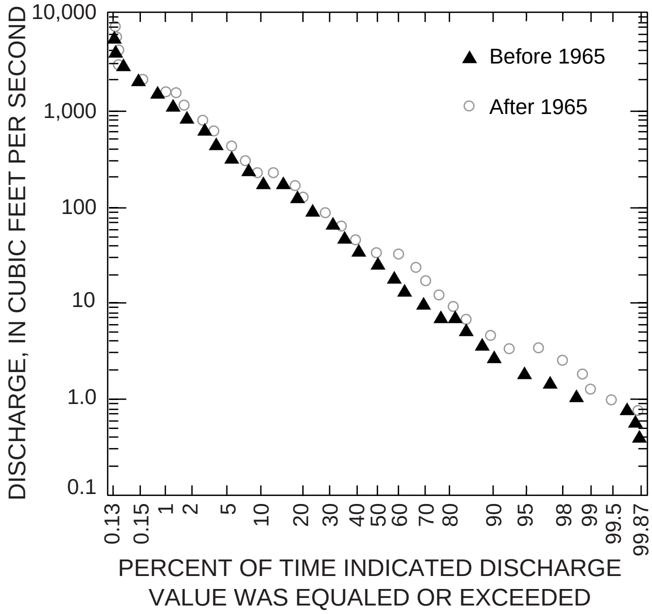

Figure 3. Discharge-duration curves for the Little Beaver Kill at Livingston Manor, N.Y., for the 14 years before 1965 and the 14 years thereafter. (Location is shown in fig. 1.)

stages which regulate stream-channel morphology (Powell, 1995). The relation between peak flows (ranked from lowest to highest flows) and exceedence probability before and after 1965 at the Cooks Falls site is plotted in figure 4A; the discharge that corresponds to a probability of 0.67 (on the regression line) represents the bankfull discharge that recur approximately every 1.5 years. Bankfull flows at the Cooks Falls gage were from 5 to 15 percent greater after 1965 than before -- bankfull estimates during 1935-64 range from 10,000 to 10,200 ft^3/s, and those during 1935-64 range from 10,500 to 11,700 ft^3/s (fig. 4A). Similar or larger increases in bankfull discharge at the Little Beaver Kill site (12-32 percent, not shown) and at the Prattsville site (10-35 percent) (fig. 4B) were also noted after about 1965. The similarity of increases at the Prattsville site, which was unaffected by NY 17, to those at the Cooks Falls and Little Beaver Kill sites indicate that the increases either resulted from regional increases in precipitation, or that other unidentified factors affected bankfull discharges across the region in a similar manner. The recurrence of extremely low flows during the 1930's and 1940's and early 1960's, and the above-average flows during most of the 1970's (Gravlee and others, 1991), suggest that the increases in peak flows that recur every 1.5 years (bankfull discharges) following construction of NY 17 resulted primarily from regional increases in precipitation after 1965.

A more obvious change at the Cooks Falls site after 1965 was that floodflows that recur at a 2- to 10-year (and longer) frequency (excedance probabilities of 0.5 and 0.1) at the Cooks Falls site were about 13 percent larger than those that occurred at those frequencies before 1965 (fig. 4A) whereas, the floodflows that recur on a 2- to 10-year frequency after

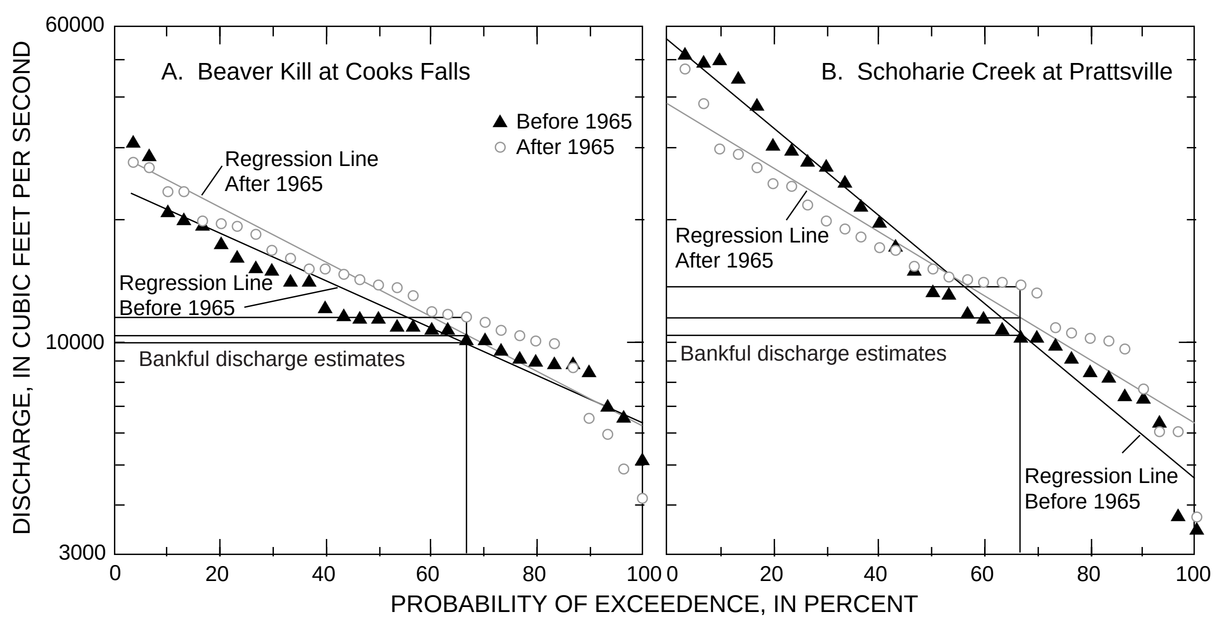

Figure 4. Exceedence probabilities (in percent) for instantaneous peak flows at the Beaver Kill at Cooks Falls and the Schoharie Creek at Prattsville (reference site) for 30 years before 1965 and the 30 years thereafter. [Bankfull discharges are estimated as the flows which recur every 1.5 years; equal to flow with an exceedence probability of 0.67. [Locations are shown in fig. 1.]

1965 at the Prattsville site were similar to, or as much as 25% smaller than, those before 1965 (fig. 4B). Peak-flow data from the Prattsville and most nearby sites (see below and fig. 5) indicate that smaller amounts of precipitation caused storm flow magnitudes to be similar or smaller in the region during the 30 years since NY 17 was constructed than during the 30 years before. Storms of the post-1965 period at the Cooks Falls site would also have been smaller than those of the pre-1965 period if

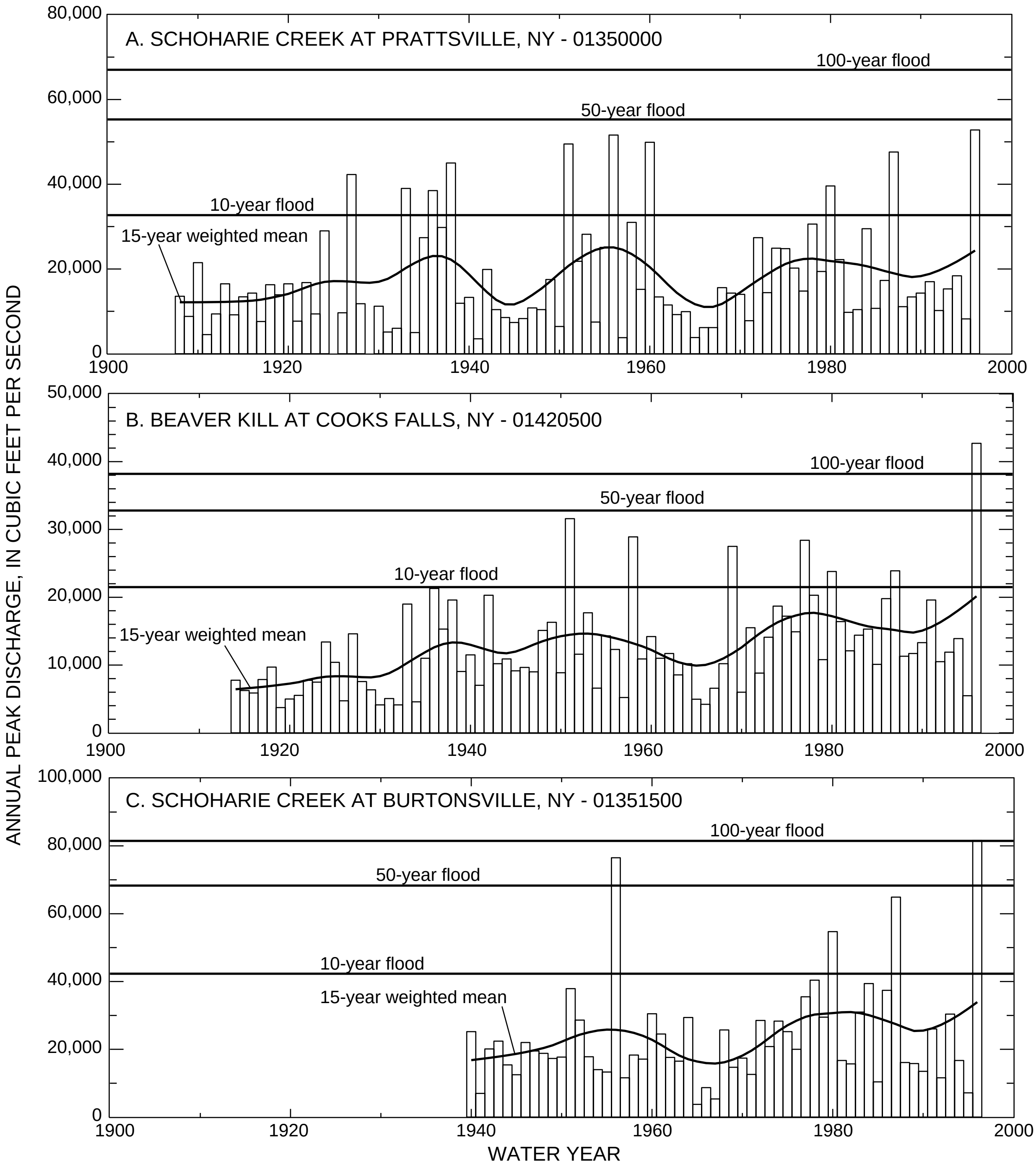

Figure 5. Annual peak flows and 15-year weighted moving average of the annual peak flows for the period of record through 1996, and long-term discharge estimates for 10-, 50, and 100- year floods (recurrence intervals) at streamflow gaging stations in Schoharie Creek at Prattsville, the Beaver Kill at Cooks Falls, and Schoharie Creek at Burtonsville, N.Y. (Locations are shown in fig. 1. Data from U. S. Geological Survey [1996]. Modified from Lumia [1998], fig. 11. Water year refers to a period from October 1 of one year to September 30 of the next year.)

precipitation trends for the two watersheds were approximately equal. Though significant differences between pre- and post-1965 peak-flow trends (regression lines) are evident (fig. 4), and, estimates for 2- to 10-year stormflows after 1965 would be of slightly greater magnitude, except for the period 1914-34 (table 2), they would not be statistically different from those before 1965 in the lower Beaver Kill Basin. Many factors, including precipitation and NY 17, could have increased the magnitude or frequency of moderate to large stormflows since 1965.

A report on flood frequencies of New York streams (Lumia 1998), indicates either a deceased, or an unchanged recurrence interval for annual peak flows and for the 15-year weighted moving average of the annual peak flows for nearby Catskill sites (Esopus Creek at Coldbrook, Catskill Creek at Oak Hill, East Branch Delaware River at Margaretville, and East Branch Delaware River at Fishs Eddy) after 1965; as does the reference site (Schoharie Creek at Prattsville) (fig. 5A). Other streams, such as Callicoon Creek at Callicoon, (adjacent to the Beaver Kill Basin) and Roundout Creek Near Lowes Corners, also show decreases in annual peak flows after 1965 (table 2). Even though small increases in the magnitude of annual peak flows after 1965 at the Cooks Falls site are evident (fig. 5B, table 2), the variability in the data is large; thus, differences in the magnitude of 2-, 10-, 25-, and 100-year stormflows for the 29 years before and the 29 years thereafter are generally not statistically significant (table 2). Though no significant differences for any period are evident at adjacent sites (table 2), the magnitude of 2-, 10-, 25-year stormflows at the Cooks Falls site are significantly larger from 1965-94 than they were from 1914-34. Data from one nearby site (Schoharie Creek at Burtonsville) (fig. 5C) show a similar increase in peak flows (Lumia 1998); this suggests that the trend is not unique to the Beaver Kill Basin and, therefore, the increases in stormflows can not be caused solely by NY 17. The relatively steady increase in annual peak flows and in the 15-year weighted moving average of the annual peak flows that started long before NY 17 was constructed and continued through the period of record at the Cooks Falls site, (fig. 5B) further indicate that other basin-wide factors are the probably cause of increased stormflows in the basin. The increasing trend in annual peak flows (and in the 15-year weighted moving average of the annual peak flows) of the Beaver Kill at Cooks Falls and stable or decreasing trends at most nearby watersheds since the early 1900's suggest that a variety of factors, possibly unique to the Beaver Kill watershed, have altered hydrologic processes that affect the magnitude of peak flows or stormflows in the basin. The recurrence of extended droughts in the Catskill region during the 1920's, 1930's, 1940's, and 1960's (Gravlee and others, 1991) suggests that the long-term increasing trend in peak flows may, in part, be a result of a increases in precipitation in the Beaver Kill basin. The increasing trend in peak flows of the

Table 2. Estimated peak flows of 2-, 10-, 25-, and 100-year recurrence intervals for Beaver Kill at Cooks Falls, N.Y., and for three streams in nearby basins before and after 1965. Significant differences in peak flows between periods are denoted by "1". [Discharges are in cubic feet per second. Data from USGS files in Troy, N.Y. Dash indicates no record. Locations are shown in fig. 1.]

	Estimated peak flows of select recurrence interval											
	2 years			10 years			25 years			100 years		
Location	1914-34	1935-64	1965-94	1914-34	1935-64	1965-94	1914-34	1935-64	1965-94	1914-34	1935-64	1965-94
Beaver Kill at Cooks Falls	6,646	11,850	11,370[1]	12,430	20,970	23,900[1]	16,210	26,500	29,210[1]	23,100	36,000	37,060
Schoharie Creek at Prattsville	11,780	15,090	15,350	20,250	40,320	31,370	39,540	58,690	40,690	62,960	94,111	55,940
Rondout Creek near Lowes Corners[2]	-	2,505	2,647	-	6,047	5,123	-	8471,	6,614	-	12,950	9,139
Callicoon Creek at Callicoon[3]	-	4,483	3,996	-	8,113	7,019	-	10,420	8,883	-	14,530	12,130

[1] 2-, 10-, and 25-year peak discharges for 1965-94 are significantly different from those for 1914-34

[2] Record began in 1940, not 1935

Beaver Kill gets stronger as more current peak flow information (1995-97) are included (fig. 5B). Regardless of potential effects from NY 17, the ever increasing magnitude and frequency of peak flows and the resulting swifter (and more powerful) velocities of waters in the Beaver Kill could have (1) increased the rate of sediment transport and (2) altered stream-channel morphology through new patterns of degradation and deposition in stream channels and on the flood plains of the basin.

Annual Average Discharge and Base Flow

Precipitation generally accounted for 75 to 92 percent of the variability in annual average base flow and annual average discharge, and from 16 to 30 percent of the variability in the annual B/A ratio (ratio of annual average base flow to annual average discharge) at all five sites. Temporal trends in annual average base flow, annual average discharge, and annual B/A ratios at the Cooks Falls site (fig. 6A) and the basin’s reference sites (the Beaver Kill - not shown and the Willowemoc - not shown) were not significant but the trends in annual average base flow (increasing from 1924-80) and in annual B/A ratio (increasing during 1924-65, then decreasing during 1966-80; see fig. 6B) at the Little Beaver Kill site were significant. Although precipitation can account for about 30 percent of the variability in annual B/A ratios for the Little Beaver Kill, time (year) and the significant change in slope after 1965 (fig. 6B) can account for 14 to 25 percent of the variability. These trends at the Little Beaver Kill site could be interpreted as evidence that NY 17 has affected the annual average flows and (or) base flows at the Little Beaver Kill site. Trends in the annual average base flow and annual average discharge for the Cooks Falls site (fig. 6A) parallel those at the Little Beaver Kill site (fig. 6B) during the overlapping period (1924-80), but the trends at the Cooks Falls site are not significant when data from 1980-94 (and 1915-23) are included in the analysis. Therefore the significant decrease in annual B/A ratio and in annual average base flow (relative to average annual discharge) at the Little Beaver Kill site after

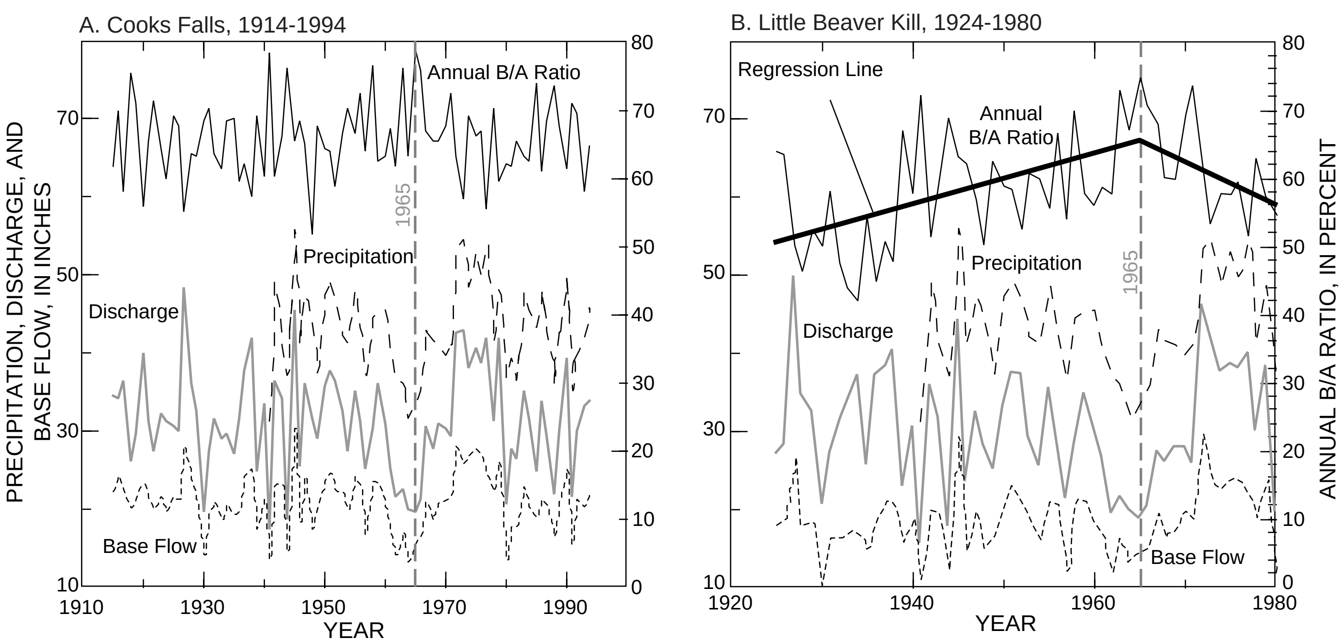

Figure 6. Total annual precipitation, average annual discharge and base flow (reported in inches of runoff), and the ratio of annual average base flows to annual average flows (annual B/A ratio) for: A. the Beaver Kill at Cooks Falls, N.Y.,1914-94, and B. the Little Beaver Kill at Livingston Manor, N.Y., 1924-80. (Locations are shown in fig. 1.)

1965 either could be real, or could be an artifact of the shortened period of record at the site. Additional discharge records from the Little Beaver Kill site would be needed to confirm a real and sustained effect of NY 17 on annual average flows and base flows in this subbasin.

Monthly Average Discharge and Base Flow

Comparisons of monthly average discharge, base flow, and B/A ratios for all four sites with total monthly precipitation and to time (year) reveal only a few significant associations; these are presented below. Monthly average discharges and base flows at the Cooks Falls and the Little Beaver Kill sites (and at the two reference sites -- Beaver Kill and Willowemoc sites) were, as expected, strongly related to precipitation but did not show any significant temporal trend, nor did the slope of any relations change after 1965.

Cooks Falls Site. Total monthly precipitation at Cooks Falls (1941-94) could account for 17 to 76 percent of the variability in monthly B/A ratio and none of the monthly B/A ratios, except for July, showed a significant temporal trend during the period, nor did the slope of most monthly trends change significantly after 1965 (fig. 7). The increasing trend in

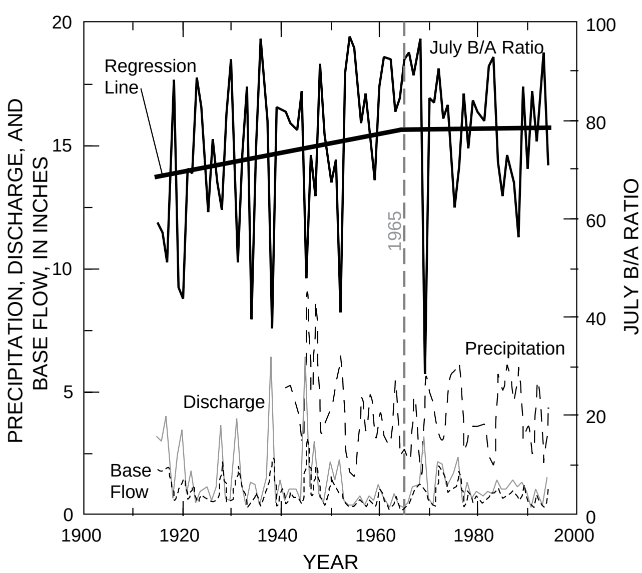

Figure 7. Total precipitation, average discharge and base flow (reported in inches of runoff), and ratio of average base flows to average flows (July B/A ratio) for July at the Beaver Kill at Cooks Falls, N.Y., 1914-94. (Location is shown in fig. 1.)

July B/A ratios with time, and a significant change in the slope of temporal relations after 1965, could account for about 11 percent of the variability in July B/A ratios (fig. 7); precipitation could account for about 54 percent of the variability. These results indicate that the average base flows for July at this site increased relative to the average discharges for July during 1914-65, then decreased relative to the average discharges for July during 1966-94 (fig. 7). Therefore, NY 17 would appear to have slightly decreased July base flows of the Beaver Kill at the Cooks Falls site. The effects of this decrease on fish communities would be difficult to interpret, however, because (1) August typically has lower average base flows than July; (2) August flows, rather than July flows, generally constitute the lowest monthly base flows, which in turn produce the smallest wetted-streambed area (fish habitat) and limit the year-round carrying capacity (total fish biomass) for a given reach; and (3) base flows for August and other months of low flow appear to be unaffected by NY 17. The decreased base flows during July could, however, result in an increased magnitude of peak stormflows (flashiness) during summer, and thereby affect flow and habitat stability throughout parts of the basin.

Little Beaver Kill Site: Total monthly precipitation (1941-80) at the Little Beaver Kill site could account for 0 to 72 percent of the variability in monthly B/A ratios (1924-80), and none of the monthly B/A ratios, except for August, showed a significant temporal trend during the period, nor did the slope of any trends change significantly after 1965. The increasing trend in August B/A ratios with time, could account for 12 percent of the variability in August B/A ratios, and precipitation could account for 42 percent of the variability. August B/A ratios increased (not decreased, as hypothesized), during the period of record (1924-80) in response to an insignificant decrease in average August discharges with time; thus, the increase in August B/A ratios may be an artifact of the shortened period of record.

Annual 1-day Low and High Flows

In general, precipitation could account for as much as 52 percent of the variability in annual 1-day low flows and 1-day high flows at all four sites in the Beaver Kill Basin. Only a few temporal trends in flow extremes are discernible and none, except for the Little

Beaver Kill site, showed a significant change in the slope of the temporal relations after 1965.

At the Little Beaver Kill site, a significant temporal trend and reversal in the slope of the relation in annual 1-day high flows after 1965 (fig. 8), accounted for about 12 percent of the variability in annual 1-day high flows. The regression line in figure 8 indicates a decreasing trend in 1-day high flows during 1925-65, and an increasing trend during 1966-80. This finding would seem to indicate that hydrologic changes occurred in the Little Beaver Kill subbasin after 1965. The discharge values (not the regression line) for the Cooks Falls site in figure 8 also show an increasing trend in 1-day high flows from 1965-80 that is similar to that for the Little Beaver Kill site; but, the trend at the Cooks Falls site reverses after 1980 when the flow record at the other site is discontinued. The similarity in trends at both sites from about 1940-80 and the reversal at Cooks Falls after 1980 suggests that the trends in 1-day high flows at the Little Beaver Kill site after 1965, like the trends in base flow, could be an a result of a shortened record. The available hydrologic records are insufficient, however, to confirm or refute this possibility.

The significant reversal in the temporal trends of annual 1-day high flows and of annual average base flows at the Little Beaver Kill site after 1965 (figs. 6B, 8), could possibly reflect genuine hydrologic changes caused by NY 17 within the subbasin. NY 17 would be expected to have a greater (and possibly different) hydrologic affect on the Little Beaver Kill subbasin than on the Cooks Falls basin because (1) the Little Beaver Kill subbasin is much smaller than the Beaver Kill at Cooks Falls and (2) NY 17 passes through about one half of the Little Beaver Kill drainage but through only about one-third of the Beaver Kill at Cooks Falls drainage, therefore, flows might be more reactive to perturbations in the Little Beaver Kill subbasin than in the Beaver Kill at Cooks Falls basin. The other two thirds of the Beaver Kill at Cooks Falls watershed contain the Willowemoc and the northern branch of the Beaver Kill, which are both not affected by NY 17 (fig. 1).

A significant temporal trend (increasing with time) is indicated for annual 1-day high flows (r^2 = 0.08) for the period of record at the Cooks Falls site (1915-94), but no significant change in the slope of the relation (regression line) is evident after 1965, even though trends in 1-day high flows partly resembled those at the Little Beaver Kill during 1925-80 (fig. 8). The trend provides further evidence that the long-term increases in the frequency and (or) magnitude of peak and stormflows in the lower basin is (1) the result of normal variations in precipitation, (2) due to protracted and interminable changes in land uses and related development, and (3) not related to any single abrupt perturbation of hydrologic processes within the basin

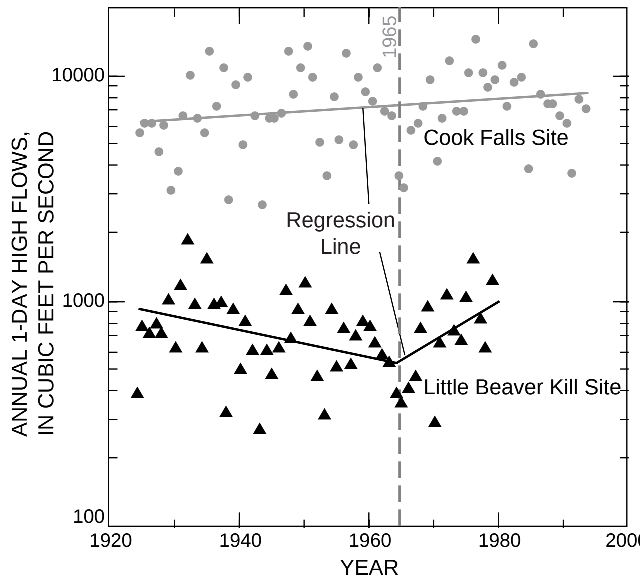

Figure 8. Annual 1-day high flows for the Little Beaver Kill at Livingston Manor, N.Y., and the Beaver Kill at Cooks Falls, N.Y., 1925-94. (Locations are shown in fig. 1.)

Monthly 1-day Low and High Flows

With three exceptions (described below), monthly 1-day low and high flows at Cooks Falls and at the Little Beaver Kill sites did not show significant trends through time, nor did the slope of the trends change significantly after 1965. Monthly low and high flows were significantly related to total monthly precipitation during more than half of the months ($r^2 \leq 0.71$).

Little Beaver Kill Site. Annual differences in April's total precipitation, a significant trend with time, and a significant change in the slope of the relation after 1965, accounted for 28 percent of the variability in monthly 1-day high flows at this site for April (not shown); precipitation alone accounted for 21 percent of the variability. A small increasing trend in April's 1-day low flows was also significant ($r^2 = 0.06$) at this site during 1924-81 (not shown). The decrease in slope of the 1-day high flows for April after 1965 and, the increase in 1-day low flows through the period of record, is inconsistent with the trends that were hypothesized.

Cooks Falls Site: Only the 1-day low flows for August ($r^2 = 0.07$), and the 1-day high flows for December ($r^2 = 0.07$), showed a significant temporal trend at this site. The increase in slope for the 1-day low flows for August after 1965 was significant, but again is inconsistent with the decrease that was hypothesized.

These results indicate that either (1) the observed trends were caused by factors other than NY 17, (2) the hypothesized trends were incorrect, or (3) NY 17 has little or no effect on the monthly 1-day high and 1-day low (average) flows within the Beaver Kill Basin.

Limitations of Analyses

The methods used in this study could have failed to detect certain hydrologic changes associated with NY 17 in the Beaver Kill Basin if those changes were different from those hypothesized, or were masked by the effects of other factors, such as the following:

(1) Inconsistent temporal components to changes in the basin may have produced nonstandard hydrologic affect signals (e.g., binary vs. continuous) after NY 17 was constructed, and some of these signals were not recognized by our linear trend analyses. For example, increased sedimentation (directly associated with construction of NY 17) could have caused short-term (1-, 2-, 5-, 10-year) increases in channel deposition followed by channel degradation as the sediment was transported out of the system. Potential short-term changes in stage-to-discharge relations and stream channel morphology might have been masked by analyses of data for 14- or 29-year periods before and after 1965.

(2) Construction of secondary roads and railroads and associated hydraulic structures (ditches, culverts, and embankments), within the Beaver Kill basin before NY 17 was built, and before streamflow records were maintained, could have overshadowed lesser hydrologic changes that NY 17 would have produced alone.

(3) Large seasonal and yearly fluctuations in total precipitation (which account for most of the variability in most hydrologic factors, as noted earlier), could have masked lesser but significant hydrologic changes in the basin which might be strongly associated with NY 17. For example, small changes in annual average and base flows (and their temporal trends) due to NY 17 might be impossible to differentiate because of very high precipitation during the 1970's.

(4) Gradual alteration of surface-water and shallow soil-water flowpaths through natural and anthropogenic processes such as forest regeneration (after deforestation that occurred in the first half of the 20th century), reduced farming, and increased housing development could have resulted in hydrologic changes that could either counteract possible effects related to NY 17 or conceal these hydrologic changes within preexisting trends. For example, long-term increases in peak flows at the Cooks Falls site (fig. 5B) are obviously related to some factor(s) other than NY 17 until about 1965, thereafter, any real effect of NY 17 on peak flows could not be separated from the long-term trend.

In addition, the Schoharie Creek site may have been an inadequate reference site. It was used as the primary reference site, however, because it was the only nearby subbasin of a size similar to that of the Cooks Falls site, it was in the same physiogeographic region, and it had a record covering the same period as that of the Cooks Falls site. Hydrologic processes within the Schoharie Creek at Prattsville watershed may affect streamflow somewhat different from those in the Beaver Kill Basin and its subbasins, as reflected in the lower average flows and annual runoff (table 1) and higher peak flows (fig. 4) at the Prattsville site than at the Cooks Falls site. The differences between the basins are generally not relevant to our analyses, as data from the reference site are assessed primarily to distinguish regional from basin-specific origins for changes in hydrologic trends within the Beaver Kill.

Certain hydrologic changes also may have been undetected because the historical data (mostly daily discharges) that were available represented incomplete periods of coverage (years of record for each site), were of insufficient resolution (daily), and may also reflect an inadequate number and placement of gaged sites within the basin, to indicate major changes in stream hydrology after construction of NY 17. For example:

(a) The locations of active and discontinued streamflow gages (fig. 1) were not ideal for an evaluation of subbasins that are entirely traversed, and not traversed, by NY 17. Two locations that would have been ideal for this purpose would have been on the Beaver Kill and the Willowemoc Creek near their confluence at Roscoe (fig. 1). Data from a new Beaver Kill (unaffected) site would provide a better reference for comparison with data from the Willowemoc (affected) site.

(b) The periods of record for the two discontinued stream gages were generally too short to characterize changes in hydrologic trends after NY 17 was constructed. A longer period of record for the Little Beaver Kill (1924-81) and the Beaver Kill (1937-70) sites would have improved detection of changes in trends that may have occurred after NY 17 was built.

(c) The available discharge data (mostly daily, except for peak flows) may have insufficient resolution to indicate hydrologic trends; hourly or 15-minute discharge data might identify any such trends more precisely, but these data are either unavailable or available only in undigitized (graphic or punch tape) formats. Regeneration of early unit values was beyond the scope of this study.

SUGGESTIONS FOR ADDITIONAL STUDY

In addition to analysis of hourly or 15-minute discharge data, renewed discharge monitoring at the three discontinued gages, and (or) adding streamflow-gaging stations on the Beaver Kill and Willowemoc Creek near their confluence at Roscoe, would improve the ability to define discharge regimes and detect long-term changes in hydrologic characteristics throughout the Beaver Kill Basin. Discharge data from these sites could be used to verify changes and long-term trends in hydrologic characteristics and identify changes in the quantity and stability of fish habitat throughout the Beaver Kill Basin since NY 17 was completed.

Immediate needs for quantifying changes and trends in high flows (flood stages) at several sites throughout the basin could be met through use of low-cost crest-stage gages maintained by local observers. These simple devices register peak stages, which can be recorded after large flows and related to annual measures of stream cross sections (channel morphology) to provide estimates of annual peak and bankfull discharges, flood-recurrence intervals, and several-stream classification characteristics.

Another potential method of identifying changes in stream-channel morphology and fish habitat in the Beaver Kill would be a review of New York State Department of Transportation records and aerial photographs that may document conditions on the flood plain, along the riverbank, and in the streambed before and after construction of NY 17. A complete analysis of these data could help characterize (1) the percentage of river reaches that were truncated and straightened during construction of NY 17, railroad beds, and other roadways; (2) the amount of flood-plain area that was lost through basin development and construction of elevated land structures; (3) the percentage of stream banks that were hardened or armored in recent decades to reduce erosion; and (4) the periods during which sediment may have been deposited or eroded, and channels incised or built up, after major construction activities within parts of the Beaver Kill Basin. Results of these analyses could be of value because a large amount of channel straightening seems to have occurred in the Little Beaver Kill subbasin upstream from the gaging station during the NY 17 construction period (J. Conyngham, oral commun., 1998).

This study ignored a major environmental factor -- stream-water temperature -- which might be altered through increased water temperatures and rates and volumes of summer-storm runoff from the NY 17 road surface. Little is known about the capacity for NY 17 to alter runoff regimes or to affect stream temperatures in parts of the Beaver Kill Basin; increased water temperatures during summer storms could increase thermal stresses on resident fish and decrease the dissolved oxygen concentrations and thereby adversely affect the survival of certain fish species and the health and distribution of their populations. A study of summer thermal conditions (1) at representative stream reaches throughout the basin, (2) in surface runoff from NY 17 and from undisturbed subbasins, and (3) at stream reaches upstream and downstream from runoff sources associated with NY 17, could document the temporal and spatial extent of elevated temperatures that might adversely affect survival and populations of trout and other resident fish species.

An effort to characterize trout survival at selected locations through on site bioassays and(or) population assessments could document (1) the effects of highway-heated storm runoff on trout survival, (2) the thermal limits (temperature thresholds) for trout survival, and (3) the potential effects of thermal episodes on trout populations within this system. These data, and information on the spatial extent of elevated water temperatures, would in turn help delineate the temporal and spatial distribution of adverse thermal conditions resulting from summer-storm runoff from NY 17 in the Beaver Kill Basin.

CONCLUSIONS

Analyses of base flows, discharge-duration curves, stage-to-discharge relations, peak and bankfull discharges, and flow extremes (1-day low and high flows) provide only inconclusive evidence that NY 17 has altered discharge patterns within the Beaver Kill Basin.

Increases in high-flow indices during the period of record at the Cooks Falls site are primarily related to the trends in precipitation and to periodic droughts, but the lack of comparable changes at nearby streamflow-gaging stations, and the absence of a sharp change in the trends after 1965, indicate that these increases were primarily due to continual, gradual shifts of hydrologic processes throughout the basin, rather than to NY 17. These changes probably occurred partly in response to gradual changes in land uses within the Beaver Kill watershed. The increases in high-flow indicators before the construction of NY 17 occurred at about the same rate as they did thereafter, thus, the effect of NY 17 on streamflow of the Beaver Kill, if any, appears to be minimal and could have only augmented existing trends in the basin. The increases in peak flows in the lower Beaver Kill basin during the past 80 years, though only weakly related to NY 17, have probably increased the Beaver Kill's ability to alter channel morphology and sediment transport.

Increases in daily discharge duration and in 1-day high flows, and decreases in annual average base flows and in the ratios of annual average base flows to annual average flows after 1965 at the Little Beaver Kill site, would seem to indicate that hydrologic processes within the subbasin have been altered by NY 17, but this can not be substantiated from the short period of discharge record since the completion of NY 17.

Hydrologic trends at the Cooks Falls and Little Beaver Kill sites in the Beaver Kill Basin since the mid-1960's appear to reflect -- (1) long-term trends and large annual variations in regional precipitation, (2) gradual changes in anthropogenic pressures and natural processes occurring throughout the basin, and (3) changes in high-flow indices that may or may not be related to NY 17. Hydrologic changes in the basin are most clearly indicated by differences in the duration and (or) the frequency of moderate to large discharges that are expressed on a daily (average) or peak (instantaneous) basis.

Though concern over potential changes in trout habitat was the impetus for this investigation, the hydrologic information used by this study could not directly address effects that the above mentioned hydrologic changes may have had on the quantity and stability of habitat and resident trout populations within the Beaver Kill Basin. Future evaluations of the potential effects of NY 17 on stream-channel morphology, trout habitat, and resident fish populations of the Beaver Kill might include documentation of (1) stream discharge and peak flows at additional sites, (2) historical changes in channel morphology and in sediment transport at nongaged sites, (3) the ability of NY 17 to affect summer stream temperatures and the spatial extent of adverse thermal conditions across the basin, and (4) the effects of increased summer stream temperatures on trout survival and on resident trout populations across the Beaver Kill Basin.

SELECTED REFERENCES

Binns, N. A., 1979, A habitat quality index for Wyoming trout streams: Wyoming Game and Fish Department, Fish Resources Report 2, 75 p.

Blackport, R., MacGregor, R., and Imhof, J., 1995, An approach to the management of groundwater resources to protect and enhance fish habitat: Canada Journal of Fisheries and Aquatic Sciences Manuscript Report 2284, 70 p.

Fausch, K. D., Hawkes, C. L., and Parsons, M. G., 1988, Models that predict standing crop of stream fish from habitat variables -- 1950-1985: U.S. Forest Service General Technical Report PNW-GTR-213, 52 p.

Francis, A. M., 1983, Catskill rivers -- birthplace of American fly fishing: Pisscataway, N.J., Winchester Press, 258 p.

Gravlee, G. C. Jr., Lumia, R., Wolcott, S. W., and others, 1991, New York -- Floods and Droughts, in Paulson, R. W., Chase, E. B., Roberts, R. S., and Moody, D. W. (compilers), National Water Summary 1988-89: U. S. Geological Survey Water Supply Paper 2375, p. 415-424.

Lumia, R., 1998, Flood of January 19-20, 1996 in New York State, U. S. Geological Survey Water-Resources Investigations Report 97-4242, 61 p.

Powell, R.O., 1995, Stream channel stability: New York City Department of Environmental Protection, 106 p.

Rutledge, A.T., 1993, Computer programs for describing the recession of ground-water discharge and for estimating average ground-water recharge and discharge from streamflow records: U.S. Geological Survey Water Resources Investigations Report 93-4121, 45 p.

Searcy, J.K., 1959, Flow-duration curves: U.S. Geological Survey Water Supply Paper 1542-A, 33 p.

Simonson, T. D., Lyons, J., and Kanehl, P.D., 1993, Guidelines for evaluating fish habitat in Wisconsin streams: U.S. Forest Service General Technical Report NC-164, 36 p.

U.S. Geological Survey, 1972, Water Resources Data for New York, Part 1: U.S. Geological Survey Surface Water Records, 302 p.

__________, 1982, Water Resources Data --New York, Water Year 1981, Volume 1. Eastern New York excluding Long Island: U.S. Geological Survey Report USGS-WRD-NY-81-1, 330 p.

__________, 1996, Water Resources Data -- New York, Water Year 1994, Volume 1. Eastern New York excluding Long Island: U.S. Geological Survey Water-Data Report NY-94-1, 448 p.