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River Flow Increases In Central New England After the Hurricane of 1938

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ABSTRACT – The New England hurricane of 1938 uprooted or broke off vast numbers of trees in watersheds of the Connecticut and Merrimack Rivers. Annual flow in both rivers increased about 5 inches during the first year after the hurricane. Another 5 inches of increased flow ran off at diminishing rates during the next two or three years. At least half of these flow increases occurred in July, August, and September when streams normally are at the lowest levels of the year. There was no evidence of increased flow five years after the hurricane when forest regrowth was well underway.

Streamflow from small watersheds (up to 1 sq. mi.) is increased by forest cutting and decreased by forest regrowth (*4*). There are, however, only a few observations of such treatment effects on larger watersheds (up to 1,000 sq. mi.). Flow increases here have been correlated with severe insect defoliation (*9*), land clearing (*14*), and forest blowdown (*5*). Continuing forest regrowth was correlated with decreased flow in the Black Hills (*13*) and in the Adirondack Mountains (*5*). Most attempts to correlate land treatments with streamflow will fail (*16*) because flow-increasing practices in one place are nullified by flow-decreasing practices elsewhere. Such failure is virtually certain in New England, where most forest land is privately owned in small parcels, precluding the rapid application of any forest treatment on a scale likely to influence river flow.

The hurricane of September 1938 was an exception, destroying enormous areas of New England forest in a single afternoon. Brooks described some of the storm's effects (*3*):

> The hurricane . . . rushed northward to Long Island and New England with the speed of an express train, augmenting wind velocities to extremes of about 120 miles per hour on the east of the path of the center. . . . The gale . . . broke off or uprooted some 275 million trees (2.6 billion feet of timber) . . . damage was most extensive on the tops and flanks of hills, in and beyond which the wind was funneled. There were also lanes of destruction where a succession of vicious gusts had plowed into the woods, breaking off the first trees or uprooting them from the sodden ground, thereby opening the then unprotected trees to leeward to the destructive attacks of subsequent blasts . . . Mount Washington, even though the storm had weakened when it reached northern New England, experienced gusts with hourly velocities in excess of 118 miles and measured gust velocities of as much as 163 miles an hour. . . .

The hurricane was, in effect, a "forest treatment" of regional proportions. The storm, light in some places but vicious in others, left wind-thrown timber in large and small bodies over some 15 million acres or 35 percent of all the land area in New England (*12*). Windfall was complete (*Figure 1*) on 600,000 acres.

Of central New England's major watersheds — the Androscoggin, Connecticut, and Merrimack rivers — the Androscoggin watershed almost totally escaped severe damage (*Figure 2*). Throughout these watersheds populations usually are less than 100 per square mile (*10*), concentrated along the broader valleys. Lumbering and clearing for agriculture began about 300 years ago, but much farmland was abandoned after 1800 and soon restocked naturally. Lumbering actu-

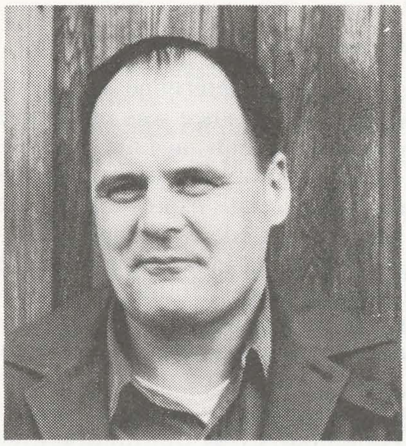

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Figure 1. A relict stand of old-growth white pine near Keene, N. H., was completely blown down by the 1938 hurricane. This photograph, taken four years later, shows dense hardwood reproduction, ranging in height from 4 to 20 or more feet.

ally peaked in 1907 (*6*), drawing heavily on this second generation of trees. But natural restocking continued, and four decades later Baldwin (*2*) reckoned forest regrowth about 20 percent in excess of the annual cut. Now these watersheds are 75 to 100 percent forested (*10*). Northern hardwoods are the common forest cover. Eastern white pine and hemlock are important conifers of the lowlands, with red spruce and balsam fir predominant at higher elevations.

Methods and Data Sources

Two methods were used to determine hurricane effects on river flow. Primary reliance was on double mass plotting of hydrologic events against a meteorological control (*1*). The points on such plottings fall along straight lines when relationships among the hydrologic events are unchanged; a change in hydrologic relationships is reflected in a change in slope of a line connecting plotting points. Initially, cumulative flow for a given river was plotted against cumulative precipitation on that river's watershed, then against cumulative flow from the contiguous watershed.[1] Similarly, double mass plottings of cumulative precipitation or of potential evapotranspiration on contiguous watersheds will show changes in climatic relations.[2] Malmstrom's (*11*) modification of Thornthwaite's procedure provided estimates of evaporative potential, based on average monthly temperature at three stations evenly spaced along each river valley. Finally, regression analysis (*20*) was used to confirm river flow increases detected by double mass plotting.

The data sources also contained other relevant facts concerning these watersheds (*Table 1*).

Table 1. Basic hydrologic information for three watersheds in central New England.

Kind of information	Andro-scoggin	Connec-ticut	Merri-mack
Stream gage location	Auburn, Me.	Montague City, Mass.	Lowell, Mass.
Watershed area (square miles)	3,257	7,865	4,635
Mean annual streamflow (in.)	24.8	23.4	21.4
Year stream gaging began	1928	1929	1923
Number of raingages under continuous observation, 1929-1970	12	38	18
Mean annual precipitation (in.)	43.0	42.3	43.1
Mean annual evapotranspiration (in.)	19.0	20.3	20.8

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[1] Flow data are published in Water Supply Papers (*17, 18*), based on an October 1 to September 30 hydrologic year.

[2] Precipitation and temperature data are published in Climatological Summaries for New England (*19*).

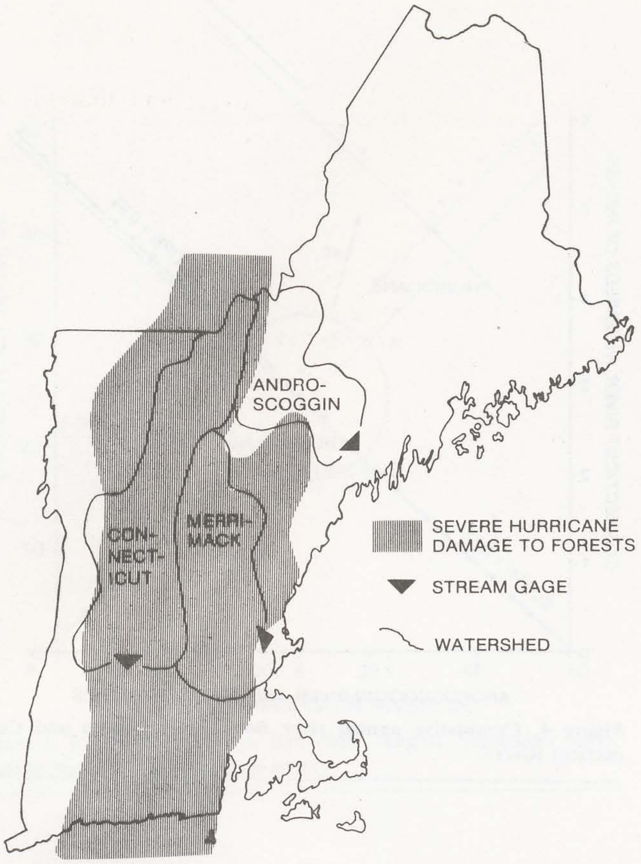

Figure 2. Severe hurricane damage in relation to three central New England forested watersheds.

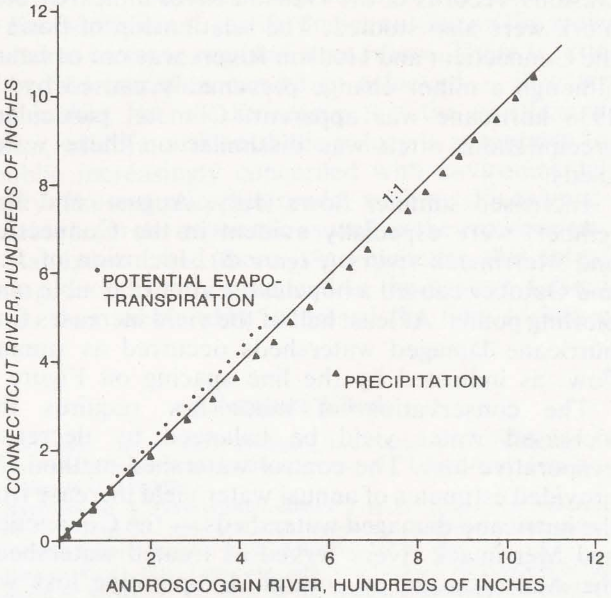

Figure 3. Cumulative precipitation and potential evapotranspiration, Androscoggin and Connecticut Rivers.

Applying the Methods

Preliminary analysis showed no apparent change in the precipitation-river flow relationship for the Androscoggin watershed from 1929 to 1970. But on both the Connecticut and Merrimack watersheds, the 1939-1945 precipitation-discharge relationship apparently changed from that prevailing during the previous 10 years; after 1945 the pre-hurricane relationship was reestablished. The "magnitude" of the 1939-45 change could be varied almost at will by using the records of different raingages or combinations of gages. This effect of inadequate sampling led to use of the entire precipitation record for each watershed.

Double mass plotting points relating precipitation to river flow fell most nearly along straight lines when there was no major population center upstream from the gaging point. For example, linearity decreased with use of flow data from the gaging station at Thompsonville, Conn., where the large industrial-residential developments of western Massachusetts are immediately upstream on the Connecticut River. There is significant import of water into and export from such developments that could alter the natural precipitation-river flow relationship. Flow data from the station at Montague City were advantageously substituted because the Connecticut River watershed upstream from there fell neatly into the central New England region. The same difficulty was encountered using Merrimack River data from Lowell, Mass. About half of that watershed area would be sacrificed to use flow data from Concord, New Hampshire, the last major industrial-residential development upstream. For the Merrimack River, the Lowell gaging site was used anyway to provide another hurricane-damaged watershed comparable in size to the Androscoggin and Connecticut.

Double mass plotting of cumulative precipitation and potential evapotranspiration (*Figure 3*) showed that valley climate along the Androscoggin River was somewhat wetter and cooler than along the Connecticut River. About the same relationship held for the Androscoggin and Merrimack valleys. More to the point, these curves showed no change among climatic relationships on these watersheds, for 10 years before the hurricane or for 15 years afterward.

From 1939 to 1943, about 10 more inches of water drained from the Connecticut River watershed than from the Androscoggin (*Figure 4*). First-year (1939) flow increase was about 5 inches, followed by diminishing increments of increase over the next four years. Analysis of covariance, based on the method proposed by Searcy and Hardison (*15*), showed no difference in slope of mathematically fitted lines describing this river flow relationship during the years 1929 through 1938 and from 1944 through 1953. The post-hurricane shift in level of these lines, however, was significant at the .05 level of probability. A similar plotting of Merrimack vs. Androscoggin flow data provided nearly identical results, although with less linearity of double mass plotting points. There was no evidence of hurricane effects on a plotting of Merrimack vs.

Connecticut River flows, presumably because they responded to hurricane damage similarly.

In an attempt to broaden the base for drawing conclusions, records of the Hudson River in nearby New York were also studied. The relationship of flows in the Connecticut and Hudson Rivers was not constant, although a minor change presumably caused by the 1938 hurricane was apparent. Climate, particularly precipitation, often was dissimilar on these watersheds.

Increased summer flows (July, August, and September) were especially evident in the Connecticut and Merrimack rivers (*Figure 5*). Inclusion of June and October caused a hopeless scatter of double mass plotting points. At least half of the yield increases from hurricane-damaged watersheds occurred as summer flow, as indicated by the line spacing on Figure 5.

The conservation of mass law requires that increased water yield be balanced by decreased evaporative loss. The control watershed method (*20*) provided estimates of annual water yield increase from the hurricane-damaged watersheds — the Connecticut and Merrimack rivers served as treated watersheds, the Androscoggin as control. Evaporative loss was calculated as precipitation minus streamflow (P-RO); subtracting any year's P-RO for the Androscoggin River from that year's P-RO for either hurricane-damaged watershed provided an estimate of decreased evaporative loss. Increased yield and decreased evaporative loss agreed reasonably well in 1939, 1940, and 1941 (*Table 2*) but were not comparable thereafter. Presumably, flow increases and evaporative decreases were too inconsequential four years after the hurricane to be detected by either method.

Table 2. Increased river flow and decreased evaporative loss from hurricane-damaged watersheds. (Inches per hydrologic year.)

	Flow increase		Evaporative decrease	
Year	Connecticut	Merrimack	Connecticut	Merrimack
1939	+4.8[1]	+5.1	−5.8	−5.0
1940	+2.4	+2.9	−1.6	+1.6
1941	+2.5	+3.8	−3.4	−4.2

[1] Significant at the .05 level of probability.

Applying the Results

Where carefully designed experiments on very small watersheds demonstrate the forest influence on streamflow rather clearly, rainfall and streamflow probably are measured close to true values. Since the results reported here were derived from hydrologic data collected for other purposes some limitations are imposed. In addition to the error inherent in most precipitation sampling, a raingage network averaging only one per 250 square miles was insensitive to small differences in watershed precipitation. Furthermore, most of the gages were exposed in valley locations convenient to human habitation, so estimates of watershed precipitation probably are biased to the low side. Even more uncertainty was involved in flow measurement on these major streams. Not only were gaging devices and sites changed from time to time, but streams froze in winter and summer flow was regulated by various storage or diversion facilities upstream (*18*). Because the hydrologic data used in this study probably were accurate to no more than 10 percent of true values, it is gratifying that results as consistent as these were obtained.

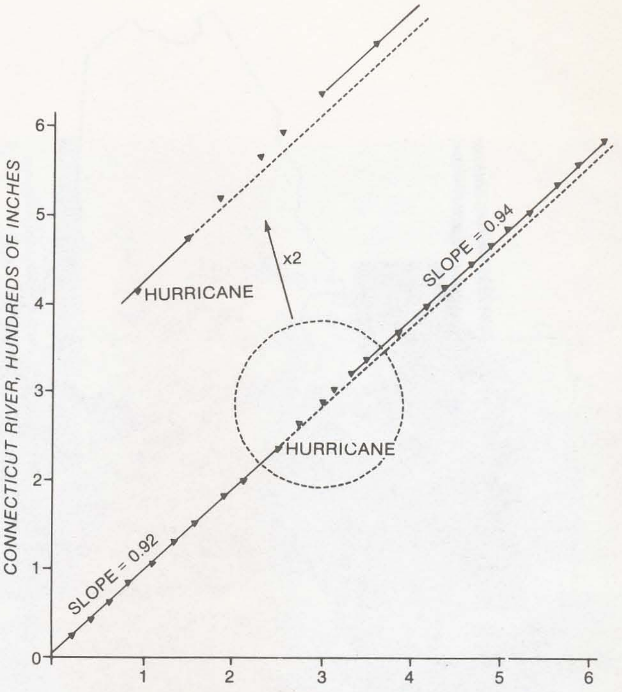

Figure 4. Cumulative annual river flow, Androscoggin and Connecticut Rivers.

Despite these uncertainties, the results do agree with experimental findings on better controlled small watersheds. Complete forest cutting and suppression of regrowth with herbicides at Hubbard Brook, on the headwaters of the Merrimack River, caused a 10-inch average annual streamflow increase during the first three years after treatment (*8*). Estimated first-year flow increase on the Connecticut and Merrimack Rivers, about half this amount, presumes forest destruction sufficient to reduce evaporative losses half as much as they were reduced at Hubbard Brook. The claim cannot be substantiated, but forest destruction by the hurricane probably was of this magnitude. Even if this much forest was not actually uprooted or broken off, many surviving trees were too badly mauled to transpire at full capacity for several years after the hurricane. The fact that the analysis showed flow increases concentrated in the summer months further demonstrates reduced evaporative loss and is consistent with experience at Hubbard Brook.

Relatively short-lived post-hurricane increases in

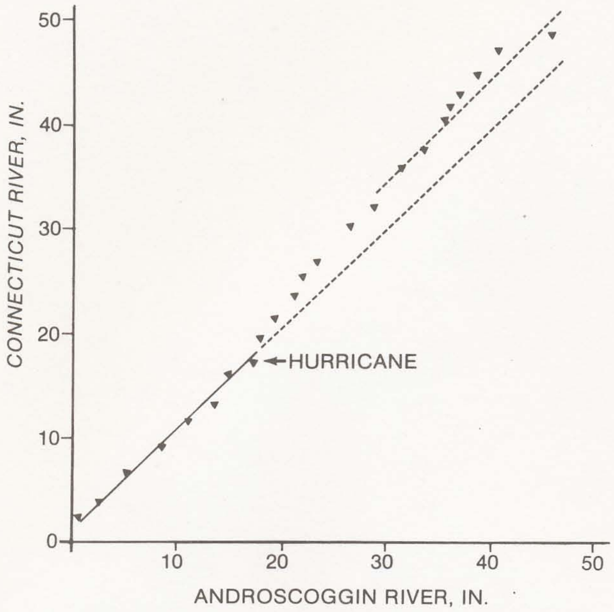

Figure 5. Cumulative summer flow (July, August, September only), Androscoggin and Connecticut Rivers.

river flow were to be expected in this region of luxuriant and rapid forest growth. The predominant hardwood vegetation sprouts vigorously. Seed stored in the forest soil needed only the sun's warmth to start growing. Small to moderate-sized vegetation was little damaged by the wind and grew rapidly, especially on areas where the dominant vegetation had been destroyed completely (see *Figure 1*). Thus, it is reasonable that evaporative loss should return in a few years to pre-hurricane levels. And flow increases probably were not prolonged by fresh cutting. With so much salvageable material on the ground, there was little reason to harvest standing timber for several years. So rapid and complete was natural revegetation that 20 years later no evidence of the hurricane was apparent to the casual observer.

These results reflect an enormous effect of regional deforestation on water resources. For example, a 5-inch increase from the Connecticut River watershed provided an added flow of 2 million acre feet to southern New England. Most of this added flow appeared when most needed in the normally water-deficient months of late summer.

Conceivably, complete deforestation on this scale might well have doubled this yield increase. About 150 years ago, perhaps two-thirds of this region had been cleared for agriculture; this study provides some basis for speculation that river flow then may have been much greater than it is today.

The major value of this analysis may be that it helps place routine forest cutting in a proper perspective with respect to flow increase in major rivers. On the national forests, for example, harvest rotations vary from 75 to 125 years. Thus, during any year, little more than 1 percent of a major watershed will be cut over, and that in small and scattered patches with ample provision for reproduction. Some sort of forest destruction, man-caused or otherwise, is the norm; so is regrowth, and with the two ordinarily near balance, routine forest cutting will do little to decrease regional evaporative losses.

Hewlett (*7*) envisioned a potential water demand in the East sufficient to justify timber cutting on the scale needed to increase regional streamflow. There is little doubt that increases can be so achieved — if water does in fact become so scarce that the sacrifice of timber, wildlife, and aesthetic values is acceptable to a public increasingly concerned with environmental quality. Present priorities render such sacrifices unacceptable from the economic as well as the environmental standpoint. And there is no evidence that forest cutting, as presently practiced in the eastern United States, has measurably increased the flow in larger streams.

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