as they apply to farm operators involved in New York's drainage improvement program is not known.

Conclusion

New York stream channelization projects are not yet widespread, and their statewide impacts have been minimal. However, within a particular watershed, channelization does exert dramatic effects on both the farm economy and the environment. Incorporating environmental concerns into the application of water management technology needs to be emphasized. Presently, there appears to be little interest or economic incentive for modifying outlet drainage procedures to minimize damage to streamside vegetation, reduce drainage of adjoining wetland areas, or create new or enhanced wetland habitats on low-priority agricultural land within project areas. Little is being done to investigate and develop alternative technologies to reduce the need for large-scale outlet ditches. According to the National Research Council (6), "There is urgent need to balance the value of using the most efficient and economical agricultural practices, beneficial to our national welfare, and the value of maintaining or improving...the quality and quantity of fish and wildlife habitats."

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Reforestation reduces streamflow in the southeastern United States

Stanley W. Trimble and Frank H. Weirich

ABSTRACT: Reforestation in the southeastern United States is reducing streamflow over large areas of land. Ten large river basins encompassing 54,000 km² had 10% to 28% of their respective areas reforested between 1919 and 1967. This reforestation reduced water yields in the river basins 3 cm to 10 cm. These reductions constituted a 4% to 21% decline in annual stream discharge, a decline that was statistically significant in a majority of the basins. The streamflow reductions as a result of reforestation tended to be greater during dry years then during wet years.

SMALL increases in forest cover significantly reduce water yields in large river basins of the southeastern United States. Further water shortages are forecast for the humid portion of the United States within the next few decades (2, 5, 9), and much of that area is forested.

Experimentation on small river basins has shown that forested areas, because of additional evapotranspiration, consume considerably more water than do similar nonforested areas. Runoff and water supplies decline as a result (*1*, *3*, *5*, *6*). Based on such experimental data, further afforestation is already banned in parts of Scotland because of anticipated runoff losses (J.S.G. McCulloch, written communication, September 6, 1983).

To date there have been no studies documenting runoff reductions as a result of afforestation within large stream basins (*3*). Such studies clearly are needed before American forests will be managed to increase water yields (*4*).

Bosch and Hewlett (*1*) indicated that small changes in forested area do not affect runoff in small experimental basins, suggesting that forest cover changes over less than 20% of the forest area apparently cannot be detected by measuring streamflow. However, we report herein that the effects of reforestation in 10% to 28% of large, populated stream basins in the Southeast were not only detectable but water yields declined 4% to 21%, amounts that were statistically significant in a majority of the basins (*8*).

The study region and methods

For our analysis we chose the Southern Piedmont, an area that has undergone dramatic transformation during this century from clean-cultivated row crops to forest and pasture (*7*). Ten basins in Alabama, Georgia, and South Carolina were selected. Our relations were based on availability of adequate streamflow records, both during the early part of this century (generally, 1900-1940) and more recently (generally 1955-1975), when forests have become more widespread (Table 1).

Streamflow adjustments were made for the more recent period to compensate for other water losses, such as reservoir and farm pond evaporation, domestic and industrial water consumption, and interbasin transfer. But these adjustments were slight, not exceeding an area depth of 1.37 cm in any basin.

Basin sizes ranged from 2,820 km² to 19,450 km²; total area was 54,020 km² (Table 1). Precipitation data were from U.S. Weather Bureau records, stream discharge records were from the U.S. Geological Survey, and land use records were from the U.S. Census of Agriculture and the U.S. Department of Agriculture.

We constructed regression models for each period to characterize the difference in

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streamflow for a given precipitation value. Most regression lines had high correlation coefficients, and the differences between the two time periods were significant at 5% in 5 of the 10 basins (Table 1). In each basin the relative slopes of the regression lines were influenced greatly by the degree to which streamflow was regulated by reservoirs. This occurred because of storage carryover from year to year.

Less regulated streams were characterized by regression lines converging at greater precipitation values. This tendency was evident in six basins, but was statistically significant in only two: the Tallapoosa and the Oconee at Greensboro (Figure 1A). For the latter the regression lines indicated about 9.9 cm less annual streamflow during the later period than for the earlier period, assuming an average precipitation of 128 cm. But the convergence of the lines indicated that there would be little difference in streamflow with precipitation ≥178 cm (Figure 1A).

The divergence of the regression lines at lower values of precipitation suggests that forests have a greater relative and absolute effect in dry years. The physical explanation for this divergence may lie in the availability of surface soil moisture: during dry years, trees draw moisture from considerable soil depths, while the dry surface soils of cultivated fields permit little evaporation. Conversely, the more or less continually wet surface of cultivated fields may have evaporation rates as high as the combined evaporation and transpiration rates of forested areas, so there is little difference in runoff during wet years. Greater water losses due to forest cover thus occur during drought, when human water needs are greatest.

Although regression analysis is a good diagnostic tool for the less regulated basins, it is of limited value in cases where a decrease in slope of the regression line is caused by a high degree of regulation. An example is the Chattahoochee at Norcross, which is now highly regulated by the Lanier Reservoir (Figure 1B).

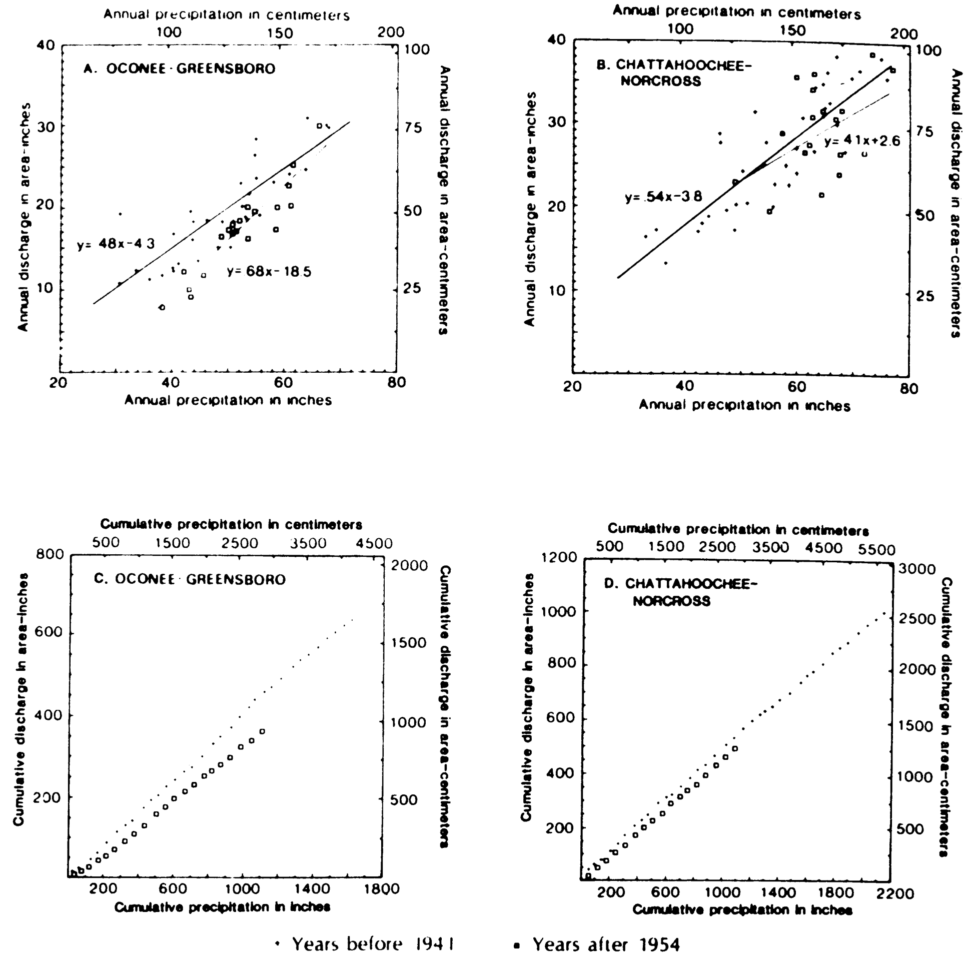

Figure 1. A & B: Regression analysis, annual discharge versus precipitation for old and recent periods. C & D: Double-mass analysis, cumulative discharge versus cumulative precipitation for old and recent periods.

For corroboration we turned to another statistical technique, double-mass analysis, that would be less compromised by change of stream regime. The difference between cumulative streamflow and cumulative precipitation is the water deficit assumed to be the result of reforestation. The Oconee at Greensboro, for example, had an annual reduction of 9.4 cm, which compared well with the value of 9.9 cm obtained by regres-

Table 1. Stream basins studied, degree of reforestation, and reductions in water yield.

River and Gaging Station	*Ocmulgee at Macon*	*Oconee at Milledgeville*	*Flint at Culloden*	*Oconee at Greensboro*	*Chattahoochee at West Point*	*Savannah at Augusta*	*Tallapoosa at Wedley*	*Chattahoochee at Norcross*	*Saluda at Columbia*	*Saluda at Silverstreet*
Basin area, km²	5,800	7,640	4,790	2,820	9,195	19,450	4,300	3,030	6,500	4,200
Dates of collection	1900-10, 12, 29-40 1955-75	1904-32 1955-75	1912-22, 29-30, 38-40 1955-75	1904-32, 37-40 1955-75	1900-40 1955, 59-75	1900-06, 26-40 1955-60, 62-70, 72-75	1923-40 1955-75	1902-40 1955-75	1929-39 1955-75	1927-39 1955-66
Percent of area reforested	27.5	27.5	25.7	21.3	20.0	15.4	11.8	11.0	10.5	9.7
Average runoff, cm	43.1	40.4	46.7	47.0	57.0	47.5	53.3	70.0	41.0	49.6
Regression analysis										
Decrease of water yield, cm	3.6	5.8	6.35	9.9	3.8	8.9	2.5	2.8	6.6	4.8
Percent decrease	8.4	14.4	13.6	21.0	6.7	18.7	4.7	4.0	16.1	19.6
Probability*	.09	.01	.01	.01	.07	.05	.06	.20	.05	.28
Double-mass analysis										
Decrease of water yield, cm	3.8	6.1	4.8	9.4	4.3	5.6	2.8	6.1	6.9	6.1
Percent decrease	8.8	15.1	10.3	20.0	7.5	11.8	5.3	8.7	16.8	12.3
Probability†	.01	.01	.01	.01	.01	.01	.05	.06	.05	.01

*Anaylsis of covariance, dummy variable
†Analysis of covariance

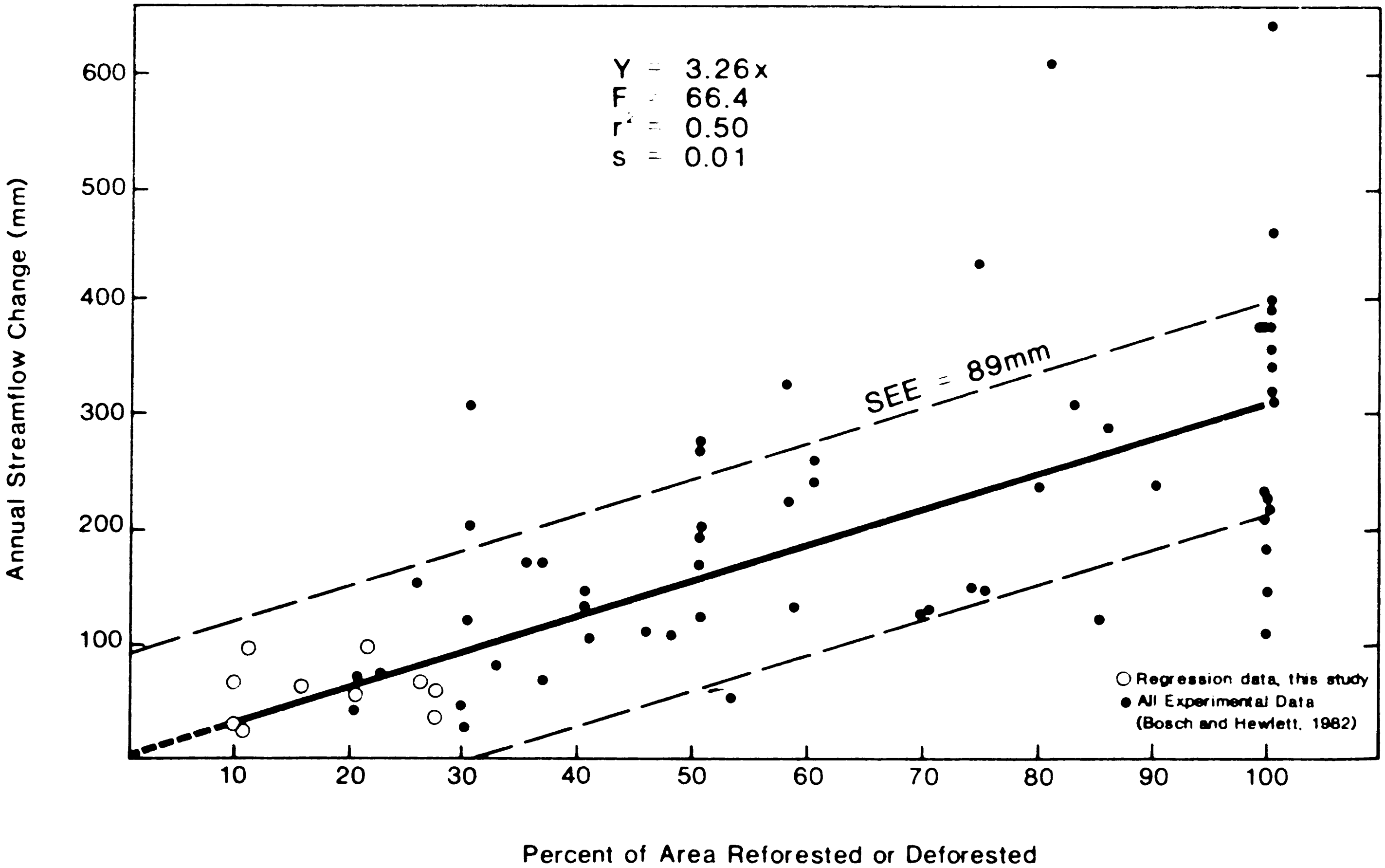

Figure 2. Change of forested area versus change of water yield, combined data set including 55 experimental forest basins (5) and the 10 basins from this study using regression data. If the regression data are replaced by the double-mass data from this study, the same r^2 results.

sion analysis. Several other basins produced similar results (Figure 1, C&D; Table 1). The greatest relative difference, as expected, was between regulated and unregulated basins.

All basins in our study have experienced appreciable afforestation and have mostly shown significant reductions in water yield. However, there is little relation between the degree of afforestation and reductions in water yield at the scale of this study. When the results of our study are placed within the context of 55 controlled experiments on small basins world-wide (*1*), the relative variance is less than that encountered in experimental watersheds (Figure 2). Most importantly, the range of the predictive equation is extended from 20% cover change to less than 10%, a range deemed unmeasurable in controlled, paired-basin experiments (*1, 3*).

Nevertheless, it appears from our work that reforestation effects not detectable by measurements on small headwater streams (<200 ha) may be detected in cumulative flow from large basins, or by regressing annual streamflow on annual precipitation for several years. Finally, the inclusion of our data (regression *or* double-mass) increased the r^2 from 0.38 (for experimental data alone) to 0.50. Our results thus extend the range and predictive power of the universal model, giving it greater utility for water yield planning.

Conclusions

Relatively small increases in forested land (10%-28% of total basins) within populated stream basins significantly reduced water yields in a large part of the southeastern United States. This remained true over large areas for long time periods, thus empirically corroborating and extending the results of 70 years of water yield experiments in small basins. The additional loss of water due to forest cover is about 0.3 m^3 per m^2 of land reforested, or about 325,000 gallons of water per acre. As a result, average streamflow has been reduced 4% to 21%. This consumptive use and reduced water yield may become more significant as demand increases for water supplies, hydroelectric power, navigation, and diluting polluted waters.

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