Reforestation Influences on Small Watershed Streamflow

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Abstract. Analysis of flow duration curves showed that reforestation of a 44-acre watershed near Coshocton, Ohio, reduced flow in the low flow tail of the curve but did not significantly reduce flows above 0.25 inch per day. Other analyses showed that reductions also occurred in the maximum annual flow volumes for all periods of flow durations of 1 day or longer. The onset of dormant season flow was significantly delayed.

Data from a 43.6-acre watershed at the North Appalachian Experimental Watershed have been the subject of several analyses during the past decade. About 70% of this watershed was reforested to pines in 1938 and 1939, whereas the remainder was left in uneven age hardwoods. The latest analysis [Ricca et al., 1970] concluded that the effects of land use and treatment changes initiated in the late 1930's had essentially become complete and that the watershed had stabilized in its new flow regime.

Previous reports on the hydrologic effect of reforestation at Coshocton have not been completely comprehensive. Evaluation of the effects concentrated mostly on seasonal and annual water yield and peak flows. Evaluation of the effects on other hydrologic phenomena appeared to be worthy of additional study. The significant reductions found in annual and seasonal streamflow amounts [Ricca et al., 1970] should be reflected by changes in flow duration curves, and a study was designed to assess such changes if they did exist.

Some uncertainty existed about the nature of the relationships between duration of flow and the significance of streamflow reduction due to reforestation. There was not much question that reforestation had reduced annual and seasonal streamflow, but there was no apparent reduction in peak rates of flow due to reforestation [Ricca et al., 1970]. A study was designed to investigate the relationships for durations between these extremes of seasonal and peak flows.

Still another analysis was set up to shed some light on possible changes in streamflow timing. Earlier studies [Harrold et al., 1962] indicated that reforestation might cause the soil moisture reservoir to dry up during the summer season. Thus, there should be some delay in the beginning of fall streamflow while this reservoir was being replenished.

WATERSHEDS

The two small watersheds examined in this report are located at the North Appalachian Experimental Watershed near Coshocton, Ohio. The topography is rolling to hilly with good surface drainage. Soils are residual with topsoils of 6-8 inches. Geological strata are sandstones, shales, clays, coals, and limestones of the Allegheny and Pottsville series of the Pennsylvanian system. Precipitation averages about 37 inches and is well distributed throughout the year. Of this, about 2 inches falls as snow.

Pine trees were planted on 70% of the 43.6-acre watershed in 1938 and 1939, whereas the remaining 30% of the area was left in hardwoods of different ages. Precipitation and runoff were measured continuously on this reforested area as well as on the 303-acre agricultural watershed, which was 4000 feet away and which served as a control. By about 1945, the trees had formed a complete ground cover, small gullies had stabilized, and the main stream bank and bed were the only remaining sources of sediment. There have been no disturbances due to fires or grazing.

The 303-acre agricultural watershed that served as a climatic index had about 40%
rotation cropland, 30% permanent grassland, and 30% woodland. Farming practices were about at the level of an average farmer in the area, and crop yields were close to the county average. Conservation farming practices were not used. Some changes had been made as a result of new crop varieties and fertilizer mixtures, but farming intensity was not much different from the level obtained in the late 1930's.

Most important is the fact that measured runoff at both gages included most or all groundwater flow [McGuinness et al., 1961]. The measuring devices were located on impervious geologic formations. Geologic investigations have shown that there was little likelihood of any subsurface inflow or outflow escaping measurement on either watershed.

**PREVIOUS WORK**

**Coshocton station.** Early analyses of the 1938–1957 data included those of Hill [1960], Harrold [1960], Brakensiek and Amerman [1960], and Harrold et al. [1962]. These analyses showed that reforestation sharply reduced surface runoff and thus gave an increased infiltration potential. Flow expected in the nineteenth year after reforestation was about 5.3 inches less than in the initial year. Lysimeter and groundwater level data indicated an increase in soil moisture use with a subsequent decrease in percolation potential. Almost 70% of the streamflow reduction was in the November–April dormant season. Reductions in high daily flows and in low daily flows were found in both the dormant and growing seasons. Some reductions were found in peak rates but not in the extremely high rates.

The next study [Mustonen and McGuinness, 1968] showed that the time trend of annual flow volumes on the wooded watershed had changed from linear. Mustonen and McGuinness did an annual water balance on both the control and reforested watersheds for the 1939–1964 period. Plottings of annual evapotranspiration (ET) values from the reforested watershed showed that ET increased by about one-third during the 1939–1950 period and leveled off thereafter, whereas no time trend was apparent on the control watershed ET plotting.

A comprehensive analysis was recently performed on the 1938–1967 data by Ricca et al. [1970]. The study confirmed the general findings of earlier studies but also showed that the hydrologic changes caused by reforestation had essentially become complete. Time trends were fitted by the hyperbolic equation

\[ Y = A + \left( \frac{B}{T} \right) \]

where \( Y \) is the independent variable, \( T \) is the time in years from the start of the study, \( A \) is a constant representing the new equilibrium rate, and \( B \) is a regression coefficient.

**Other experiments.** Hibbert [1967] reviewed results from 39 studies on the effects of altering forest cover on water yield. Four of these, other than the Coshocton study, dealt with reforestation effects, and the results of these studies are summarized below.

In South Africa, the Bosboukloof watershed was 53% reforested to pine in 1940. Streamflow decreased as the plantation became mature [Banks and Kromhout, 1963]. The Biesievlei was 98% reforested to pine in 1948 and again streamflow decreases coincided with plantation maturity [Banks and Kromhout, 1963].

On the very deep soils of the Pine Tree Branch watershed in western Tennessee, both water yield and peak flows decreased after 75% reforestation [Tennessee Valley Authority, 1968]. The White Hollow watershed with shallow soils showed reduced peak rates in the summer season but no change in water yield after 34% of the watershed was reforested.

Schneider and Ayer [1961] examined data from three small partially reforested (35–55%) watersheds in central New York. Dormant season runoff was reduced on all three areas. Growing season reductions were found only in the Shackham Brook watershed. Here, peak flow rates were significantly reduced in the dormant season. The authors attributed the observed changes in the amount and timing of streamflow to interception and shading of snow by the coniferous plantings.

Water yield in the Sacandaga River watershed was reduced as forest basal area increased over a 39-year period ending in 1950 [Eschner, 1965]. In 1950, the forest stand was reduced by a severe storm, and streamflow subsequently increased. Changes occurred mostly in the dormant season and were attributed to changes in interception.

In assessing the results of the above studies
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Plus available Coshocton data, Hibbert [1967] suggested that water yield decreases due to reforestation might average 220 mm times the percentage of area reforested. He also assumed that the decrease in water yield after forest regrowth would be about the same as the increase from cutting and presented data from Coweeta to substantiate this viewpoint.

Shortly after Hibbert's [1967] review was assembled, Satterlund and Eschner [1965] made a detailed study of timing of flow on the Shackleham Brook watershed in central New York. They found that concentrated snowmelt runoff came later in the season in the years following reforestation.

Lull and Sopper [1966] used multiple regression techniques to evaluate the influence of various climatic, topographic, and land use variables to streamflow in the Northeast. Surprisingly, the percentage of watershed area in forest cover was correlated positively with runoff, and the authors concluded that forest areas are more common on land where greater runoff is natural, i.e., steep slopes, shallow soil, and so on.

Reinhart [1970] in a recent review of the effects of deforestation and reforestation pointed out that the effects of these two processes are opposite; i.e., reforestation effects occur gradually over time, are harder to measure than the effects of deforestation, and are less well documented.

CURRENT STUDY

Studies reported in this section were designed to answer three questions. (1) Are flow duration curves useful in assessing the hydrologic effects of reforestation? (2) As periods of flow duration are made shorter, at what point does the effect of reforestation in reducing maximum annual flow become insignificant? (3) Has reforestation delayed the date in the fall when streamflow normally increases in volume?

**Flow duration curves.** Standard flow duration curves for the reforested and control watersheds are given in Figure 1. These are total period curves covering the record from May 1, 1939, through April 30, 1968, and are computed by the method given by Searcy [1959]. The graph has logarithmic probability coordinates, and the closeness of the data points to a straight line indicates that the daily flow data may well be distributed in log probability fashion.

These flow duration curves are an overall representation of flow on the two watersheds. The flow regimes on the watersheds differ, but there is no clue as to whether the differences are due to fixed watershed parameters, such as the size of the watershed area and geologic differences; or to dynamic parameters, such as differences in climatic factors; or to the influence of land use and treatment. The analytical objective is to isolate the effect of land use and treatment on the different flow regimes.

First, daily flow volumes on each watershed were arbitrarily separated into high flows (0.25 inch per day and above), low flows (0.05 inch per day and below), and intermediate flows (0.06-0.24 inch per day).

Figure 2 is a sample plotting of the low flow data from the two watersheds for a single water year. The data are plotted in rectangular coordinates to facilitate computations of differences in flow volumes between curves for the two watersheds. The area enclosed between the two curves represents the volume of low flow by which the climatic index watershed exceeded the reforested watershed during this particular 12-month period.

Fig. 1. Flow duration curves for climatic index and reforested watersheds.
A series of calculations was made to determine the difference in volumes of low flows from the two watersheds for the 29 water years between May 1, 1939, and April 30, 1968. Each of these 29 differences in volumes is made up of three parts: (1) inherent differences in the low flow regimes of the two watershed areas (differences that are not expected to be time variant), (2) differences due to spatial variation in climate between the two areas (differences that should be minimal owing to the close proximity of the two areas), and (3) differences due to the effect of land use and treatment. Thus, if there is a significant temporal relationship with the volume differences, it should be due to the effect of land use and treatment.

A series of volume differences from the high flow regimes was also derived in the same manner as that for the low flows. The intermediate flow regime differences were then obtained by subtracting low flow and high flow volumes from the total water year flow.

Regression analyses were performed on the differences in high flow, intermediate flow, and low flow regimes, and the results are given in Figure 3. A hyperbolic function was fitted to the data where pertinent. Reforestation significantly reduced both low and intermediate flows and also decreased high flows but not significantly so.

Maximum flow volumes for selected time intervals. Previous studies [Harrold et al., 1962; Ricca et al., 1970] showed that the effect of reforestation was most pronounced for annual and seasonal flow volumes but that the effect of treatment became vague as the duration period under consideration became shorter. In an effort to clarify this effect, an analysis was made of the annual maximum flow volumes for selected time intervals. Annual maximum flow volumes from the climatic index watershed were tabulated for selected periods from 1 hour to 6 months. Flow volumes occurring on the reforested watershed during the same time period as that for the maximum flows of the climatic index watershed were then listed. For instance, if the maximum 12-hour volume on the climatic index watershed in 1960 started on June 13, the volume tabulated for the reforested watershed would be the maximum volume occurring in 12 hours during that same storm period. Thus, the pairs of values analyzed were the annual maximum volume on the climatic index watershed and the maximum volume for the same duration in the same storm on the reforested watershed.

The analysis for each duration period con-
sisted of a multiple regression using the runoff from the reforested watershed as the dependent variable with time and climatic index watershed streamflow amounts as independent variables. From this, the partial correlation coefficient was calculated for the relationship of reforested flow and time, allowance having been made for the climatic variation as indexed by climatic index watershed flow. Details of the analytical method are given by Brakensiek and Amerman [1960].

Results of the analyses are given in Figure 4. For all durations from 1 day to 6 months, the correlation coefficients of adjusted reforested flow volumes with time are statistically significant. Reforestation has reduced near-maximum annual flow volumes for durations of 1 day or more over the years. No evidence of curvilinearity was found in any of the duration periods, and only linear functions were fitted to the data.

Timing of flow. Small watershed streamflow at Coshocton displays a cyclical pattern on an annual basis with the February–April months having several times more volume than the lowest flow months, August–October [McGuinness and Harrold, 1962]. By the end of the summer season, soil moisture has been depleted [Mustonen and McGuinness, 1968] and must be replenished before significant increases in streamflow will occur. Reforestation extended the root zone downward, and increasing amounts of moisture were required to fill the root zone reservoir as the period after tree planting increased [Harrold et al., 1962]. Thus the date in the fall when streamflow normally increases in volume might be delayed owing to the effects of reforestation.

Court [1962] suggested that the timing of the flow of a stream may be described well by its half-flow date, the date on which half of the annual streamflow has passed the gage. He used a water year starting October 1 and showed that the half-flow date was sensitive to changes in flow regime. The modification of Court's technique described below was used to develop information on changes in streamflow timing due to reforestation.

For each year, November 1 through April 30 dominant season tabulations were made of the dates when flow reached 10% of the seasonal total on both the climate index and reforested watersheds. Plottings of these two variables are given in Figure 5. The climatic index watershed data were again considered to be an index of climatic variation. The influence of climate was then removed from the reforested watershed values by regression techniques explained in the preceding subsection, and the adjusted reforested values were analyzed for trends with time. Results are given in the bottom diagram of Figure 5.

After adjustment for the influence of climate, the relationship of 10% flow dates to time \( r = 0.49 \) was highly significant. The flow date was delayed 1.08 days/yr over the 29-year period of record. Reference to the bottom diagram of Figure 5 shows that the expected 10% flow date was January 6 in 1940 and 29 years later it was delayed 31 days \((1.08 \times 29)\) until February 6. The correlation of unadjusted reforested values with time \( r = 0.32 \) and of the climatic index watershed with time \( r = 0.06 \) was not statistically significant.

Again, in these data there was no evidence of curvilinearity, although it is obvious that trends like these cannot continue indefinitely.
The first question considered was whether any inferences can be drawn on the effects of reforestation through an examination of flow duration curves. Searcy [1959] defined the flow duration curve as a cumulative frequency curve showing the percent of time specified discharges were equaled or exceeded during a given period. He found that geologic differences were reflected in the low flow ends of the curves from adjacent basins.

It seems obvious from Figure 3 that flow duration curve analysis can be a useful technique in assessing land use and treatment effects. In this case, the flow was divided arbitrarily into three classes. Further subdivision could be used to define more closely the regime where reforestation effects became important. Separation of the data by seasons might also be important in pinpointing effects.

The reductions in the low and intermediate flow regimes due to reforestation (Figure 3) appear to have been made in the period up to about 1950, after which little time trend is seen. The validity of these patterns tends to be confirmed by the analysis of Mustonen and McGuinness [1968], which showed that the increase in evapotranspiration on the reforested watershed also stabilized at about this time.

Schneider and Ayer [1961] in their examination of the effects of partial reforestation in central New York rejected flow duration techniques as an analytical method because no rigorous statistical comparisons could be made of data arrayed in this manner. Such rejection is no longer warranted.

The second part of the study dealt with defining the periods of flow duration where the effect of reforestation was significant. Reforested watershed adjusted flow is significantly correlated with time for all durations of 1 day or longer (Figure 4). These longer duration flows are usually the result of dormant season rains, which have little areal variability over the distance of 4000 feet between the two study watersheds. Storm rainfall inputs for these storms were quite similar; thus time trend analyses represented primarily the effect of reforestation.

For durations of 1–12 hours, maximum annual flow volumes usually result from convective summer thunderstorms, which are notable for striking spatial differences. Storm rainfall input differences for these two watersheds could have
been large enough to decrease the time trend correlation coefficient on the reforested watershed. Differences in the dormant and growing season spatial variability of storm rainfall over the two watersheds may, therefore, be the major factor in the shape of the correlation coefficient graph of Figure 4.

The delay in timing of dormant season flow from the reforested watershed (Figure 5) is in accord with the nature of the hydrologic effect of reforestation. By the end of the growing season, the deeper root system of the reforested area caused the soil profile to dry out to greater depths than the generally shallower root system of the climatic index watershed. Through the years, the root system of the pine seedlings deepened and proliferated and thereby withdrew soil water to greater depths so that more and more of the early dormant season precipitation was required to recharge the profile before aquifer recharge could begin and seepage flow to streams could increase. Thus, the beginning of significant runoff in the fall was more and more delayed.

The modification of Court's [1962] technique used in this report seemed well suited for investigating streamflow timing. Satterlund and Eschner [1965] modified Court's [1961] half-flow interval to be the shortest interval during winter-spring and to contain half the annual streamflow. The modified interval was a more precise measure of the degree of concentration of runoff than the original half-flow interval and worked well in the central New York area where snowmelt is a major factor. This modification did not seem to be as well suited to the Coshocton data where the emphasis was on detecting changes in the onset of runoff in the fall.

In each of the studies reported herein, a climatic index watershed was used to reduce the variability of the reforested watershed data. It was not necessary that the climatic index watershed be absolutely stable in time. The climatic index watershed at Coshocton displayed a slightly negative (but not statistically significant) relationship of annual runoff with time. This may be due to the trend of annual precipitation (which was also slightly negative but not statistically significant), to a gradual rise in the level of agricultural technology over the years, or to both. In any event, the method of adjusting reforested watershed values to remove year to year fluctuations due to climatic variations was such that these slight negative trends were also removed regardless of their cause. Thus, the assessment of the influence of the effects of reforestation was on the conservative side.

CONCLUSIONS

Reforestation has resulted in a reduction of low and intermediate flows, in a reduction in maximum annual flow volumes for all durations of one day or greater, and in a significant delay in the onset of dormant season flow. The studies point up the necessity of operating experimental watersheds over a sufficient period of time for gradual trends to become apparent. Termination of gaging after the 1957 analyses were completed would have left us with much less insight into the hydrologic effects of reforestation than is now available.

REFERENCES

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