Factors Affecting Large Peakflows on Appalachian Watersheds: Lessons from the Fernow Experimental Forest

James N. Kochenderfer
Mary Beth Adams
Gary W. Miller
J. David Helvey
Abstract
Data collected since 1951 on the Fernow Experimental Forest near Parsons, West Virginia, and at a gaging station on the nearby Cheat River since 1913 were used to evaluate factors affecting large peakflows on forested watersheds. Treatments ranged from periodic partial cuts to complete deforestation using herbicides. Total storm precipitation and average storm precipitation intensity were the most significant variables affecting peakflows, and were far more important than timber harvesting activities. Since January 1913, of the 20 highest-ranked peakflows on the Cheat River at the Parsons gaging site, 11 have occurred since 1984 during a period of limited timber harvesting. These results support earlier findings that forests do not prevent floods and that prudent forest harvesting operations do not increase large flood peakflows.

The Authors
JAMES N. KOCHENDERFER and MARY BETH ADAMS are, respectively, research forester (retired), and, project leader/research soil scientist with the U.S. Forest Service’s Northern Research Station at Parsons, West Virginia.

GARY W. MILLER is a research forester with the Northern Research Station at Morgantown, West Virginia.

J. DAVID HELVEY (retired) was a project leader and research hydrologist with the Northeastern Forest Experiment Station at Parsons, West Virginia.

Cover Photos
Top: stormflow from a 3,355-acre forested watershed on the Fernow Experimental Forest after 1.33 inches of rain fell in March on 8 inches of snow. Bottom: baseflow from the watershed in May at the same location.

Manuscript received for publication 1 March 2007
INTRODUCTION

A common misconception, often repeated by the lay public and professional land managers, is that floods are associated with timber harvesting. As far back as 1863, G.P. Marsh proposed in “Man and Nature” that flooding is affected by forest clearing (Hewlett and Doss 1984). The controversy over the influence of forest harvesting on streamflow regulation continued into the early part of the 20th century (Dodds 1969). Despite a dearth of scientific evidence at the time, conservationist Gifford Pinchot, when asked at a Congressional hearing whether floods along southern Appalachian rivers were traceable to the denuding of forests, replied: “Directly, directly…It is a perfectly clear cut proposition” (House of Represent. 1907).

The possible relationship between forest clearing and flooding gained national attention in March 1907 when heavy rains in the headwaters of the Monongahela River were blamed for flooding at Pittsburgh, Pennsylvania. The flooding caused millions of dollars in property damage (McKim 1970), and flooding was attributed to excessive cutting and burning of forests in the watersheds of the Allegheny and Monongahela Rivers. After reviewing the historical records, Kite concluded that the Cheat River, a major tributary of the cut and burned watersheds, apparently contributed little to the flood. His conclusion is supported by a lack of evidence of flooding in community newspapers, such as the Parsons Advocate, during March 1907. This small community was located on a flood plain at the convergence of two rivers forming the Cheat River, the second largest tributary of the Monongahela River, downstream from some of the most severely denuded forest land in the East.

On the other side of the forest-flood issue was Colonel H. M. Chittenden (1909), a member of the U.S. Army Corps of Engineers. He disagreed with Pinchot, arguing that “periods of long-continued, wide spread and heavy precipitation alone cause great floods in large rivers.” Chittenden added that during such periods, “The forest bed becomes completely saturated, its storage capacity exhausted, and it has no more power to restrain floods than the open country itself.” He proposed that engineering solutions such as reservoirs, levees, the clearing of river channels, and raising grades were necessary for flood protection.

Although the controversy surrounding the degree of control that forests exert on streamflow would continue for many years (Dodds 1969, Anderson et al. 1976), on March 1, 1911, Congress passed the Weeks Law, which authorized “the purchase of forested, cut-over, or denuded lands within the watersheds of navigable streams necessary to the regulation of the flow of navigable streams.” This law authorized government agencies to purchase land after state consent, which eventually became the national forests of the Eastern United States.

During the next several decades, forest research stations were established to better understand how to manage forests to achieve multiple objectives, including a dependable supply of clean water. As part of this effort, watershed research was initiated in 1951 on the Fernow Experimental Forest near Parsons, West Virginia (Fig. 1). Results from watershed studies at such research stations including the Fernow refuted commonly held concepts about forests and water. For example, the once popular notion that cutting trees causes springs to dry up (e.g., Maxwell 1894) and reduces streamflow was disproved (e.g., Hibbert 1967, Hornbeck et al. 1993). Other research demonstrated that cutting trees actually increases streamflow temporarily, particularly during growing seasons, because water losses to interception and
transpiration are reduced, thereby increasing soil moisture and streamflow. Still other research demonstrated that reforestation of abandoned farmland on large drainage basins in Massachusetts (Patric and Gould 1976) and the southern Piedmont (Trimble et al. 1987) reduced streamflow.

Some of this research also focused on peak stormflows and flooding. Perhaps the most widely quoted study on the relationships between forests and floods was that of Lull and Reinhart (1972). They concluded that:

- “The forest, because of its full occupancy, provides for any site a maximum opportunity for controlling runoff from flood-producing rainfalls; even so, the forest cannot prevent floods.”
- “Infiltration capacities of the forest floor are almost everywhere greater than rainfall intensities.”
- “The forest is the best of all possible natural cover for minimizing overland flow, runoff, and erosion.”
- “With reasonable care, the forest can be cut with little detriment to its site-protective capacity.”

Hewlett (1982a) supported those findings, stating that “forest operations do not seriously increase flood flows in major streams.”

More than 90 years after the Pinchot-Chittenden debate, and despite much significant research, the perceived relationship between forests and floods continues to exert
a major influence on land-management decisions in the United States. Recent floods in West Virginia have again raised concerns that land-use activities such as timber harvesting are influencing the frequency and magnitude of flood events. This is not surprising because forests currently cover 78 percent of the State (Griffith and Widmann 2003) and timber harvesting is widespread, occurring on an estimated 235,000 acres in 2005, according to the West Virginia Division of Forestry.

Since the impacts of various kinds of timber harvesting and other land uses on streamflow have been evaluated on gaged watersheds on the Fernow Experimental Forest since 1951, we felt that an evaluation of Fernow data for large storms would provide timely and useful information. We assembled a data set of peak streamflows for the 50 largest storms between 1951 and 2004 for seven watersheds on the Fernow (http://www.fs.fed.us/ne/parsons/webdata/data/downloads). Although much of our present knowledge about forest hydrology has been obtained from experimental watersheds (Hewlett et al. 1969), caution should be used when extrapolating results from studies evaluating timber harvesting impacts on peakflows from small (fewer than 100 acres) experimental watersheds to large river basins containing thousands of acres. Entire research watersheds typically are subjected to the same treatment in short timespans so that the impacts of various forest practices on the quantity and quality of streamflow can be evaluated (e.g., Reinhart et al. 1963). In reality, entire watersheds of major streams are not subjected to these same intense land-use practices. Patterns of land ownership and multiple management objectives ensure a variety of uncoordinated management activities on larger watersheds. For example, timber harvesting activities, which occur on about 2 percent of the forest land in West Virginia each year, usually are confined to small portions of larger watersheds. A review of West Virginia Division of Forestry Timber Harvest Notification forms submitted between 2000 and 2006 on the 462,080-acre Cheat River watershed above Parsons revealed that annual harvesting occurred on less than 2 percent of the watershed.

Also, such harvests typically remove only part of the vegetation (selection or diameter-limit harvests). The effect of harvesting will differ from those due to deforestation or conversion to other land uses (Hornbeck 1973). The regrowth of eastern forests is so rapid and vigorous that the effects of timber harvesting on streamflow diminish rapidly (Hornbeck et al. 1993). In this paper we focus on the impacts of forest management activities on peakflows and flooding. Our objectives were to: 1) use peakflow data from the Fernow Experimental Forest to evaluate dominant factors believed to affect peak streamflow from forested watersheds; and 2) compare results from small (Fernow) and large watersheds (Cheat River basin) with respect to flooding and peakflows.

STUDY AREAS AND HISTORICAL USE

The Fernow Experimental Forest is located in the unglaciated Allegheny Plateau region of north-central West Virginia (Fig. 1). Topography in this region of the Allegheny Mountains is characterized by steep mountains and narrow valleys. The average elevation of the study area is about 2,500 feet. The predominant soil is Calvin silt loam with moderate erosion hazard (Losche and Beverage 1967) underlain with fractured sandstone and shale of the Hampshire formation. Soil depth usually is less than 3 feet. The first harvesting activity occurred between 1905 and 1910. At that time, most smaller trees and species such as sugar maple (*Acer saccharum* Marsh), American beech (*Fagus grandifolia* Ehrh.), and black birch (*Betula lenta* L.) were considered unmerchantable and often were left standing. Today, dominant tree species include various oaks (*Quercus* spp.), yellow-poplar (*Liriodendron tulipifera* L.), and sugar maple.

Research on forest hydrology began on the Fernow in 1951 when streamflow and precipitation measurements began on watersheds 1 through 5 (Fig. 2, Table 1). Data were collected continuously while the watersheds were undisturbed during a 6-year calibration period to develop relationships between the watersheds. In 1957-58, studies were initiated to evaluate the effects of four cutting practices on streamflow (Reinhart et al. 1963). Watershed 4 (WS4) has not been cut since the original 1905-10 harvesting, and serves as the reference watershed. Data collection began on WS6 and WS7 in 1956.
A wide range of treatments has been applied to the Fernow watersheds over the years (Table 1), ranging from none or minimal treatments (reference WS4), partial cutting (WS2, WS5), commercial clearcut with no best management practices (BMPs) (WS1), and normal silvicultural clearcutting harvests using BMPs (WS3), to clearcutting followed by herbicide treatments that rendered the watersheds (WS6, WS7) barren of vegetation for several years. Gaps in the records represent periods before the construction of gaging stations or periods when they were inactive.

The Cheat River watershed above the Parsons gaging station (Fig. 1) contains 722 square miles (462,080
acres) of drainage area. Elevations range from 1,600 to 4,861 feet at Spruce Knob, the highest point in West Virginia. Annual precipitation averages about 53 inches. The original forest included extensive dense stands of red spruce (Picea rubra L.) and eastern hemlock (Tsuga canadensis L.) above an elevation of 3,000 feet (Fig. 3). It was estimated that the original spruce forest in West Virginia contained nearly 500,000 acres (Hopkins 1891), including 140,000 acres of spruce forests on the Cheat River watershed. Since 72 percent of the Cheat watershed above the Parsons gaging station is above 3,000 feet in elevation, it is reasonable to assume that the original spruce and hemlock forests covered at least half of the watershed. A forest inventory in 2000 indicated that the two counties (Tucker and Randolph) that comprise most of the Cheat River watershed above Parsons are about 86-percent forested (Griffith and Widmann 2003).
In the mid-1880s, loggers began harvesting timber in the Cheat River watershed (Fansler 1962); this large-scale logging continued until the early 1920s (Fig. 4). Clarkson (1964) described the cutting as heavy, resulting in large accumulations of dried slash. Sparks from steam-powered logging equipment often set fire to the highly inflammable slash. These fires resulted in the conversion of large areas of spruce forest to fire cherry (*Prunus pensylvanica* L.), blackberry (*Rubus* spp.), and bracken fern (*Pteridium aquilinum* L.). In some areas, deep humus was burned down to bedrock (Fig. 5) (Brooks 1911). The effects of wildfires remain evident in the high plateaus of Tucker and Randolph Counties within the Cheat River watershed. Merely cutting these original forests without burning would not have inflicted the long-term damage associated with burning because undamaged soil, spruce regeneration, and some spruce seed sources would have remained after cutting. Although some of this land was planted by U.S. Forest Service crews in the early 1930s (Fig. 6), much of the high-elevation land formerly occupied by red spruce and hemlock includes inferior stands of hardwoods today (Hornbeck and Kochenderfer 1998). The area of West Virginia occupied with forests dominated by red spruce has shrunk from the original estimate of 500,000 acres to the current estimate of less than 50,000 acres (Griffith and Widmann 2003).
Figure 4.—The Babcock Lumber Co. logging Blackwater Canyon in the Cheat River watershed in 1910 (photo courtesy of David F. Strahin).

Figure 5.—Fire, which often followed logging in the red spruce-hemlock, destroyed the thick organic layer that once covered exposed roots and rocks (National Archives photo).
METHODS
Data Acquisition and Analyses
Fernow Storms Data Set
On the Fernow, stream discharge used for these evaluations was measured with 120° V-notch weirs. Precipitation is measured with recording gages and standard 8-inch rain gages (Adams et al. 1994). Annual precipitation averages 58 inches and is distributed evenly between dormant (November 1 to April 30) and growing seasons (May 1 to October 31). Annual streamflow from WS4 averages 26 inches: 6 inches during the growing season and 20 inches during the dormant season.

Data from seven Fernow watersheds with the longest period of record were used in this study (Fig. 2, Table 1). Streamflow records were examined for the reference watershed (WS4) to determine the 50 largest peakflows since record collection began in May 1951. Peakflows on the other six watersheds also were determined for these storm dates. These 50 largest storms were chosen because they have the greatest potential to influence downstream flooding. We also were trying to increase the number of observations available for statistical analysis, though the “optimum” number of storms for such statistical analyses is unknown. Precipitation measured during each storm, taken from recording rain gages, also includes snow that may have been on the ground at the time of each event; about 38 percent of the storms were influenced by snow. Meteorological records from the Fernow were used to determine the snow contribution for each event.

The total storm precipitation was measured with the Fork Mountain rain gage, the gage closest to the watersheds. As a result, the precipitation amount, independent of snow, is the same for each watershed for a single storm event. Because of the proximity of the watersheds and because most of these storms are unlikely to be limited geographically summer thunderstorms that could vary in precipitation delivery among watersheds (34 percent of the storms occurred during the growing season), this single value is believed to be a reasonable representation of total storm precipitation. Antecedent
precipitation for each watershed was determined by
the Thiessen polygon method (Hewlett 1982b), which
weights rain-gage catch by the area each gage represents,
and was calculated for 7 and 14 days before each storm.

Nine variables that were hypothesized to affect peakflow
were recorded or estimated for each of the seven
watersheds. These are related to both the character of
the storm event and to a variety of watershed physical
features: These include:

1. AVG. INTENSITY—Average storm intensity, in
inches per hour (in/hr), is total storm precipitation
(inches) divided by storm duration (hours); average
storm intensity ranged from 0.02 to 0.92 in/hr.

2. BASAL AREA—Estimated total stand basal area in
square feet per acre (ft²/acre) of woody vegetation
growing on the watersheds at the time of each
storm. This variable reflects the average density of
woody vegetation on each watershed.

3. SKIDROAD LENGTH—Total length of
skidroads (miles) on each watershed at the time of
each storm event.

4. LOGGING INTERVAL—Time interval (years)
on each watershed since logging activity for each
storm event. This variable describes the recency of
the timber-cutting effect.

5. TOTAL STORM PRECIP—the precipitation
(inches), including snow, measured during each
storm event without a 6-hour precipitation-free
period. It ranged from 1.37 to 6.06 inches.

6. 14 day-AP—Total 14-day antecedent weighted
precipitation (inches) measured on each watershed
prior to each storm event.

7. MDA streamflow—Mean daily antecedent
streamflow in cubic feet/second/square mile (csm)
recorded for each watershed on the day before
each storm event.

8. ELEV—Maximum elevational difference (in feet)
is the difference between the highest and lowest
elevations on each watershed.

9. SNOW—Snow accumulation on the ground
at the time of the storm (an indicator variable).
Water equivalent of snow ranged from 0.47 to 3.0
inches.

The ranges of values for the variables that differed among
watersheds is shown in Table 2. Other variables such as
1-hour storm intensity and 7-day weighted watershed
antecedent precipitation were considered but excluded
because they were duplicative or correlated with these
variables. Data are available at http://www.fs.fed.us/ne/
parsons/webdata/data/downloads.

**Table 2.—Range of values for variables used in multiple regression analysis, by watershed, Fernow Experimental Forest**

<table>
<thead>
<tr>
<th>Variable</th>
<th>WS1</th>
<th>WS2</th>
<th>WS3</th>
<th>WS4</th>
<th>WS5</th>
<th>WS6</th>
<th>WS7</th>
</tr>
</thead>
<tbody>
<tr>
<td>BASAL AREA (ft²/acre)</td>
<td>2.1 - 138.4</td>
<td>60.8 - 111.1</td>
<td>0.0 - 151.8</td>
<td>100.1 - 158.2</td>
<td>87.3 - 116.4</td>
<td>0.0 - 139.1</td>
<td>0.00 - 119.4</td>
</tr>
<tr>
<td>SKIDROAD LENGTH (mi)</td>
<td>0.0 - 3.22</td>
<td>0.0 - 1.05</td>
<td>0.0 - 2.10</td>
<td>0.00</td>
<td>0.00 - 2.80</td>
<td>0.00 - 1.28</td>
<td>0.00 - 1.27</td>
</tr>
<tr>
<td>LOGGING INTERVAL (years)</td>
<td>1 - 52</td>
<td>1 - 53</td>
<td>0 - 53</td>
<td>49 - 97</td>
<td>0 - 53</td>
<td>0 - 59</td>
<td>0 - 59</td>
</tr>
<tr>
<td>14 day-AP (inches)</td>
<td>0.97 - 6.88</td>
<td>0.81 - 6.88</td>
<td>0.67 - 6.95</td>
<td>0.69 - 7.20</td>
<td>0.73 - 6.26</td>
<td>0.69 - 6.53</td>
<td>0.73 - 6.64</td>
</tr>
<tr>
<td>MDA streamflow (csm)</td>
<td>0.15 - 24.02</td>
<td>0.17 - 34.32</td>
<td>0.23 - 22.97</td>
<td>0.29 - 23.42</td>
<td>0.29 - 26.84</td>
<td>0.18 - 29.99</td>
<td>0.29 - 29.58</td>
</tr>
<tr>
<td>ELEV (ft)</td>
<td>640</td>
<td>320</td>
<td>400</td>
<td>405</td>
<td>348</td>
<td>240</td>
<td>480</td>
</tr>
</tbody>
</table>

**Statistical Analyses**
To help identify factors with the greatest influence on
peak streamflows, we developed nine candidate models
based on hypotheses about the relationship between peakflows and the other variables (Table 3). Flow from the watersheds was standardized to cubic feet per second (cfs) per 100 acres to account for size differences among watersheds. The dependent variable is standardized peakflow (cfs/100 acres) and the explanatory variables are related to the storm events and physical parameters on the watersheds. The peakflows from the various watersheds expressed on a unit-area basis generally were consistent (Table 4). For comparison, descriptive statistics are also provided for peakflows recorded only during the pretreatment calibration period (Table 4).

The nine candidate models were evaluated using multimodel regression inference techniques described by Burnham and Anderson (1998). These models, representing hypotheses developed using expert judgment, were compared to determine a most plausible model. Each model was analyzed separately using multiple regression to derive Akaiki information criterion and to determine goodness of fit for each model. The Akaiki coefficients were then used to calculate Akaiki weights and a most plausible model was selected. This method is believed to be superior to stepwise regression techniques when the number of possible models

---

**Table 3.—Candidate models used to evaluate hypotheses about influences on peak storm flows**

<table>
<thead>
<tr>
<th>Model</th>
<th>Independent variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Storm Precip.</td>
<td>TOTAL STORM PRECIP</td>
</tr>
<tr>
<td>Snow model</td>
<td>TOTAL STORM PRECIP</td>
</tr>
<tr>
<td>Storm Intensity</td>
<td>AVG. INTENSITY</td>
</tr>
<tr>
<td>Precipitation amount and intensity</td>
<td>TOTAL STORM PRECIP</td>
</tr>
<tr>
<td>Soil wetness</td>
<td>14 day- AP</td>
</tr>
<tr>
<td>Simplest soil wetness</td>
<td>TOTAL STORM PRECIP</td>
</tr>
<tr>
<td>Road</td>
<td>SKID ROAD LENGTH</td>
</tr>
<tr>
<td>Watershed characteristics</td>
<td>LOGGING INTERVAL</td>
</tr>
<tr>
<td>Trout Fisherman’s</td>
<td>BASAL AREA</td>
</tr>
</tbody>
</table>

**Table 4.—Average standardized peakflows (csm/100 acres), standard deviation, and number of storms, Fernow Experimental Forest (pretreatment calibration descriptive statistics refer to storms occurring before 1957)**

<table>
<thead>
<tr>
<th>Watershed</th>
<th>50 storms data set</th>
<th>Pretreatment calibration storm data set</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>WS4</td>
<td>10.32</td>
<td>4.39</td>
</tr>
<tr>
<td>WS1</td>
<td>11.31</td>
<td>5.37</td>
</tr>
<tr>
<td>WS2</td>
<td>12.29</td>
<td>5.29</td>
</tr>
<tr>
<td>WS3</td>
<td>11.06</td>
<td>5.09</td>
</tr>
<tr>
<td>WS5</td>
<td>13.37</td>
<td>6.10</td>
</tr>
<tr>
<td>WS6</td>
<td>11.06</td>
<td>2.17</td>
</tr>
<tr>
<td>WS7</td>
<td>11.78</td>
<td>4.68</td>
</tr>
</tbody>
</table>
exceeds sample size. Uncertainty in model selection is reduced significantly by the candidate model process. These models produce output that is interpreted more readily from a hydrologic sense than one developed by a statistical technique that builds models by arbitrary selection of parameters.

Cheat River Basin Data
Data on peak discharge for the gaging site on the Cheat River near Parsons (U.S. Geol. Surv. 1995, 2002; Ward et al. 1997, 2001; http://nwis.waterdata.usgs.gov/wv/nwis/peak) were examined to determine the largest peak discharges recorded or estimated from July 6, 1844 through September 2001 (Tables 5, 6). Streamflow measurements began at this site in January 1913; hourly streamflow data for the four largest storm events recorded since 1913 at the gaging site on the Cheat River were used to plot hydrographs for these events. Earlier peakflows were estimated from USGS Water Data Reports. Precipitation data for Parsons (1899 to 1950) were obtained from the National Climatic Data Center (2000). Precipitation data collected at the U.S. Forest Service Timber and Watershed Laboratory at Parsons since 1951 were used in these analyses.

Table 5.—Dates and peak flow rates for the six largest flood events observed at the Parsons gaging site on the Cheat River.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Flood date</th>
<th>Peak flow (cfs)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>November 5, 1985</td>
<td>170,000</td>
<td>Ward et al. (2001)</td>
</tr>
<tr>
<td>2</td>
<td>January 19, 1996</td>
<td>90,100</td>
<td>Ward et al. (1997)</td>
</tr>
<tr>
<td>3</td>
<td>July 6, 1844</td>
<td>85,000</td>
<td>Ward et al. (2001)</td>
</tr>
<tr>
<td>6</td>
<td>July 10, 1888</td>
<td>71,000</td>
<td>Ward et al. (2001)</td>
</tr>
</tbody>
</table>

Table 6.—Peak discharge for 20 largest storms on Watershed 4, 1951 to 2000, and on Cheat River, 1913 to 2000

<table>
<thead>
<tr>
<th>Rank</th>
<th>Date</th>
<th>Peakflow (cfs)</th>
<th>Watershed 4</th>
<th>Cheat River near Parsons</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2/9/1994</td>
<td>18.41</td>
<td>2</td>
<td>1/19/1996 90100</td>
</tr>
<tr>
<td>3</td>
<td>10/15/1954</td>
<td>18.06</td>
<td>3</td>
<td>10/15/1954 81000</td>
</tr>
<tr>
<td>4</td>
<td>7/19/1996</td>
<td>17.59</td>
<td>4</td>
<td>2/9/1994 78300</td>
</tr>
<tr>
<td>5</td>
<td>6/6/1981</td>
<td>17.18</td>
<td>5</td>
<td>2/19/2000 57800</td>
</tr>
<tr>
<td>6</td>
<td>1/19/1996</td>
<td>15.88</td>
<td>6</td>
<td>5/8/1994 52700</td>
</tr>
<tr>
<td>7</td>
<td>5/7/1994</td>
<td>15.58</td>
<td>7</td>
<td>7/19/1996 52500</td>
</tr>
<tr>
<td>8</td>
<td>2/10/1957</td>
<td>15.49</td>
<td>8</td>
<td>3/19/1963 52400</td>
</tr>
<tr>
<td>9</td>
<td>2/19/2000</td>
<td>13.33</td>
<td>9</td>
<td>3/12/1917 50500</td>
</tr>
<tr>
<td>11</td>
<td>7/29/2001</td>
<td>11.87</td>
<td>11</td>
<td>7/31/1996 50000</td>
</tr>
<tr>
<td>17</td>
<td>8/11/1984</td>
<td>9.97</td>
<td>17</td>
<td>3/29/1924 41100</td>
</tr>
<tr>
<td>20</td>
<td>3/21/1962</td>
<td>9.40</td>
<td>20</td>
<td>1/22/1917 37500</td>
</tr>
</tbody>
</table>

RESULTS AND DISCUSSION
Fernow Large Peakflows

The 50 largest peakflows on WS4 since 1951 ranged from 5.93 cfs (December 31, 1989) to 25.44 cfs (November 4, 1985), with an average value of 9.87 cfs (SD = 4.20). Storm precipitation ranged from 1.37 inches for the February 24, 1977 storm to 6.06 inches for the November 4, 1985 storm, with average storm precipitation of 3.06 inches (SD = 0.98). Note that while the largest storm peakflow (November 4, 1985) was associated with the highest precipitation amount, this relationship does not always hold as some of the smaller peakflows also were associated with high precipitation amounts. Of these 50 storms, 17 occurred in the growing season and 33 during the dormant season.

Factors Affecting Peakflows on the Fernow Watersheds

Results of the candidate model analyses suggest that the most plausible model is Precipitation amount and intensity, which includes the variables TOTAL STORM PRECIP and AVG. INTENSITY (Table 7). We hypothesized that these two meteorological variables would be more important than the watershed characteristics and management activities for the largest storms. During large storms, the water-holding capacity of the soil (watershed) may be exceeded and streamflows can increase rapidly as a result. Although forests use large amounts of water compared with most other land uses, interception and transpiration are greatly reduced in hardwood forests during dormant seasons. Soil-moisture deficits are greatly reduced and similar during dormant seasons in both cut and uncut hardwood forests (Troendle 1970). Growing-season moisture deficits also may be reduced temporarily when a sufficient number of trees is cut on forested watersheds, because moisture losses from transpiration and interception are reduced. Thus, streams draining forested watersheds are more responsive to precipitation during periods when soil-moisture deficits are low and storage space for additional water is limited (as during the dormant season).

Also, since infiltration rates of forest soil usually exceed rainfall rates, there is virtually no overland flow on forest land (Patric 1976). When a steep 64-acre watershed was clearcut on the Fernow, overland flow occurred only on skid roads with no water control structures (Reinhart 1964). Stuart and Edwards (2006) concluded that timber harvesting has little effect on water resources because canopy removal and normal harvesting activities do not significantly affect the function of the forest floor. Bates (2000) concluded that during most storms, even after harvesting, subsurface flow remains the primary mechanism for stream generation. In our analyses, total storm precipitation alone explained 39 percent of the variability in the model; adding average storm intensity explained another 4 percent. By comparison, adding basal area and logging interval rather than average storm intensity explained less than 1 percent of additional variability.

Note that most of the storms occurred more than 5 years after the most recent logging disturbance: 84, 60, 62, 76, and 76 percent for WS1, WS2, WS3, WS6, and WS7,

<table>
<thead>
<tr>
<th>Model</th>
<th>R²</th>
<th>Probability of greater F</th>
<th>AIC</th>
<th>Akaike weights</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Storm Precip.</td>
<td>0.391</td>
<td>&lt; .0001</td>
<td>845.506</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Snow</td>
<td>0.465</td>
<td>&lt; .0001</td>
<td>807.113</td>
<td>0.031</td>
<td>4</td>
</tr>
<tr>
<td>Storm intensity</td>
<td>0.039</td>
<td>0.0005</td>
<td>987.185</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Precip amount and intensity</td>
<td>0.430</td>
<td>0.0001</td>
<td>800.579</td>
<td>0.822</td>
<td>1</td>
</tr>
<tr>
<td>Soil wetness</td>
<td>0.396</td>
<td>&lt; .0001</td>
<td>846.688</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Simplest soil wetness</td>
<td>0.391</td>
<td>&lt; .0001</td>
<td>847.276</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Road</td>
<td>0.431</td>
<td>&lt; .0001</td>
<td>806.368</td>
<td>0.045</td>
<td>3</td>
</tr>
<tr>
<td>Watershed characteristics</td>
<td>0.397</td>
<td>&lt; .0001</td>
<td>848.466</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Trout Fisherman’s</td>
<td>0.437</td>
<td>&lt; .0001</td>
<td>804.780</td>
<td>0.101</td>
<td>2</td>
</tr>
</tbody>
</table>
respectively. For WS5, 35 percent of the storms occurred more than 5 years after logging; the percentage was 100 for WS4, which had not been logged since 1910. About 30 percent of the storms occurred within the first 3 years after logging disturbance. This illustrates the inherent difficulty of evaluating streamflow response to extreme storms. Since these large storm events occur randomly at unpredictable times, their occurrence rarely coincides with watershed treatments on experimental watersheds and they cannot be replicated in controlled experiments.

The relatively low $R^2$ values we observed also may result from other factors that differ among watersheds or that were not measured in our analyses. For example, differences in the variable source area, which could vary with soil depth or stream channel morphology, were not quantified and may have improved our ability to predict peakflows. Although soil depth is assumed to be reasonably uniform across these watersheds, some differences are likely. Because of these minor differences as well as with differences in stream channel morphology, the source area for streamflow generation may differ among these otherwise homogeneous watersheds. Aspect, which can affect snowmelt, was not quantified in our analysis.

We conclude that storm characteristics explained a considerable amount of variability in peakflow while disturbance history characteristics explained little or none of the variability in peakflow, and that the meteorological variables (storm precipitation characteristics) were the most important in explaining the variability of large peak stormflows from these forested watersheds even when different impacts of timber harvesting are considered.

Brewer et al. (1982) performed similar analyses but with data from 1952-78 snow-free periods from WS4. They found that rainfall depth and initial streamflow rate accounted for 87 percent of the variation in peakflow. Their preferred models generally underestimated larger peakflows. A graph of predicted versus observed peakflows for WS4 based on the Precipitation Amount and Intensity model (Fig. 7) suggests that while there is considerable scatter around the equal peakflow line (the 1:1 line), this model predicted peakflows reasonably well over most of the range of flows.
Snow can be an important component of storms during the dormant season, so including an indicator variable for snow accumulation on the ground (Snow model) increased the $R^2$ over that of the Total Storm Precip. model. Indeed, the Snow model had the highest $R^2$ (Table 7), suggesting that storms that include snowmelt behave differently than those not influenced by snow. A model that included the variables TOTAL STORM PRECIP, AVG. INTENSITY and SNOW was the most plausible in a post-hoc exploratory analysis, providing additional evidence for the importance of snow in dormant-season peakflows. The influence of a snowpack on peakflow was demonstrated in the storm of January 19, 1996. This storm would not have been included among the top 10 (Table 6) without the additional water derived from 18 inches of snow (2.39 inches of water equivalent) on the ground before the storm. The storm on February 9, 1994, also was influenced by a snowpack as 5 inches of snow (0.5 inch of water equivalent) was on the ground prior to the storm.

Two of the three largest stormflows are related to hurricanes that deposited significant amounts of rain in a relatively short period and during the dormant season. The storm in November 1985 was the result of Hurricane Juan, and the storm in October 1954 was related to Hurricane Hazel. Large rainfall events over wide areas often are associated with hurricanes in the central Appalachians. The presence of forest cover did not appreciably reduce peak flows in the Shenandoah River watershed of Virginia during an extreme rainfall event in 1996 caused by Hurricane Fran (Sturdevant-Rees et al. 2001). Lull and Reinhart (1972) pointed out that floods from forested watersheds are common and provided numerous examples of record peakflows from well forested watersheds in the Eastern United States. Kochenderfer et al. (1997) showed that while timber harvesting can increase growing-season stormflow volumes and peakflow rates of small storms temporarily, these increases do not have important downstream implications, that is, they generally are not associated with flooding.

Stormflows and peakflows were increased during the growing season after forest clearing in New Hampshire but stormflows that occurred after soil-moisture recharge in the fall and before spring snowmelt were unaffected (Hornbeck 1973). The increased response on the cleared watershed during the growing season was attributed to reduced transpiration and interception, which caused wetter soils and reductions in moisture storage capacity. In a paired watershed experiment in which the hydrologic impacts of clearcutting and site preparation on the Georgia Piedmont were evaluated, it was found that small stormflows generated under dry antecedent conditions could be increased by 50 percent or more but that larger flood discharges, which usually occur under wet conditions, are little affected (Hewlett and Doss 1984). Results of a watershed study in which forest-harvest and site-preparation treatments in the Ouachita Mountains of Arkansas were evaluated showed that stormflow and peakflow for a large, 100-year event were not significantly increased by the treatments (Miller et al. 1988). In evaluating the effects of clearcutting on stormflow hydrographs in Missouri, Settergren and Krstansky (1987) concluded that clearcutting may increase total stormflow yields and peakflows, but that the magnitudes are not important with respect to flood flow generation.

Largest Cheat River Peakflows

The Cheat River has experienced major floods since the arrival of European settlers in that area in the 1700s. The first recorded flood in July of 1844 did little damage to the settlements, perhaps because the area was sparsely populated at that time. The next recorded flood, in July 1888, was much more damaging even though the estimated peak discharge was lower than the flood in 1844. According to Fansler (1962): “The flood of July 1888 must have been the highest ever to come to the Cheat River ... the whole valley from Parsons to Rowlesburg was under water. Horses, cattle, sheep, and hogs were washed away.” However, the available evidence indicates that the November 1985 flood was much greater and many times more destructive than any experienced since the area was settled. Peakflow rates at the Parsons gaging site on the Cheat River for the six largest floods observed since settlement are shown in Table 5. These storms also are ranked in descending order according to the maximum peakflows recorded for each event. Peak discharge for 1844 and 1888 were estimated from floodmarks and datum in use prior to August 17, 1944 (Ward et al. 2001).
A major storm occurred on July 17, 1907, but it was excluded from this analysis because no estimate of peakflow was available at the Parsons gaging site. The aerial extent of this storm is unknown but the 4.7 inches of rain recorded by National Weather observer S.W. Swisher, on that date at Parsons (Natl. Clim. Data Cent. 2000) were similar to the 4.3 inches recorded at Parsons during the storm in October 1954. Similar peak discharges were reported for these storm events on the Cheat River at Rowlesburg (U.S. Army Corps of Eng. 1963). The flood of November 5, 1985, was the largest event recorded on the Cheat River (Kite and Linton 1993). Peakflow for this storm was nearly twice that recorded for the next largest storm (Table 5).

Comparison of Peak Discharge on the Cheat River and WS4 Watersheds

Peak discharges for the 20 largest storms for the Cheat River basin near Parsons and WS4 are shown in Table 6. Only four of the largest storms on the Cheat River at the Parsons gaging site occurred before 1951 when the Fernow watersheds, including WS4, were gaged. Except for the sixth-ranked storm (January 19, 1996), only the four highest-ranked storms on WS4 resulted in major downstream flooding on the Cheat River. There are both differences and similarities in rankings but the 1985 storm was the largest on both watersheds, and the storm on October 15, 1954 ranked third on each list. A major difference in ranking occurred with the storm on January 19, 1996, which ranked sixth on WS4 but second on the Cheat River watershed at the Parsons gaging site. Precipitation records on WS4 and at the Bearden Knob weather station near Davis, West Virginia, indicate that about 2 inches of rain fell at both sites between 3 and 9 a.m. on January 19. The difference in storm response probably can be attributed to the greater depth of the snowpack on the high-elevation Cheat watershed.

Measurements on January 5 at the Bearden Knob station indicated a snow depth of 28 inches versus 18 inches measured on WS4 (equivalent to 3.72 and 2.39 inches of water, respectively). Temperatures remained above freezing at both sites from about 10 a.m. on the 16th until 9 a.m. on the 19th when it stopped raining. Average wind speed on January 18 and 19 was 10 to 20 miles per hour; this also enhanced snowmelt. The melting snowpack along with the rainfall were sufficient to cause the Cheat River to flood. The dramatic temperature drop recorded at Bearden Knob, from 53 ºF at 3 a.m. to 20 ºF at noon peaking time on the Cheat at Parsons resulted in a rapid decline in snowmelt and streamflow. This illustrates how the interaction of meteorological events can influence peak discharges.

It is interesting that 6 and 7 of the 10 largest peakflows recorded since 1951 on WS4 and since 1913 at the Cheat gaging site, respectively, have occurred since 1984 (Table 6). Most of the largest peakflows were recorded during the dormant season for both WS4 and the Cheat River when evapotranspiration losses were low. This was not unexpected because watersheds usually are wetter and more responsive to precipitation during those periods. The occurrence of individual large storms is comparable between the two watersheds. Seven of the top 10 storms on the Fernow also were included in the 10 highest ranked storms on the Cheat.

Note the large number of peakflows recorded at the Parsons gaging station in 1996 (Table 6). Five of the 20 largest peakflows were recorded during that year; 4 occurred during the growing season. In 1996, 70.4 inches of precipitation fell at Parsons, the greatest amount since official measurements began in January 1899. Many large storms occurred during 1996, reducing soil-moisture deficits (lower storage capacity), thereby making streams more responsive to precipitation in 1996 than in years with less precipitation.

The storms of October 14, 1954, and November 5, 1985, are the two largest recorded on Fernow WS4 that were unconfounded with snow. A more detailed look at these events provides insight into the relationship between streamflow and precipitation during large storm events. The distribution of precipitation in West Virginia during the 1954 storm is shown in Figure 8. Rainfall amounts probably were greater over limited areas, but the rain-gage network was too sparse to define individual storm cells. Some hydrologic characteristics of this storm are shown in Figure 9. On October 14, rain fell from 7:30 a.m. until 11 p.m. This storm had the highest 4-hour rainfall intensity (2.25 inches) of the 10 highest ranked storms on WS4. Streamflow rose rapidly, peaking
at about 6 p.m. Antecedent soil-moisture content was low judging from the streamflow rate just before the storm began (0.04 cfs). The hydrologic response factor, defined by Hewlett (1967) as the percentage of storm rainfall converted to streamflow, was about 60 percent. Flood damage was severe in the small communities of Hambleton and Hendricks. Several houses and basements were damaged extensively by floodwater, forcing many
residents to vacate their homes until the next morning. Fortunately, no lives were lost and no homes were washed away or damaged beyond repair.

The 1985 storm resulted from a complex sequence of meteorological events beginning when Hurricane Juan made landfall in the Gulf Coast on October 31 (Colucci et al. 1993). The approximate precipitation distribution over the study area is shown in Figure 10. Unfortunately, rain gages usually are located in areas where people live and records for high-elevation remote areas are scarce. Although the rainfall patterns between the 1954 and 1985 storms were similar, with maximum amounts in the headwaters of Dry Fork River, the total amounts were much greater during the 1985 storm. In the study area, initial rainfall intensity was low; less than an inch of total rainfall was recorded for November 2 and 3 on the Fernow (Fig. 11). At about 9 a.m. on November 4, rainfall intensity increased over the entire study area. During the next 15 hours, about 5 inches of rain fell at the Fernow and more than 7 inches were reported at Spruce Knob. Maximum rainfall intensity was not unusual (0.50 in/hr) but an average rainfall rate of 0.34 in/hr was sustained over a 15-hour period.

Streamflow response on WS4 is shown in Figure 11. Antecedent soil-moisture content was moderate when

the intense rainfall began on November 4, as indicated by the base flow rate of 0.06 cfs. The response factor (70 percent) was greater than that recorded for the 1954 storm. A larger percentage of precipitation was returned as streamflow under the wetter conditions created by the additional 1.4 inches of precipitation in the 1985 storm.

Flood damage from the 1985 storm was many times greater than ever experienced before in this region. Many homes and businesses were washed away or damaged beyond repair (Fig. 12). The rarity of a flood of this magnitude can be inferred from other bits of information. First, several homes and other buildings along the Cheat River and its tributaries were washed away by the floodwaters. Many of these structures had stood for more than 100 years. For example, the house shown in Figure 13 was under construction adjacent to the Cheat River below Parsons during the 1888 flood. The gentleman in the photograph, Ernest Fitzwater (1901-1990) stated that his father told him that while he was helping construct the house, the water reached the first floor and floated flooring boards that were being installed. By contrast, the water level was about 8 feet higher during the 1985 flood. Also, many large trees growing along the streams were uprooted by the floodwaters. Figure 14 shows a red oak tree that grew along the Black Fork River just upstream from Parsons.
Figure 11.—Hydrologic characteristics of the November 1985 storm from data collected on Watershed 4 on the Fernow Experimental Forest.

Figure 12.—Damage along Pennsylvania Avenue in Parsons, West Virginia, from a flood that occurred on November 4-5, 1985 (photo courtesy of John Warner).
Figure 13.—Water barely reached to the first story of this house during the 1888 flood on the Cheat River. During the flood of November 1985, water reached the second floor.

Figure 14.—This 130-year-old red oak near Parsons, West Virginia, was uprooted during the flood of November 1985.
A growth-ring count indicated that the tree was 130 years old. Before the flood, the tree grew on a bank several feet above the river edge. Most of the bank was stripped away by the floodwaters. The magnitude of the 1985 flood is illustrated in Figure 15, which shows baseflow on the Dry Fork River above Parsons during the summer of 1986. The photo shows a chair deposited in a tree behind the young swimmer.

**Comparison of Storm Hydrographs**

Hydrographs are compared in Figures 16 and 17 for the four largest storms recorded on WS4 with the same storms recorded at the gaging site on Cheat River near Parsons. An additional lower ranked storm (January 19, 1996) also is shown for WS4 so it can be compared with the same storm that ranked second at the Cheat River gaging site. A hydrograph is not shown for the 1985 storm on the Cheat River because the gaging station was destroyed during that event. Peakflow for the 1985 storm was estimated from extension of the rating curve above 55,000 cfs (Ward et al. 2001). Estimated peakflow for the 1985 storm was much greater than peakflows recorded for the other highest ranked storms on the Cheat watershed. It was almost twice as high as that recorded for the second highest ranked storm (January 19, 1996). On WS4, peakflow for the 1985 storm was only 28 percent larger than peakflow for the second highest ranked storm (February 9, 1994). The magnitude of peakflows for the other top ranked storms within both watersheds were similar. On average, stormflows at the Cheat gaging site peaked about 5 hours later than those on Fernow WS4.
Figure 16.—Hydrographs of the four largest storms recorded on Watershed 4 on the Fernow Experimental Forest since measurements began in 1951. A lower ranked storm (January 19, 1996) is included for comparison purposes (see Figure 17).

Figure 17.—A peakflow indicator line for the storm of November 1985 and hydrographs for the other three largest storms recorded at the gaging site on the Cheat River near Parsons, West Virginia, since measurements began in 1913.
CONCLUSIONS

Results from our analyses and from other researchers provide little support for the commonly held view that timber harvesting increases the severity of floods. However, careful forest management, including planning and placement of roads, use of BMPs, and thoughtful execution of the operations is necessary so that other off-site effects, e.g., erosion and sedimentation, are minimized or negated. We conclude that:

- The total storm precipitation (39 percent) and average storm precipitation intensity (4 percent) model accounted for most of the variation (43 percent) in peakflow.
- Meteorological variables were more important than disturbance history in explaining the variability in large stormflows.
- The unexplained variation in our peakflow models probably reflects the complex interaction of meteorological variables that result in large peakflows as well as variables such as soil depth, stream channel morphology, and watershed exposure, none of which were included in our models.
- The two highest ranked peakflows on both the Fernow and Cheat watersheds occurred during the dormant season.
- Although prolonged snowpacks are uncommon in the central Appalachians, snow can be an important component of dormant-season peakflow.
- More than half of the 10 largest peakflows recorded on these well forested watersheds have occurred since 1984 during a period of limited timber harvesting and a high percentage of forest cover.
- The storm of 1985 generated record peakflows on both watersheds though the relative size of the 1985 peakflow was much larger on the Cheat than on the Fernow watersheds.

ACKNOWLEDGMENTS

The authors thank Doug Owens, John Campbell (deceased) and Linda Plaugher of the Northern Research Station for compiling streamflow data, assisting with literature searches, and typing the manuscript; and Ronald D. Evaldi of the U.S. Geological Survey in Charleston, West Virginia for providing streamflow data. Frederica Wood provided assistance with data management and compilation of these data sets. Desta Fekedulegn provided guidance in our early analytical discussions. John Stanovick, statistician with the Northern Research Station, assisted in the statistical analyses. Reviews of the draft manuscript by Jim Vose, Jeffrey Wiley, and Bill Gillespie were most helpful and appreciated.

LITERATURE CITED


Data collected since 1951 on the Fernow Experimental Forest near Parsons, West Virginia, and at a gaging station on the nearby Cheat River since 1913 were used to evaluate factors affecting large peakflows on forested watersheds. Treatments ranged from periodic partial cuts to complete deforestation using herbicides. Total storm precipitation and average storm precipitation intensity were the most significant variables affecting peakflows, and were far more important than timber harvesting activities. Since January 1913, of the 20 highest-ranked peakflows on the Cheat River at the Parsons gaging site, 11 have occurred since 1984 during a period of limited timber harvesting. These results support earlier findings that forests do not prevent floods and that prudent forest harvesting operations do not increase large flood peakflows.

KEY WORDS: Forest harvesting, floods, watershed research, peakflows
Capitalizing on the strengths of existing science capacity in the Northeast and Midwest to attain a more integrated, cohesive, landscape-scale research program