Testimony to the West Virginia Forest Management Review Commission

Hydrology of Eastern U.S. Forested Mountain Watersheds: Rigorous Testing of the Curve Number Method for Flood Analysis

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Mr. Chairman and members of the Commission, I will cover four topics in this testimony.

- 2001 West Virginia flooding and the controversy over forest harvesting effects
- What is the curve number method of hydrologic analysis
- 2003 findings that the curve number hydrologic analysis is not sufficient to change West Virginia forest management policies
- Rigorous testing of the curve number method

The May and July 2001 floods in Southern West Virginia causing loss of life and extensive damage to property remain a serious concern for citizens and public officials. After the floods, speculation was that forest harvesting and other resource management may have contributed to the death and destruction. Based on these concerns, one or more class action law suits have been filed. In 2001, the Governor of West Virginia ordered (Executive Order No. 16-01) the Department of Environmental Protection (DEP) to investigate. State engineers used a standard rainfall-runoff relationship to estimate that forest management practices in West Virginia caused 4 to 6 percent of the flooding on two example watersheds. The National Resource Conservation Service (NRCS) curve number method was used by DEP to make these estimates.

- State Forester Dye found that the standard curve number method was probably not precise and accurate enough to distinguish a 6 % effect nor to justify changing West Virginia Best Management Practices (BMPs)
- The State of West Virginia followed up with the U.S. Forest Service to define curve number limits for forested mountain watersheds and to develop adequate methods to support policy making

Although the State of West Virginia used a practical approach for urban and agricultural runoff, the professional engineering, hydrology, and forestry communities have not fully recognized the imprecision and inaccuracy of this method. Even those teaching the method have not recognized the full implications for forecasting runoff caused by the fact that curve numbers vary significantly with the volume of rain falling in a given storm. This variability means that the method cannot distinguish the effects of best management practices on forested watersheds, and can only distinguish trends due to major land use changes, and usually only for smaller storms. Different techniques must be used to analyze individual storms, like those of May and July of 2001.

Public Misconception: Forest Affects on Floods

The largest rain storms quickly saturate soils and other water storage opportunities on watersheds that subsequently produce extreme amounts of runoff which dominates any effect of land use. Contrary to the scientific facts,

- Disagreements about forest clearing and floods in U.S. date to 1863 when G.P. Marsh wrote a book called "Man and Nature." From: Hewlett (1984).
- Gilford Pinchot, first Chief of the U.S. Forest Service, used this public misconception that forests are sponges that prevent large scale flooding in convincing Congress to authorize the agency in 1905 and to purchase private lands.

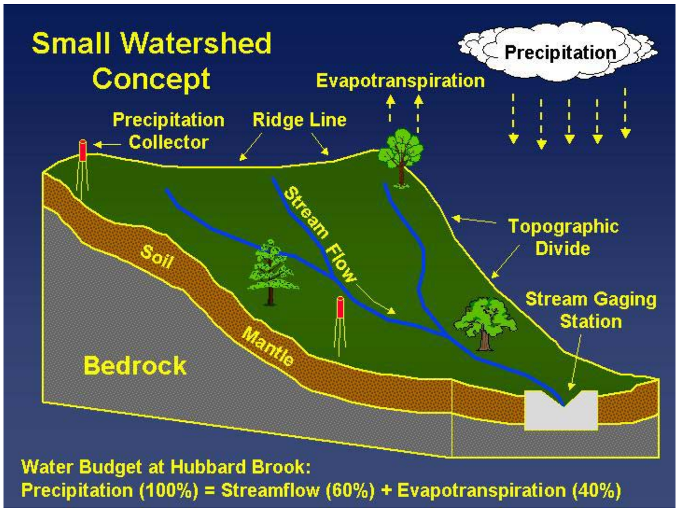
Only recently have scientists begun to fully address the controversy.

- " …the scope for forests to reduce the severity of major floods that are derived from an extended period of very heavy rainfall is rather limited." From: UK Forestry Commission, 2002
- "The myths and misperceptions about the causes of flooding that have misguided decision-makers, planners and managers alike need to be replaced by rational understanding based on facts. Too many local, national and international agencies have used 'conventional wisdom' and unsupported claims to advance their own institutional interests and because it has been politically advantageous to channel aid funds to upland reforestation and conservation projects. The media has unfortunately perpetuated many of the myths regarding forests and floods out of a well-intentioned, but ill-informed, desire to protect the environment, especially the forests of upper watersheds." From: Center for International Forestry Research for the Food and Agricultural Organization of the United Nations, 2005.
- At the Fernow, Coweeta, Hubbard Brook, and other experimental forests the U.S. Forest Service has established the beneficial effects of forest cover on reducing peak discharge and storm flow volumes for minor storm events 1 to 5 years after harvest. However, during major flood-producing events, the effects of forest cover on reducing peak discharge are minimal.
- The State of West Virginia has so far avoided this global misconception in reacting to the flooding of 2001.

What is the curve number method of hydrologic analysis?

- Standard engineering method by NRCS for agricultural, rangeland, and urban ungaged watersheds
- Relates given rainfall volume to runoff volume using soil type, vegetative cover, and antecedent runoff conditions
- Curve number (40 to 100) formula defines the portion of rainfall that becomes runoff

- Curve number derived from 1928 to 1953 agricultural plot data; extended in 1985 to urban land uses



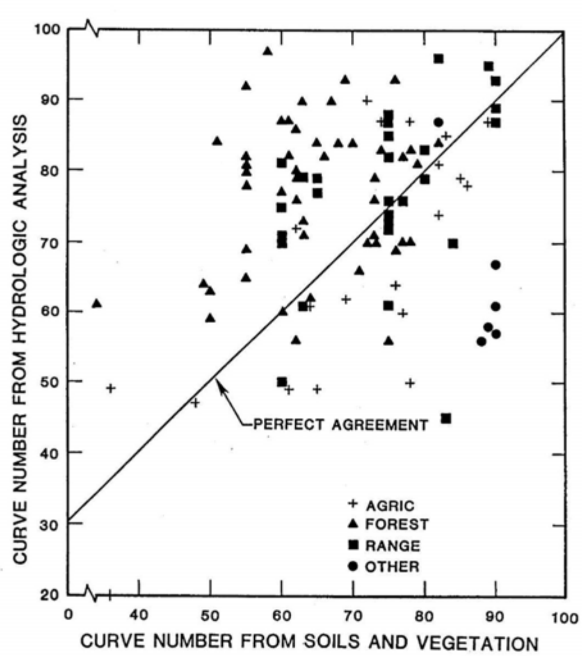
The empirical equations are

$$CN = \frac{1000}{S+10} \quad \text{and} \quad \frac{Runoff}{P} = \frac{F}{S}$$

- S = maximum potential retention
- F = water retention
- P = maximum potential runoff ≈ rainfall volume

<u>Limitations of the Curve Number Method</u>

- Does not fit all rainfall-runoff responses, especially poor for forested and wildland settings



- Not formally adapted to forests and practices; primary focus was for rain-fed agriculture where most of the land-use adjusted curve numbers apply
- Hydrologic soil group classifications are not consistent according to the NRCS
- Handbook curve number tables may be authoritative, but not documented
- Calculated runoff is more sensitive to curve number than to rainfall
- Infers an unrealistic loss rate sequence

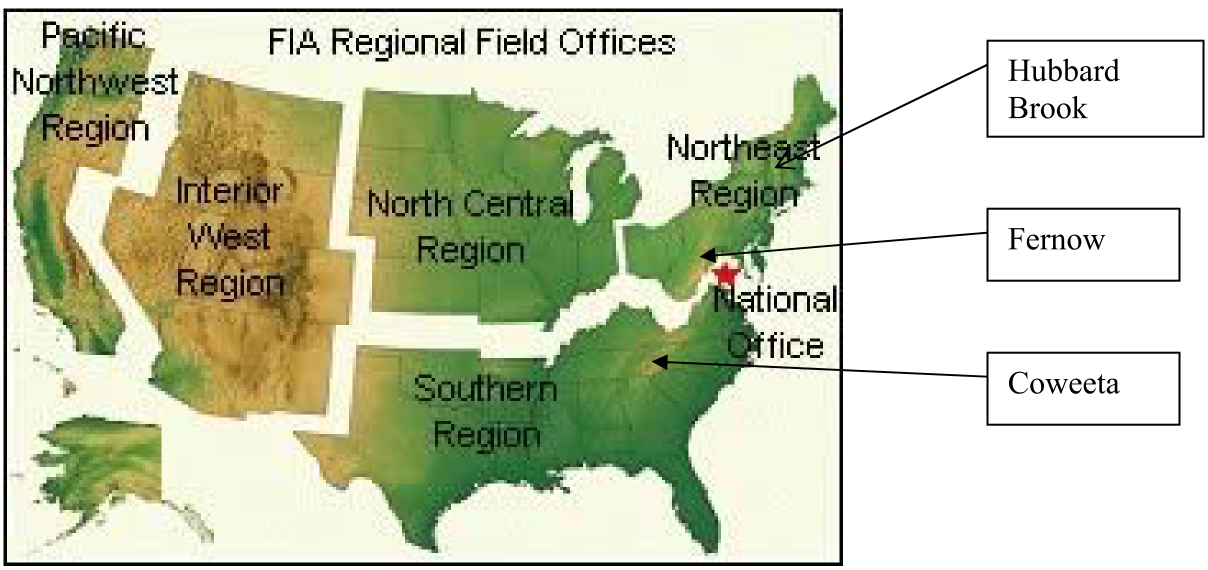
Illustration of the uncertainty in curve numbers. From Hawkins (1984).

McCutcheon (2003) for the West Virginia Division of Forestry

- Curve number method has not been formally adopted for forests, especially management practices
- Fernow WS 4: -48 to 77% error in peak flow simulation by NRCS methods used by Flood Advisory Technical Taskforce
- Fernow WS 2: -20 to 55% error in peak flow
- Cannot sustain Flood Advisory Technical Taskforce conclusion that a 6% peak flooding affect is real
- Need definitive study to determine if curve number is useful at all for Appalachian forested watersheds

Most Recent Results

Derivation of curve numbers from three mountainous, experimental forests in the Eastern U.S. with high quality data to support West Virginia policy deliberations.



Four methods to derive curve number

- Design and Analysis
  - NRCS Tables (no one knows where the curve number came from)
- Determination from data
  - NRCS median (for 2 year runoff event)

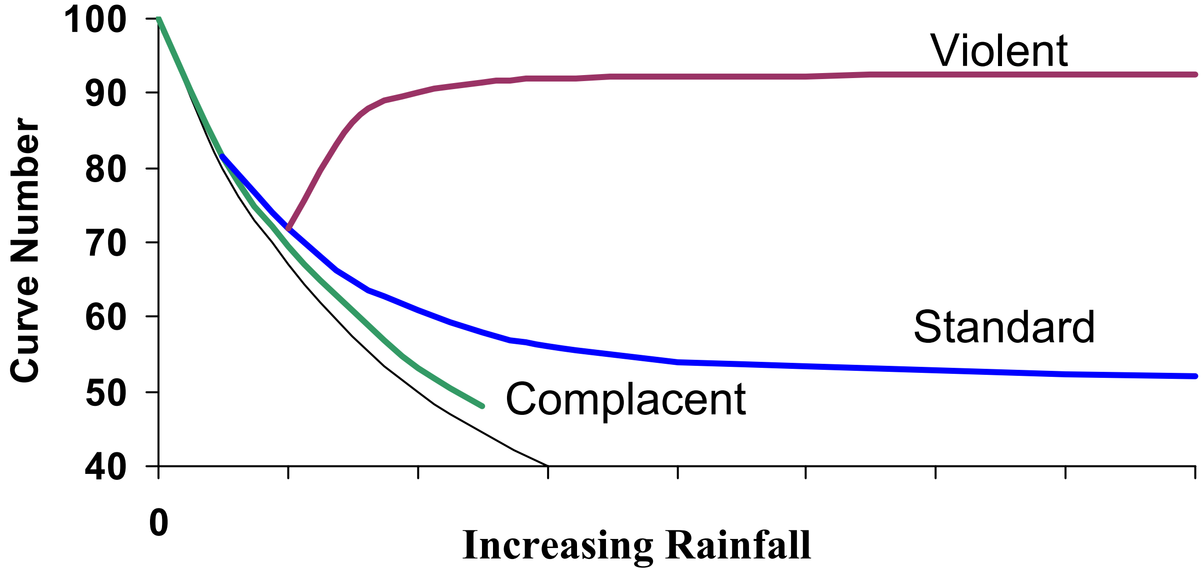
- Asymptotic curve number for largest floods on record
- Optimal curve number for full record of runoff

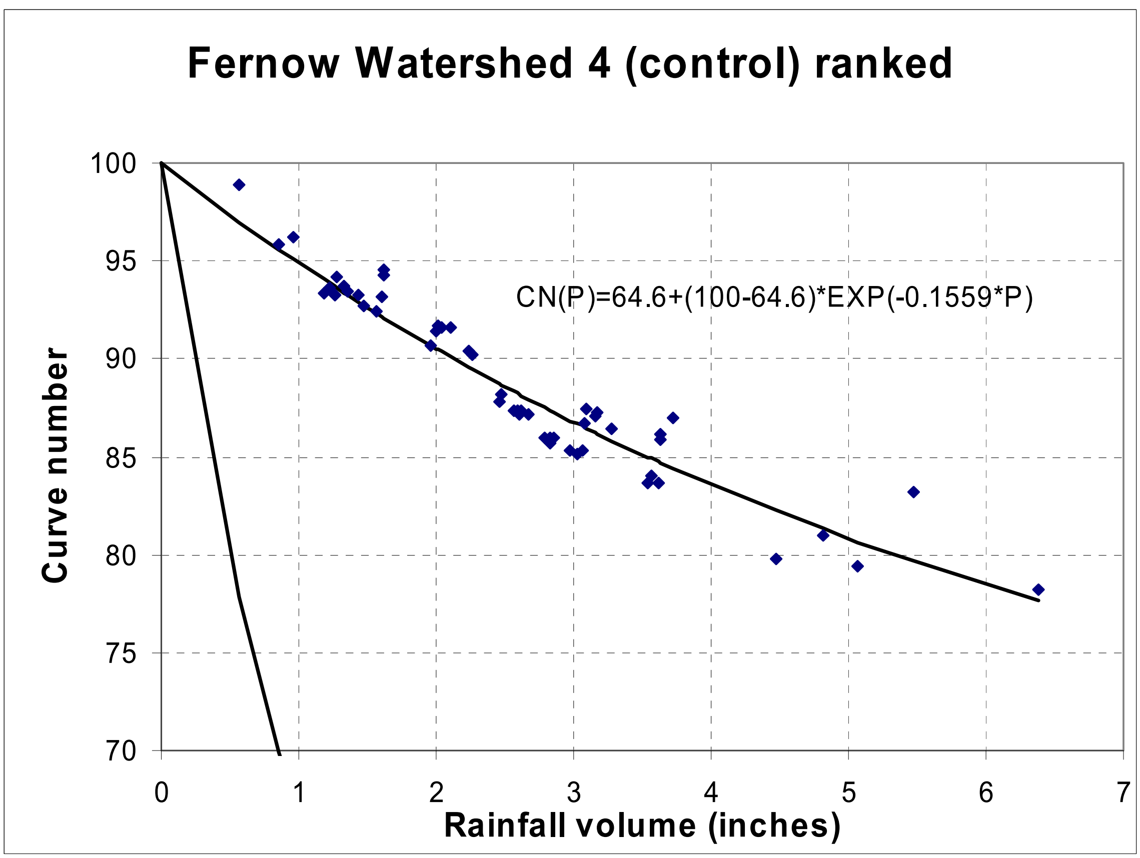
Curve number recommended by the NRCS (1997) [no treatments or practices for forests or woodlands are listed]

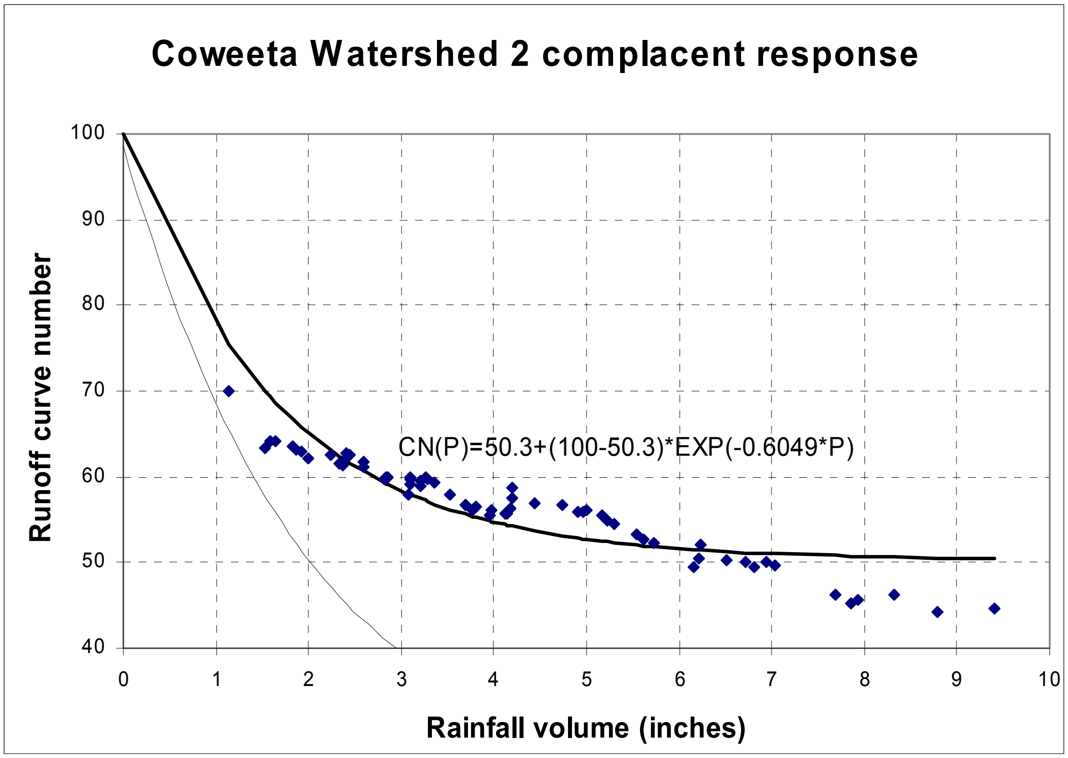
Land use description	**Hydrologic condition**	**Curve number for hydrologic soil group**			
		A	**B**	**C**	**D**
Forestland-grass or orchards-evergreen deciduous	Poor	55	73	82	86
	Fair	44	65	76	82
	Good	32	58	72	79
Brush	Poor	48	67	77	86
	Fair	35	56	70	77
	Good	30	48	65	73
Woods	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	25	55	70	77
Forest-range: Herbaceous	Poor	-	80	87	93
	Fair	-	71	81	89
	Good	-	62	74	85
Oak-aspen	Poor	-	66	74	79
	Fair	-	48	57	63
	Good	-	30	41	48
Juniper	Poor	-	75	85	89
	Fair	-	58	73	80
	Good	-	41	61	71

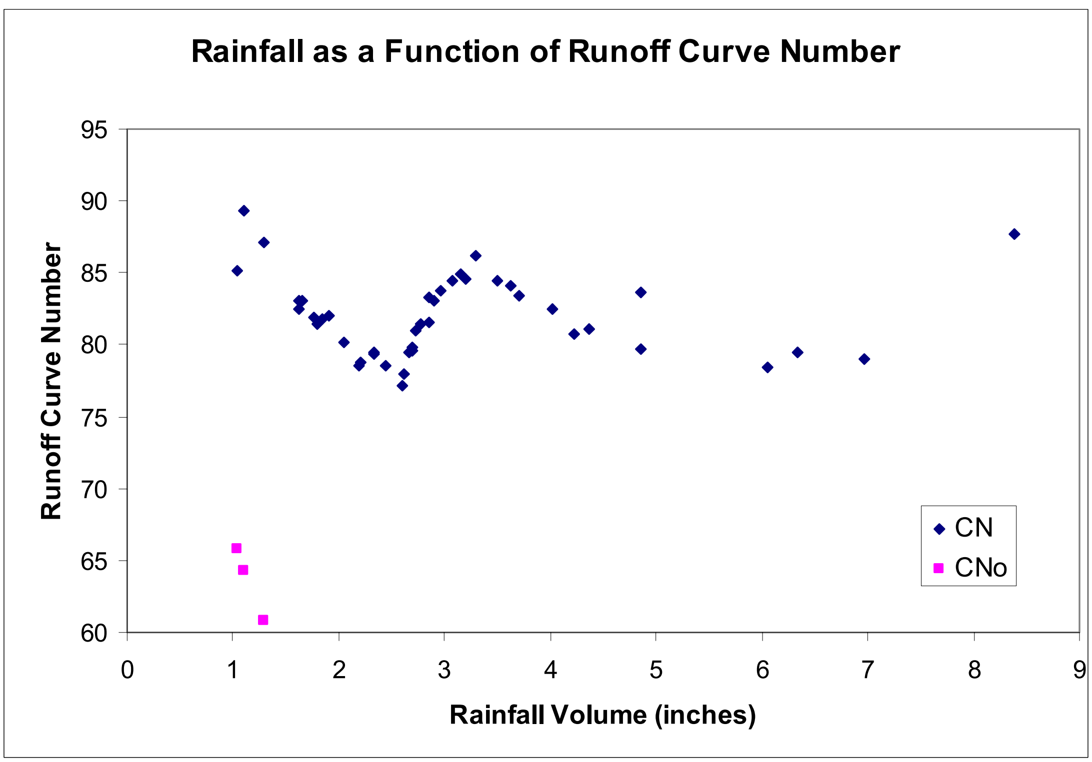
Median curve numbers

Watershed	**Curve number values**				**Percent of practical range**
	NRCS tabulated	**5% extreme**	**Median**	**95% extreme**	
Coweeta WS-2	55	34.8	58.2	78.3	73 %
Coweeta WS-28	55	48.1	60.0	70.9	38 %
Coweeta WS-36	55	42.0	75.0	92.5	84 %
Coweeta WS-37	55	54.8	72.6	85.3	51 %
Fernow WS-3	70	56.9	88.9	98.0	69 %
Fernow WS-4	70	77.4	89.7	95.7	31 %
Hubbard Brook WS-3	46	79.6	83.0	85.9	11 %
Hubbard Brook WS-5	41	60.8	84.0	94.7	57 %

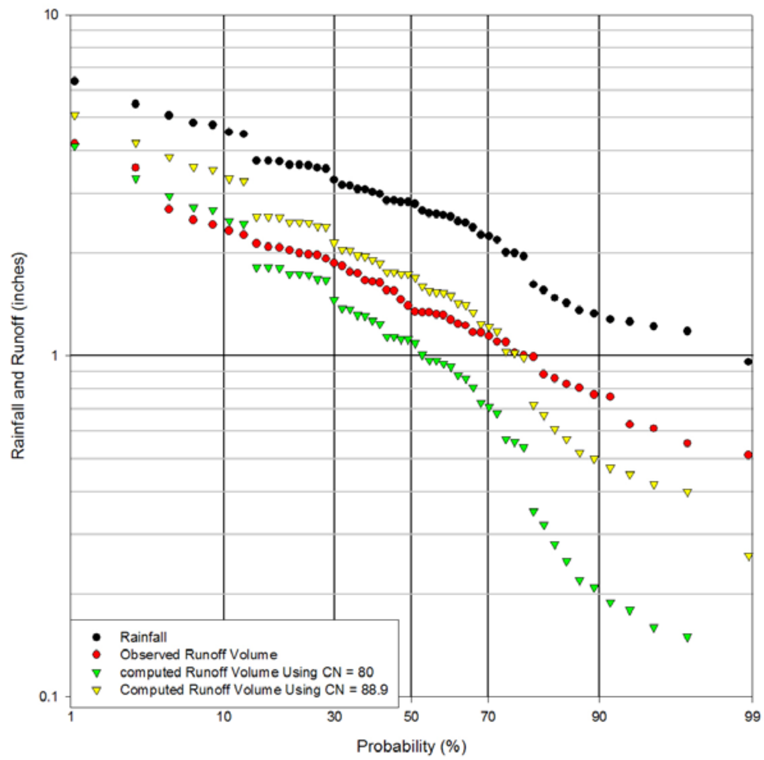

100
90
80
70
60
50
40
0
Curve Number
Increasing Rainfall
Violent
Standard
Complacent


Fernow Watershed 4 (control) ranked
CN(P)=64.6+(100-64.6)*EXP(-0.1559*P)
Curve number
Rainfall volume (inches)
100
95
90
85
80
75
70
0
1
2
3
4
5
6
7





Hubbard Brook Watershed 5 (control) unique response. NRCS tables: CN = 46. CN covers 20 % of the practical range (40 to 100).



Optimal curve number for Fernow Watershed 3 (CN = 85)

Key Points:

- Curve numbers have not and probably cannot be reliably defined to determine rainfall-runoff relationships for different silvicultural practices, including extreme floods.
    - Curve number method not formally adopted for forest runoff forecasting
    - Cannot distinguish clear cutting or any best management practice with different curve numbers.
    - Some tabulated forest curve numbers cannot be related to actual runoff.
- When the curve number was calibrated for extremely large flood runoff from these watersheds, the method under predicts by more than an order of magnitude, small frequent runoff volumes. When the curve number was calibrated for median runoff occurring every two years, extremely large runoff floods were over predicted and frequent small runoff volumes were significantly under predicted.
    - The Flood Advisory Technical Taskforce recommends calibration but the curve number method was not intended for this. More accurate methods are available to analyze measured runoff.

- The uncertainty involved in this method of runoff estimation for ungaged watersheds is too extensive even for urban and agriculture runoff for which the method has been formally adopted but the most uncertain are forecasts of forest runoff.
- Curve numbers derived from Fernow and Coweeta experimental forests vary too much with individual storm rainfall volumes to provide a consistent derivation of a standard curve number.
- Accurate runoff forecasts using curve numbers is not possible for some watersheds.

Highlights

- Protection of West Virginia citizens and economy in these policy deliberations are impressive
- West Virginia Flood Advisory Technical Taskforce used standard hydrologic analysis but the curve numbers cannot distinguish forestry effects of 4 to 6 %
- Rigorous testing of the curve number method defines the limits of the technique
- West Virginia leadership should lead to new or improved hydrologic analysis for forested Appalachian watersheds by 2007
- USFS *et al*. has made outstanding investments in experimental forests to support vital policy making in West Virginia forest management
- New models of the runoff process must be developed to soundly manage forestry practices in West Virginia and other forested mountainous areas

These findings are consistent with the expectations of the original architects of the curve number method dating to 1954. Since the method was originally published by the NRCS, many of the limitations have been overlooked, including that the method was only intended for forecasting trends, and should not be used to analyze individual storms. Different concepts are necessary to provide more precise forecasts, especially to support major policy decisions like those contemplated by the State of West Virginia.

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Dr. McCutcheon is an internationally known expert in ecological engineering and phytoremediation, water quality, hydrology, hydrodynamics, sediment transport, cleanup of toxic organic chemicals and metals, and environmental engineering. He is a Director of the Board of the 139,000-strong American Society of Civil Engineers (ASCE) and President of the American Ecological Engineering Society. Author of 3 books, he was editor and editor emeritus of the ASCE *Journal of Environmental Engineering* and now co-editor of *Environmental Science and Pollution Research*. He has served on the editorial boards of *Ecological Engineering*; *International Journal of Phytoremediation; Ecological Studies, Hazards and Solutions*, a series of books for publication in Russia; and the ASCE *Hazardous, Toxic, and Radioactive Waste Practice Periodical*. The EPA awarded Dr. McCutcheon bronze metals in 2001 and 2002. In 1999, he (with others) received an EPA Science and Technology Achievement Award Level III (selected by the EPA Science Advisory Board) for developing the first watershed-scale stream model for temperature total maximum daily load calculations. The American Chemical Society selected him (with others) to receive the 1997 EPA Science Achievement Award in Chemistry for the investigation and development of zero-valent iron walls to treat chlorinated solvents in ground water. The 1995 EPA Science Achievement Award in Waste Management selected by the Association for Air and Waste Management and EPA was awarded Dr. McCutcheon (and others) for development of a new field of phytoremediation–degradation of organic compounds by green plants. The Engineers Week Committee of the Georgia Engineering Alliance recognized him as the 2004 Engineer of the Year in Government. The 2004 Government Civil Engineer of the Year, 2004 Membership Chair Award, 1994 Torrens Award (outstanding editor among 21), and 1984 Young Civil Engineer in Government, all by ASCE, and 1992 Engineer of the Year in the EPA by the National Society of Professional Engineers have been awarded to him as well. Consulting experience includes (1) water quality assessments in Italy, (2) arid lake and harbor water quality assessments in China, (3) flood investigations in New Orleans and North Carolina, and (4) reviews of basin water quality studies, including review of plans for the Han River in Korea prior to the 1988 Olympics. Dr. McCutcheon served on an American Institute of Architects Reconnaissance Team to investigate the recent mega tsunami damage in Sri Lanka. He accompanied an ASCE Mississippi Section team to assess damage to civil engineering firms and the infrastructure they build and maintain on the Mississippi Coast (October 6, 2005). As a member of the Order of the Engineer, Steve McCutcheon has sworn to uphold the highest ethical standards. He is a member of the Environmental Ethics Faculty at UGA. As a registered U.S. engineer in Louisiana, Dr. McCutcheon has served as an expert witness on flooding in New Orleans, Louisiana. He testified for the Army Corps of Engineers at 401 Water Quality Hearing in Wisconsin on dredging and before a joint scientific board of the Province of Alberta and the Canadian Government on oil sands mining. Steve McCutcheon was given EPA awards for the bioremediation cleanup of the EXXON VALDEZ oil spill in Alaska and the emergency modeling of a chemical spill in the Sacramento River. Dr. McCutcheon has been extensively involved in risk and exposure assessments at a number of hazardous waste sites involving metals and organic chemical contaminated sediments and soils. He worked briefly on the 1980 response to the eruption of Mt. St. Helens in Washington. As a leader in phytoremediation and ecological engineering, Dr. McCutcheon was at the forefront in developing uses of plants to clean up hazardous wastes and control contaminant releases to reduce clean up costs at military facilities for the U.S. Strategic Environmental Research and Development Program to redirect U.S. weapons research. He is a noted lecturer in Australia, the Czech Republic, the Ukraine, and Italy. He has supervised student research and advised at UGA, Clemson, University of Central Queensland (Australia), University of Roorkee (India), University of Mississippi, University of Alabama, Florida International University, Georgia Tech, Rice, University of Iowa, University of Texas-El Paso, and Auburn. He developed and wrote guidance for the U.S. EPA on regulating waste loads into estuaries and streams. For the internationally reviewed *Handbook of Hydrology*, he is the lead author of "Water Quality." He has authored or co-authored over 245 publications. He has received over $US 6 million in grants, awards, and support.