Flood Advisory Technical Taskforce

Runoff Analyses of Seng, Scrabble, and Sycamore Creeks

June 14, 2002

EXECUTIVE SUMMARY

Background

The Flood Analysis Technical Team (FATT) in conjunction with the Flood Investigative Advisory Committee, both enacted by Governor's Executive Order No. 16-01, performed an investigation evaluating the hydrological aspects of the May and July, 2001, floods in southern West Virginia. The investigation focused on possible flooding impacts from logging and mining activities.

Model Development

The study concentrated on peak discharge runoff using comparative analyses. The results reached in this report provide an indication of the impacts of mining and logging practices and the consequent behavior of the watershed throughout the July 8, 2001, storm event.

Watershed Selection

Selection requirements for the study watersheds were based upon acreage, occurrence of flooding impacts, and industry intervention, i.e., logging and mining disturbances. Choosing watersheds of limited size reduced the complexity of the study, and more importantly, the time to completion. Study sites were required to have experienced flooding impacts from the July 8, 2001, event. Finally, to satisfy the executive order, logging and mining influences had to be present and quantifiable. From this selection process, Seng Creek in Boone County, Scrabble Creek in Fayette County, and Sycamore Creek in Raleigh County were chosen. Seng Creek and Scrabble Creek were analyzed using runoff comparison methods. Sycamore Creek, which had no significant logging and mining disturbances, served only as a perspective watershed.

Project Conclusion

Based upon the modeling results, mining and logging did influence the degree of runoff in the study watersheds. Seng Creek had mining impacts (measured in runoff volume – ft^3/sec.) ranging from -0.2% to 3.0% and logging impacts ranging from 3.9% to 5.9% at the various evaluation points. Scrabble Creek had mining impacts ranging from 9.3% to 21.1%, while logging impacts ranged from 0% to 4% at its evaluation points. With negligible logging and mining disturbances, Sycamore Creek experienced "out-of-bank" flows with extensive surface water impacts.

Recommendations to Reduce Flooding Impacts from Mining and Logging

Recommendations are proposed to minimize and limit runoff peaks from future logging and mining operations. These recommendations focus primarily on improvements relative to the following watershed characteristics:

- Terrain characteristics and slope of natural undisturbed ground
- Type of mining activity, e.g., Approximate Original Contour vs. Variance
- Extent of mining
- Degree of reclamation
- Extent and type of logging activity
- Degree of post-timbering regrowth

FATT Runoff Analyses

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I. INTRODUCTION

On July 8, 2001, the southern portion of West Virginia experienced major precipitation events with rainfall totals that ranged up to 6.77 inches south of Beckley in Raleigh County. The result was disastrous flooding throughout the southern coalfields that devastated many communities causing widespread property damage. Many hundreds of homes were damaged or destroyed, as were many businesses. Counties particularly hard hit were Boone, Doddridge, Raleigh, Fayette, McDowell, Mercer, Summers and Wyoming. Most of these counties are in the heart of West Virginia's southern coalfields and have extensive underground and surface mining activities. Timbering is also prevalent in this region of the State. This region also experienced other substantial, yet more localized, flooding events in May, 2001, and on July 25, 2001. In the aftermath of these events there were many concerns raised by the public and other entities as to the extent that mining and timbering activities may have exacerbated flood damage. Consequently, Governor Bob Wise issued Executive Order No. 16-01 creating a Flood Investigation Advisory Committee and a Flood Analysis Technical Team to focus specifically on the impacts of the mining and timbering industry on the July 8th flooding.

II. OBJECTIVES AND COMMITTEE MISSIONS

The overall objective of the Governor's executive order and this undertaking is to investigate the scientific and hydrologic cause of the flooding events which occurred in May and July, 2001, and to further assess the impact on flooding from current and past methods of coal mining and timbering in the affected counties and watersheds.

The Flood Analysis Technical Team (FATT) is comprised of professionals within the Department of Environmental Protection (DEP), Division of Mining and Reclamation (DMR) and operates under the general guidance of the Director of DMR. Members of the technical team include: Jim Pierce, Mike Reese, John Vernon, John Ailes, and Ed Griffith. The Technical Team was given the mission to prepare a report for the Secretary of DEP addressing the cause of the floods of May and July 2001, and specifically tasked with the following duties:

- Provide technical assistance and research support to the Secretary
- Investigate alternative mining or forestry practices if such current practices are found to have had a deleterious impact on peak water flows in affected watersheds
- Propose recommendations to the Secretary of the Department of Environmental Protection

The Flood Investigation Advisory Committee was created through the executive order and consists of not less than sixteen members, twelve of which were appointed from the public. The Secretary of the DEP and the Administrator of the Division of Forestry or their designees serve in an ex-officio capacity. The Advisory Committee was assigned the following duties:

- Assist and support the investigation of the scientific and hydrologic cause for the flooding of May and July 2001
- Assist in the determination of the effect and, if any be found, the impact on the flooding from current or past methods of coal mining and timbering practices in the affected counties and watersheds
- Provide assistance to the Flood Analysis Technical Team
- Retain or hire such hydrological, forestry, mining, or meteorological experts, as it deems necessary to assist it in reviewing any draft technical assessment prepared by the Flood Analysis Technical Team
- All such other general powers deemed necessary and proper to assist it in carrying out its particular duties under Executive Order No. 16-01

III. WATERSHED ANALYSIS METHODOLOGY

A. Introduction

Immediately after the July 8, 2001, floods, DEP initiated reconnaissance investigations of all mining and mining related sites located in the southern counties of West Virginia that had been impacted by the July 8, 2001, flood event. In addition to documenting the flood damage and high-water marks, DEP contacted the following agencies and obtained pertinent information concerning the July 8, 2001, storm event:

- National Oceanic and Atmospheric Administration (NOAA)
- National Weather Service (NWS)
- U.S. Army Corps of Engineer – Huntington District (COE)
- Office of Surface Mining Reclamation and Enforcement (OSM)
- United States Geological Survey (USGS)
- United States Department of Agricultural (USDA) Natural Resources Conservation Service (NRCS)

DEP contacted the NWS and was informed that there were three separate storm events that entered the southern counties of West Virginia and caused the flooding of July 8, 2001. The unofficial, non-certified, precipitation measurements that had been gathered by NWS for the July 8, 2001, storms are shown in Table 1.

NWS noted that prior to the flood event of the July 8, 2001, rivers and small streams were at normal to slightly below normal flows. Antecedent soil conditions in the region were normal to dry. This information was verified by DEP communications with the COE, USGS, and NRCS West Virginia offices.

The NWS county flash flood guidance values for Boone, Fayette, Kanawha, McDowell, Raleigh, and Wyoming, from the morning of July 8, 2001, ranged from 1.8 to 2.9 inches of rain. These guidance values are the precipitation amounts that would cause flooding problems in three hours. Some rainfall amounts generated by the storm events exceeded, or were just under the rainfall total.

The COE, Huntington District, provided to the DEP a precipitation comparison chart of storm events for the Huntington district that included the counties of southern West Virginia. This precipitation data was from NWS cooperative observers and NWS stations, COE project gages, and satellite gages. The COE noted that some of the precipitation data was not verified and the flooding had impacted some gages and these values could not be verified. (Table 2).

The West Virginia Geological Survey and the USGS provided to the DEP provisional recurrence intervals of locations flooded by the July 8, 2001, storm event. (Table 3). They also informed DEP of their efforts to determine the peak discharges of the streams on July 8, 2001, where the flooding had compromised or destroyed their stream gaging stations.

Probably the most misunderstood term with regard to flooding or storm events is recurrence interval. The recurrence interval of a flood or storm is defined as the average number of years between a flood or storm event of a given magnitude and any equal or larger flood or storm event. For example, over a time period of a thousand years, the ten-year flood or storm event would be the flood or storm event which was equaled to or exceeded one hundred times, or an average interval of ten years. Some people erroneously believe that if a one hundred-year flood or storm event occurs this year, it will be a hundred years before another flood or storm event as large or larger occurs. Unfortunately this is not true. If a one hundred-year flood or storm event occurs this year, a larger flood or storm event may occur next year and a still larger flood or storm event the next. The point to remember is that the recurrence interval for flood or storm event is based on a statistical average of events that have occurred, not on advance knowledge of what will occur.

B. Determination of Watershed Study Areas

The first task assigned to FATT was to determine which watersheds to analyze. FATT determined that three watersheds that had been impacted by flooding should be studied. Of these three watersheds, two had to be representative of flood-impacted watersheds that contained surface coal mining and logging operations. The third watershed would be a watershed with no mining or logging operations within the last 10 – 20 years.

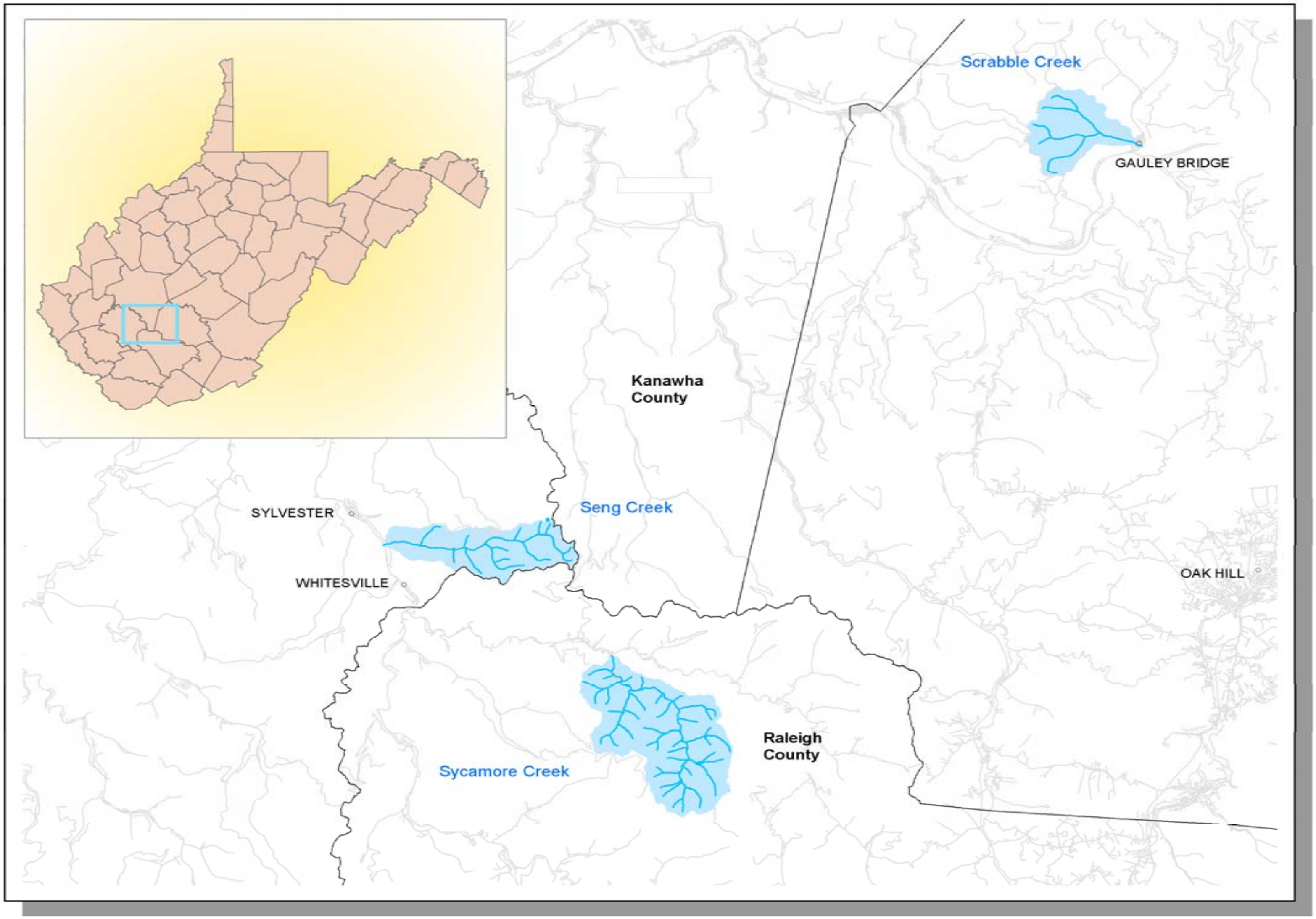
FATT determined from the beginning that the hydrologic modeling of the watersheds would be of same or similar types in order to obtain accuracy in the model similitude. This was to be achieved by comparing the watershed characteristics and only model the watersheds that were the same or similar in characteristics. The characteristics used to determine which watersheds to model were:

- Area or size (less than 5,000 acres)
- Topography (elevation and slope)
- Climate
- Meteorological event
- Vegetation type and density
- Soil type, soil depth, moisture content
- Watershed morphology and geomorphology
- Land use (urbanization, mining, logging, forest, etc.)
- Stream flood plain and floodway dimensions
- Stream profile
- Geology
- Stream roughness and characteristics
- Watershed elevation range
- Stream drainage networks or patterns
- Base flow characteristics
- Lithology of strata within the watershed
- Watershed aspect
- Watershed orientation
- Watershed shape
- Streams associated with heavy sediment transport
- Streams associated with frequent debris blockage
- Streams affected by back pooling of other streams
- Watersheds that had major forest fires within them in the last ten years

FATT reviewed relevant data available for watersheds impacted by the flooding on July 8, 2001, in the southern counties of West Virginia. After the data review and field and aerial inspections by DEP, a general list of watersheds that could be evaluated within the scope of the study was developed. Based on this information, FATT decided to isolate the watershed modeling to the single storm event that developed and progressed through Boone, Clay, Kanawha, western Fayette, and western Raleigh Counties. This limited the hydrograph modeling to a single NRCS Type II storm front that could readily be delineated, measured, and accurately mapped by certified doppler radar images from the NOAA National Weather Service station at Charleston, WV. The certified doppler radar images had been "ground-proofed" and validated by the NWS, COE, USGS, and other authorized cooperative observation weather stations before NOAA would publish the certified precipitation measurements.

The other critical characteristics relative to runoff modeling were that the watersheds had to have current regulated mining and reclamation and logging operations within the watersheds. Included with this was the topography (elevation changes and slope), stream drainage network or pattern, geology and lithology of watersheds, watershed size, lack of frequent debris blockages and back pooling from other streams, soil types, soil depth, soil moisture content, and other parameters. FATT determined that the ability to achieve hydrologic model similitude would be achieved by modeling Seng Creek in Boone County, Scrabble Creek in Fayette County, and have a "control" watershed in Sycamore Creek in Raleigh County.

WATERSHED STUDY AREAS



One significant parameter noted in the hydrologic modeling of Seng Creek and Scrabble Creek was the different post-mining land configurations. Seng Creek's surface mine was a typical mountain top removal with an approximate original contour (AOC) variance and large excess disposal structures in the hollows. Scrabble Creek's mining operation was a mountain top removal operation with the topography restored to AOC with large excess disposal structures in the hollows.

C. Watershed Hydrologic Model Parameter Development

To develop the hydrologic model for each watershed, FATT interviewed residents at approximate 500' intervals along the stream from the mouth of Seng and Scrabble Creeks to the surface mine sediment control structure discharge outlets. These individuals denoted the highwater marks of the flood on July 8, 2001, at those locations. E. L. Robinson, Inc., surveyed stream channel cross-sections every 500' on the main stream reaches of Seng and Scrabble Creek up to and including the cross-sections of the primary mine sediment control structure outlet within the stream reach. All documented highwater marks of the July 8, 2001, flood were located and included in the survey. All permanent bridges and culverts in the watersheds that were not destroyed by the flooding were located and dimensions and elevations were obtained at the inlet, outlet, and a point approximately 200 feet upstream and downstream of the structures. E. L. Robinson, Inc., surveyed control sections at specified locations along Sycamore Creek.

In correspondence with the USDA NRCS West Virginia State Conservationist, Hydrologist and Soil Scientist, it was determined that prior to and including the day of the storm event (July 8, 2001) an antecedent moisture condition of II should apply and that the storm distribution event as determined by the NRCS Technical Reports was a normal Type II storm distribution. The NRCS established runoff curve numbers for surface mine areas in March of 1990 and these values are available to the public in the NRCS Engineering Field Manual. The soil scientist and hydrologist for the West Virginia NRCS recommended to FATT that the official published county soil survey and runoff curve numbers be used in the development of any hydrologic analysis of surface runoff in watersheds located in southern West Virginia. These published NRCS soil types and groups, values, runoff curve numbers, land classifications, and land use descriptions were used by FATT in its evaluation of the studied watersheds.

The land cover description, land cover type and hydrologic condition, hydrologic soil group, and the runoff curve numbers that were provided to DEP are included in Table 5.

D. Hydrologic Modeling Methods Evaluation

FATT, with consultation of Federal and State agencies, determined that two fundamentally different approaches have been developed and utilized to describe, analyze, and provide the basis of watershed hydrologic analyses. These are the unit hydrograph method and the variable source area concept.

1. Unit Hydrograph Method

The classic approach to evaluating runoff in the short term is the engineering oriented unit hydrograph based on the relationship between precipitation intensity and infiltration during a storm. The unit hydrograph, focuses on the observation that the unit hydrograph is produced by surface runoff or overland flow that occurs because precipitation intensity exceeds infiltration capacity. Introduced first, the unit hydrograph and its attendant methods for hydrograph separation (into storm flow and base flow, primarily) currently dominate the engineering approach to watershed hydrology analyses. Based on several important assumptions, the unit hydrograph and its associated analytical methods have considerable utility in providing a means for precisely and in reliable replicated fashion analyzing assumptions themselves. It provides insight into the nature of the runoff process, as well as a means of evaluating and predicting stream behavior within the watershed with historic storm events and synthetic storm events.

2. Variable Source Area Method

Here is where the distinction between storage and process begins to break down; this concept embraces both elements. Runoff is the result of interaction of a rainfall (or snowmelt) event and numerous different types of storage over the entire watershed. This gives rise to the variable source area concept, which recognizes the three-dimensional, dynamic nature of the runoff process, along with the knowledge that that process is in no way a simple one. The concept was initially named and presented by Hewlett and Hibbert who, after pointing out that “hydrograph separation is one of the most desperate analysis techniques in use in hydrology”, noted that:

> Stream flow is generated chiefly by processes operating beyond perennial stream channels, [that] the yielding proportion of the watershed shrinks and expands depending on the rainfall amount and antecedent wetness of the soil, [and] the concept that stream flow from a small watershed is due to shrinking and

> expanding source area – the variable source area concept – grew out of studies of the drainage of sloping soil models at the Coweeta Hydrologic Laboratory.

Prior to that, Betson had reported that “runoff originates from a small but relatively consistent, part of the watershed,” but that, in apparent contradiction thereof, there seemed to be variable portions of the watershed that contributed runoff at different times during storms. In a subsequent study, Betson and Marius (1969) had reported that the area contributing runoff was definitely not constant and the “variation in the depth of the topsoil caused a heterogeneous runoff pattern”.

Variable source area is, in many ways, more difficult to comprehend than is the unit hydrograph method. It demands a conceptualization of the entire watershed. Ultimately, therefore, it demands synoptic, critical analysis of all the relevant factors affecting runoff from the drainage basin. Of special importance is consideration of the watershed’s response to water input under a given set of antecedent moisture conditions. Essentially, all of the factors that affect the movement and storage of water must be within the conceptual boundaries for analysis of the watershed by the hydrologist. They are the underpinning of an ecological approach to the hydrologic analysis of the watershed.

E. FATT’s Watershed Model Development Concepts and Concerns

1. Unit Hydrograph Method Development and Use by FATT

Introduced by Sherman (1932), the unit graph or unit hydrograph represents on paper the combined surface and subsurface runoff (“storm flow”) from each separable segment of a watershed. It is a specialized case of the storm hydrograph, the pulse response of the watershed to the water input. This information was ascertained by field observations of hundreds of watersheds within the United States that resulted in the empirical equations that were used to develop the principles for the unit hydrograph and its associated equations relative to soil types and hydrologic soil conditions, land use, and land cover. This methodology led in the direct development by the Soil Conservation Service (SCS) of equations to determine curve numbers for defined soil types, soil hydrologic groups, land uses, and cover types within specific topography ranges. Wisler and Brater continued this work and provided a succinct statement of the principles of unit hydrograph theory:

- A unit hydrograph is a hydrograph of surface runoff resulting from a relatively short intense rain, called a unit storm
- A unit storm is defined as a rain of such duration that the period of surface runoff is not appreciable less for any rain of shorter duration. Its duration is equal to or less than the period of rise of a unit hydrograph, that is, the time of the beginning of surface runoff to the peak. For all unit storms, regardless of their intensity, the period of surface runoff is approximately the same.
- A distribution graph is a graph having the same time scale as a unit hydrograph and ordinates, which are the percent of the total surface runoff that occurred during successive, arbitrarily close, uniform time increments. Alternative and interchangeable units for the ordinates are cubic feet per second per square mile per inch of surface runoff. The most important concept involved in the unit hydrograph theory is that all unit storms, regardless of their magnitudes, produce nearly identical distribution graphs.

The basic assumptions underlying the unit hydrograph theory are:

- The contribution of each watershed segment does not interfere with the runoff from other segments
- That the runoff contributions from all the units are additive (Singh 1976). The unit hydrograph is a valuable analytical and educational tool. Its analytical value is particularly useful in determining storm-designed facilities such as culverts, reservoirs, and flood control works and analysis of small to medium watershed surface runoff response time (Dunne and Leopold 1978).

Linsley, Kohler, and Paulhus (1949) point out that consideration of the unit hydrograph "leads naturally to the hypotheses that identical storms with the same antecedent moisture conditions produce identical hydrographs." Proportionality exists between various measurable parameters of the hydrograph (e.g., height, length and rainfall duration) and, since the recession or falling limb is asymptotic to zero, and its rate of fall and duration are functions of its initial value (related or equal to the peak flow), the integration of the area under the hydrograph, which is volume of flow (cubic feet per second times time in seconds) will also be proportional to the storm's parameters.

Current watershed studies have shown that the ratio of storm hydrograph height to length is a constant, that peak flow is a function of rainfall excess, that the recession or falling limb has a characteristic and constant shape, and that the unit hydrograph may be used for separating storm flow from base flow in order to achieve the foregoing measurements. In the event of accretion to groundwater during the storm, previous knowledge concerning the isolated runoff causing event's unit hydrograph may be useful in separating storm flow and base flow during these more complex periods as well. However, many times, it is necessary on ungaged watersheds for the hydrologist to calculate and determine the base flow using watershed modeling software. This watershed modeling methodology is comparative to the procedure that FATT used to analyze the ungaged study watersheds.

The unit hydrograph method works best for a relatively compact watershed with no major channel or groundwater storage, and hence may be used for watersheds under about 2000 square miles of area. It is best if the rainfall duration modeled for the watershed is approximately one-fourth the watershed basin lag (the time between the centroid of precipitation and the occurrence of the peak discharge) (Linsley, Kohler, and Paulhus 1949). On occasion, application of the unit hydrograph theory has been extended to larger and more complex watersheds and even to groundwater hydrographs. However, FATT chose watersheds that were less than 2000 square miles and did not have complex inter-basin water exchanges or complex groundwater situations contained within the watershed boundaries.

Smoothed, the plot of discharge (or head) over time is an oversimplified representation of a single storm event in a stream's history. In fact, a stream gage provides data to plot such a curve. Such plots of discharge versus time demonstrate the following:

- The curve assumes a characteristic shape for a given watershed, (i.e., delta shaped, linear, etc.)
- Further understanding of the runoff processes on that watershed becomes possible
- Runoff response is affected when land use, cover type, topography, stream alterations, or other runoff-affecting factors are altered

The hydrograph is a complex integration of runoff from each sub-basin or portion of the watershed that contributes to the peak flow, as well as an integrator of all the factors that affect it (American Society of Civil Engineers 1949). Violation of the assumptions underlying the hydrograph method provide the range of limitations of its use, the most common violations are:

- The storm does not uniformly, instantaneously, and completely cover a sub-basin and/or watershed analyzed

- The storm moves in an orientation to the watershed that will result in a considerable impact of the shape of the resultant storm hydrograph (i.e., moving at an angle greater to angle of 45 degrees to the main stream reaches of the sub-basins and/or watersheds, or up or down the main axis of the sub-basins and/or watersheds)
- The most commonly occurring natural violation is that the outflow from one watershed unit does not interfere with the outflow from another watershed unit nor does the pooling effect of one watershed unit impact another watershed unit

The measurements associated with the sub-basin and watershed hydrographs are empirical or incomplete approximations of the true and full relationships between many influencing parameters. However, there remains some very useful application of unit hydrograph theory in the hydrologic modeling of sub-basins and small to medium watersheds.

The DEP FATT used the unit hydrograph method in the hydrologic analysis and modeling of sub-basins and watersheds in order to predict peak flows of the historic storm event of July 8, 2001, and synthetic storm events based on a 25-year/24 hour and a 100-year/24 hour storm. FATT then compared the watershed hydrological modeling results with actual field surveyed high water marks of the July 8, 2001, flood in the watersheds studied.

F. Watershed Characteristics Used by FATT in Modeling of Watersheds

On an impervious watershed surface with constant slope, area, soil type and roughness (minute depression storage as well as resistances to surficial laminar flow), the peak flow will be a function of precipitation intensity and can be calculated. As with the situation with the unit hydrograph, one must make assumptions concerning the areal extent of the storm and the time-distribution of the precipitation. Normally, the hydrologist makes the assumption that the watershed is instantly, uniformly and completely covered by precipitation (rainfall) that has a constant rate from start to finish for the storm event. This modeling assumption makes the hydrologic model solution easier, and any deviation from such assumed uniformity complicates the solution.

Time of concentration is defined as the time necessary for a precipitation event to cause runoff in a given watershed. This is the period that is necessary for saturation of the surface in the sub-basin or watershed to occur.

Additional complicating hydrologic modeling factors include:

- Presence of groundwater storage
- Varying subsurface runoff
- Length of time between storms
- Nonuniformity of watershed
- Temperature
- Aspect
- Slope
- Type of vegetation
- Season
- Stream alteration
- High turbidity or excess sediment transport
- Channel scouring and associated sediment transport
- Stream alteration do to land mass slips into the stream
- Debris or damming of restrictions of flow with the stream reaches
- Climatic seasons

These factors influence evapotranspiration, stream reach discharge rates, peak discharges and the hydrologic season and the response of surface runoff to existing hydrologic conditions and their variables. The potential for variability in sub-basins and watersheds during storm events requires:

- The acceptance of unmeasureable influences
- The need for estimation by more than one technique, and/or
- The identification and elimination of the influence of minor or insignificant variables relative to the modeling of the sub-basins and/or watershed

Of primary importance is the presence or absence of groundwater storage and its possible contribution to peak discharge of surface runoff during storm events. This effect is important for hydrologic modeling of small to medium size watersheds, such as the watersheds chosen by FATT. For this reason, much of the early peak flow determination work as performed by other researchers was done with “small” sub-basins or watersheds; those that have, by definition (Chow, 1964), a drainage area of less than 100 square miles.

1. Base Flow Recession in Watershed Model

If, during the runoff event, there is an accretion to groundwater, or there are more than one-storm pulses, then a complex hydrograph will result. However, FATT was able to select watersheds in which there was a single thunderstorm event that could be tracked over the watersheds, which resulted in the flooding, and the accretion was approximately equal to zero. Base flow recession analyses was carried out on clearly separate storms, therefore a more complete ability in the hydrologic analysis resulted in the protection of the base flow recession and storm flow. This resulted in FATT being able to clearly delineate the effects of base flow from the runoff resulting from the storm event.

2. Stream Behavior

   The parameters associated with a high intensity storm event or a flash flooding event have been modeled by researchers, but have yet to be refined and determined to be reliable. It is possible that select sections of a sub-basin or small watershed can be modeled that have limited impact from stream alteration, channeling, scouring, high turbidity, excessive sediment transport, debris blockage, damming of the stream reaches and other unknown parameters. FATT recognized and addressed these limitations of modeling of the sub-basins and watersheds chosen for the case studies in the early development of historic data for said sub-basins and watersheds. Subsequently, FATT determined and used only those stream reaches that had minimum impact by these and other factors that would influence the historic watermarks associated with the flood event that occurred during the flood events of July 8, 2001, to calibrate and validate the hydrologic models.

3. Watershed Morphology

   In southern West Virginia the watershed hydrology, in addition to natural geomorphology, is altered by man-made structures in the watersheds analyzed by FATT. Man-made structures that influenced the morphology of the watershed included:

   - Filling in of the natural flood plains and stream channels with material
   - Alterations of stream channel cross-sections
   - Removal of dense, deep-rooted vegetation from natural stream banks, making them easily erodible and subject to stream alteration and channel scouring
   - Removal of streambed gravel to use in construction
   - Construction of structures in the normal floodplains of the stream that were displaced by the flood waters and in many cases resulted in debris blockage and resulting in flooding of the streams

- Undersized culverts and bridges whose cross-sectional area did not allow for the adequate passing of the flood event stream discharge and thus caused flooding at that point and upstream of that point until said structures failed or were overtopped by the flood waters
- Trash, debris, and unwanted items (i.e., car parts, appliances, etc.), that were in the normal floodplain and when flooding occurred they were lifted up by the flood waters and were moved a point where they caused debris blockage and/or damming until the flood waters forced the blockage to break or the flood waters went over and/or around said blockage

4. Sedimentation

In geomorphology, there are many theories, classification, and details of the aggradation and erosion processes that sculpt the sub-basin and watershed landscape. Major, broad-scale geologic processes are those by which the land surface is lifted and prepared for the processes that wear it down. Locally, aggradation occurs when the stream velocity is diminished such that the water can no longer carry large sized particles. This process is called sedimentation. The process where sediment is suspended in water is commonly referred to as sediment transport and is associated with many variables such as lithology, water temperature, stream velocity and other unknown factors. Due to these unknown variables, FATT chose not to include the analyses of sediment transport associated with the July 8, 2001, flood event.

5. Model Watershed Area or Size

Past research has made numerous attempts to define a “small watershed”, either by actual size (e.g., 100 square miles) or function (e.g., response to precipitation inputs), or types of storage (e.g., no groundwater storage). Some runoff calculation formulas specify a watershed size limit.

The Runoff Committee of the American Geophysical Union stated that:

> From the hydrologic point of view, a distance characteristic of the small watershed is that the effect of overland flow rather than the effect of channel flow is a dominating factor affecting peak runoff. Consequently, a small watershed is very sensitive to high-intensity rainfalls of short duration, and to land use. On larger

> watersheds, the effect of channel flow or the basin storage effect becomes very pronounced so that such sensitivities are greatly suppressed. Therefore, a small watershed may be defined as one that is so small that its sensitivities to high intensity rainfalls of short duration and to land use are not suppressed by the channel storage characteristics.

Chow's (1964) definition is based upon a combination of the function and response concepts, specifically, the interaction of rainfall intensity and channel storage. This definition is fine in principle because it is a "floating" one rather than being specifically tied to some arbitrary, finite area. However, the definition is untenable in that it uses overland flow, which is runoff over the surface of the soil before becoming channelized. Generally overland flow is not a natural feature of non-urban hydrology.

Recognizing that there are broad groupings of factors that affect runoff and storage extending from the large-scale atmospheric and climatic factors, through weather, hydrographic, geomorphic/basin, soils-vegetation/land use, and channel/groundwater storage factors, FATT chose to define a small watershed as follows:

> A small watershed is one where channel and groundwater storage is not sufficient to attenuate or contribute to a flood peak primarily influenced by weather and land use.

6. Watershed Delineation

Watersheds are often not immediately discernible from a map or on the ground. The first step in watershed analysis is to identify the watershed outlet (lowest point or base level) on a map or computer model. Once the watershed has been identified, a number of parameters can be calculated that aid in describing and quantifying the characteristics of the watershed. The determination of several watershed parameters provides information that is useful in making decisions about how to manage the watershed in addition to simply describing it.

As implied in the definition of "watershed", the area of the drainage basin level can be identified on a topographic map. Most common of these maps are the quadrangle sheets and digital elevation models (DEMs) issued by the U.S. Geological Survey. These maps typically cover 7½, 15, or 30 minutes of arc (scale units 1 = 24,000, 62,500, and 125,000, respectively), and show streams, wetlands, forest vegetation, and several cultural features in addition to the contours. Other sources of maps for modeling are those generated by aerial photogrammetry, remote sensing imagery, and **Li**ght **D**etection **A**nd **R**anging techniques, known as **LiDAR**. Cultural features, include useful surveying details, such as latitude and longitude, map names, and, where appropriate, boundaries that are marked on the ground, benchmark elevations, and elevations of peaks and water bodies, mine boundaries, logging boundaries, urbanization extent, etc., can be established by remote sensing imagery, airborne scanning laser altimetry (LiDAR), aerial photography, etc.

Unfortunately, the topographic boundary (divide) of the watershed as determined may not be the true hydrologic boundary. The watershed may be larger than indicated by the topographic divide because waters are diverted into it by a phreatic divide outside the watershed topographic boundary drawn on the map. The absence of non-conforming topographic and phreatic divides were field verified by FATT. Their determination resulted in FATT utilizing the topographic divides as the boundary for the watersheds studied.

FATT used various sources for watershed boundary delineation. LiDAR and USGS DEM sources with field verifications enabled proper watershed boundary delineation.

G. Watershed Modeling Parameters Evaluated and Utilized by FATT

Upon establishing the watershed boundary, several watershed parameters were determined by FATT. Those included watershed size with the associated feature aspects of elevation (maximum, minimum and mean values). Other watershed parameters considered were distribution of elevation, aspect, orientation, perimeter length, shape, and drainage network patterns. The following physical parameters were used in evaluating hydrologic characteristics.

1. Area or Size of Watersheds

Watershed area and size is important in order to estimate water resource parameters such as total annual yield and flood potential, and to evaluate land use measures that control water quality, quantity, or regime. Most importantly, size is an essential consideration in the initial evaluation of a watershed's hydrologic behavior. The hydrologic modeling analyses of the watershed by FATT were performed on watersheds of similar size.

The area of a watershed may be determined by any of several methods. FATT used a computerized area measurement system. While it is recognized that a good portion of the watershed is, in all likelihood, on a slope, the area that is reported is the horizontal projection of the watershed boundary.

FATT recognized the importance in differences in land use, land cover, topography, watershed area, and groundwater storage reservoirs. These parameters were tested for their sensitivities in the FATT models.

In terms of runoff per unit area, the peak flow is lower and later on larger watersheds. Small watersheds are said to have “flashy” hydrologic behavior, that is, they exhibit higher high flows and lower low flows. Calculation of the ratio of maximum to minimum flows reveals higher ratios on small watersheds, an interesting but unstandardized measure of “flashiness.”

2. Elevation and Slope of Watersheds

Elevations of specific points on a watershed may be read directly from a topographic map and interpolated/extrapolated for other points, or calculated by the modeling software. Slope is simply the gradient, or vertical difference between two points whose elevations are known divided by the horizontal distance between them. Elevation is important because precipitation generally increases with increasing elevation due to an orographic effect and slope is important because it is a prime factor in infiltration capacity. Combined with elevation, slope can be an important factor in orographic effects, and combined with aspect, slope is also important in insolation considerations that play a role in evapotranspiration. Generally, as slope increases, so does precipitation flow velocities.

3. Aspect and Orientation of Watersheds

Aspect is the direction of exposure of a particular portion of a slope, expressed in azimuth (0-369°, compass bearings (e.g., N 47°E) or the principal compass point (N, NE, E, SE, etc.). Orientation is the general direction of the main stem of the stream on the watershed. A watershed with an east-west orientation is likely to have slopes that are predominantly north and south in aspect.

Aspect is an especially important feature of the watershed in view of insolation. A 45-degree south-facing watershed at 45°N presents a surface that is parallel with a horizontal surface at the equator and perpendicular to incoming radiation. In most situations, the rays of the sun have a greater length of travel through the atmosphere which attenuates their intensity. For example, at the summer solstice, with the sun at its maximum northerly declination of 23½°, the 45° south-facing slope at 45°N latitude and the horizontal surface at the equator receive nearly the identical amount of radiation. At certain times, the south-facing slope is certain to be a great deal dryer, have greater evapotranspiration, and therefore support more xerophytic vegetation than other nearby slopes. Conversely, north-facing aspects will tend to be cooler, have vegetation typical of more northern locations, yield greater annual runoff, and exhibit more flashy runoff behavior.

The overall effect of aspect is that highly insolated (exposed to sunrays) facets are likely to have lower average annual runoff than other portions of the watershed. Soils, if well developed, may increase water holding capacity, resulting in more sustained low flows, and have ample storage for attenuating flood peaks. Runoff will therefore tend to be less flashy as well. The reverse is likely to be true for aspects with lower isolation.

4. Watershed Shape

The shape of the watershed can have a profound effect on the hydrograph and stream behavior, particularly from small watersheds, and especially in relation to the direction of the storm movement. Watershed shape has a distinct influence upon the time of concentration. Consequently, time of concentration can be used to aid in studying the effects of watershed shape on the hydrograph and on stream behavior.

The combination of watershed shape and direction of storm movement is important. For example, if the rainstorm moves down the watershed over a 1-hour time period, the peak will be very high because the upper reaches of the watershed will be contributing runoff to the peak at the same time as the storm is over the outlet of the watershed. Conversely, if the storm moves up the watershed, the peak will be greatly attenuated.

Watershed shape has no obvious effect on average annual water yield. The primary effect of watershed shape appears to be its influence on the peak flow during a rainstorm on a small watershed. If storage on the watershed is limited, and there is considerable influence of shape on the magnitude of the peak, then the minimum flow might be affected as well. Such an effect is most likely in the extreme case, for example, where the watershed is long and narrow and exhibits little or no groundwater storage.

In extensive studies on models, watershed shape did not have as great an effect on peak flows as other characteristics such as slope or soil depth, and it may be dominated by direction of storm movement, antecedent moisture conditions, precipitation inputs, or other factors (Black 1972).

Time of concentration (in this case, time from start of precipitation until the peak flow occurs) was not affected by direction of storm movement, but the lag time (time from start of precipitation until stream starts to rise), and storm peak magnitude was affected dramatically.

Consideration of watershed shape is likely to be important when considering the effect on peak flows and regime from a portion of a watershed dependent upon its location in the larger watershed of which it is a part. Thus, for example, increased runoff from a small, logged watershed may have a different effect on the peak from a larger downstream watershed (within which the logged area is nested) dependent upon where the logged area is within the larger watershed.

5. Drainage Network of Watersheds

The drainage network of a watershed is the system that collects the water from the entire area and delivers it to the outlet. It includes the subsurface and surface drainage. In most cases, the entire drainage network is not revealed to the hydrologist, while the surficial stream drainage pattern is. The pattern of streams is only the surface manifestation of that larger system, and may carry a widely varying percentage of the total runoff. Most of the research into drainage networks has actually been directed at this surface portion; it is readily discernible on the map, can be measured and characterized, and can be described both numerically and verbally.

Initial evaluation of drainage networks was on the basis of stream order designated by 1, 2, 3, etc. A stream of order 1 has no tributaries; a stream of order 2 has tributaries of order 1, and so on. In the European system, a Class I stream is the main stem of the drainage, discharging directly to the ocean or a large water body. Class II streams are major tributaries to Class I, and Class II are minor tributaries discharging into Class II streams. Wisler and Brater (1959) point out that the original method of designation of using "I" for the smallest tributary, and working downstream assigning the next higher number when two tributaries of the like number join. The method is not conducive to comparative uses, or to calculations as shown. A major difficulty with stream order is that streams of different class may have different flow magnitudes because they have different tributary systems. Conversely, streams of the same class can drain watersheds that are considerably different in size dependent upon which magnitude of stream is designated "Class 1," thus making it difficult to compare or generally inventory the classes. Horton's system of stream order designation commenced at the tributary level (Class I) and the number increased as more and more tributaries were involved, thus, the higher the number assigned to the main stem, the larger the watershed and the greater the number and extend of its tributaries (Linsley, Kohler, and Paulhus 1949). Strahler (1957) modified the system to apply to segments of streams between confluences. A great deal of research has been done on stream development theory, network evolution, bifurcation ratios, and relationships between drainage network and geology. While stream order has been shown to be related to other basin characteristics, no expression of stream order has been consistently or usefully related to runoff behavior.

Verbal description of the surface drainage pattern has not been formalized, but geomorphology tests typically refer to drainage patters in terms that are derived from describing leaf venation, fruit- or tree-forms, or other well-recognized formations. Thus the names: dendritic, palmate, pinnate, wye, trellis, radial, and annular are among those most often used. According to laboratory studies on watershed models, drainage pattern appears more important than drainage density in influencing peak flows and lag times (Black 1972).

Streams are classified in geologic texts as being influent, effluent, or intermittent. The influent stream provides water to the groundwater storage. The effluent stream conveys water from groundwater storage year round: this is the so-called permanent, or perennial stream. Ephemeral streams flow immediately following runoff-causing events, especially in arid climates; the bed may dry up rapidly, even following torrential runoff (Strahler and Strahler 1973). Intermittent streams, which also may flow immediately following a runoff-causing event, provide water to perched water table or to deep seepage. Standing on the bank of a stream that is flowing one moment and disappears into its bed the next, it is impossible to determine whether the stream is intermittent or ephemeral by its appearance. A watershed may exhibit any of these classes in different reaches of the stream.

Watershed characteristics have an effect on runoff behavior from small watersheds. An understanding of the impact of those characteristics on stream behavior is essential to successful hydrologic analyses and modeling of watersheds. These aspects were evaluated when choosing our study watersheds.

6. Watershed Geology

The most important geologic property in considering a watershed's hydrology is its soil. The type of soil determines its infiltration rate and its porosity; that is, how quickly the soil can absorb water and how much water the soil can hold per foot of depth, respectively. Sand, gravel, loam, and peat soils have high infiltration rate and high porosity, while rocky or clay soils have low ones. Those soils with high infiltration capacity and high porosity will contribute less to flooding, since they absorb and retain more rainfall than other soils. It should be noted here that since the infiltration rate is usually a fraction of an inch per hour at most, neither infiltration nor porosity are significant factors except when discussing rainfalls of low intensity and long duration which are those that cause worse flooding on large watersheds.

Also important for soils of any given type is the depth of soil. The depth of soil determines the total capacity of storage available. This simply means that, for a given type of soil, a watershed where the soil is deep can hold much more moisture than one where the soil is shallow. The total moisture-holding capacity of a soil is important because when this storage volume has been filled with water, no further moisture falling on or running over the surface will be absorbed. This indicates that the potential decrease in floodwater volume is roughly proportional to the depth of the soil for a given soil type.

7. Watershed Lithology

Associated with a watershed's geology is the lithology of the strata in the watershed and its ability to resist erosion and thus decrease sedimentation. Sedimentation denotes the processes of erosion, transportation, and deposition. Erosion consists of detaching soil or rock particles and moving them to a channel in which they may be transported. Erosion may be caused by the impact of raindrops or by a combination of drag and lift forces on soil particles resulting from the fluids motion.

The regulated surface mining and logging operations likely minimized some sedimentation impacts in the watersheds by virtue of compliance with the rules and regulations enforced by that specific regulatory agency. The sediment and drainage control structures for mining and logging were not modeled with any attenuation in the structures. Readily available information relative to the storm volume attenuation in the structures was unavailable. Consequently, broad assumptions would have been necessary to model the effect of available storage volume upon the July 8, 2001, storm runoff. Therefore, FATT assumed that all sediment control structures were full of water and no attenuation occurred within the structures.

8. Watershed Sediment Transport

The topic of the influence of sediment transport was discussed in depth with the NRCS, COE and OSM. FATT and these agencies agreed that the sediment loading should be considered if the strata lithologic data, sediment load, and other sediment transport parameters are available. However, no reliable data of this nature was available for any of the watersheds studied. In addition, the NRCS, COE and OSM stated that time and budget constraints normally prevent detailed sediment transport studies to be included in their hydrologic analyses of flood events. As a result, FATT decided to restrict its watershed hydrologic analyses to only the relationship of non-sediment laden water and its impact on the flood events of July 8, 2001.

H. Modeling Software Utilized by FATT

Once the watersheds were chosen by FATT for hydrologic analyses modeling, the FATT personnel investigated the most accurate and representative hydrologic modeling techniques and tools currently available. After consultation with Federal and State agencies, FATT determined that watershed hydrologic analysis is typically done using lumped parameter models such as the U.S. Army Corps of Engineers (CEO) HEC-programs, Natural Resource Conservation Service (NRCS) TR-20, and other models. FATT chose to use the HEC-1 model within BOSS International's suite of watershed modeling programs to model the hydrology of the watersheds.

BOSS Watershed Modeling System (WMS) is a comprehensive software environment for hydrologic analysis and modeling. The Engineering Computer Graphics Laboratory of Brigham Young University, in cooperation with the U.S. Army Corps of Engineers Waterways Experiment Station, developed it. The BOSS WMS software was used by FATT to model and develop the hydrologic models in the study watersheds. The computer results were used to determine the potential impact that mining and logging operations may have had on the flooding on July 8, 2001, in the studied watersheds.

Throughout this study, FATT periodically consulted BOSS International. BOSS provided a computer technical representative to discuss the limitations of the WMS program and the feasibility of our modeling approach. All recommendations offered by BOSS were evaluated by FATT. Boss International's involvement was solely at the discretion of FATT, but was thought necessary to assure a defensible modeling approach.

The WMS program is a broad-based hydrologic modeling system. Of the many available aspects of the program, FATT chose the most applicable features, based upon our available data. The following items highlight some of the program's features and source/input data requirements evaluated by FATT.

1. Watershed Software Modeling Capabilities and Limitations

   The distinguishing difference between WMS and other applications designed for setting up hydrologic models is its unique ability to take advantage of digital terrain data for hydrologic model development. WMS uses three primary data sources for model development:

- Geographic Information Systems (GIS) Data
- Digital Elevation Models (DEM's)
- Triangulated Irregular Networks (TIN's)

GIS data includes points, lines, and polygons to represent basins, streams, and key points such as outlets or culverts. In WMS, GIS data are called Feature Objects. Feature objects data can be used by itself to create a watershed models for hydrologic analysis or as a companion in the development of watershed models with DEMs.

With WMS, properly structured hydrologic models can be created automatically from points, lines, and polygons. This data was developed and stored in a GIS by DEP's Technical Applications and Geographic Information Systems (TAGIS) unit by importing from ArcInfo and ArcView, or DXF files. In WMS, lines used to define a stream network have direction. For each line (arc), there is a beginning and an ending node and "flow" along the line is defined in this direction.

In WMS there are three primary feature object types:

- Point data representing the watershed outlet and any sub-basin outlet or confluence points
- Arc (i.e., lines) data representing a stream network
- Polygons representing watershed boundaries, land use areas, and soil type areas

2. FATT Watershed Modeling Procedures

The FATT used BOSS International's WMS for defining models of the watersheds and developing hydrologic data, using digital elevation models (DEMs). A DEM is simply a two-dimensional array of elevation points with a constant x and y spacing. While a DEM results in data redundancy for surface definition, their simple data structure and widespread availability have made them a popular source for digital terrain modeling and watershed characterization. The DEMs used for modeling the three watersheds were based on USGS 30-meter (Seng Creek) and 10-meter (Scrabble Creek) models, and 3-meter airborne scanning laser altimetry (Light Detection And Ranging or LiDAR). LiDAR is increasingly gaining favor for accurate dense topographic mapping as it can penetrate the vegetation canopy and give actual ground elevations (Flood and Gutelius 1997). Topographic information developed with LiDAR can be generated over large areas at a horizontal resolution of 1 – 3 meter and a vertical accuracy of $\pm$ 15 cm. To increase the accuracy and speed of the development of the horizontal and vertical control for the watersheds being studied by FATT, DEP's Technical Applications and Geographic

Information Systems (TAGIS) unit met with FATT and strongly suggested that airborne scanning laser altimetry, more specifically, LiDAR, should be used to save both time and money in gaining the information needed to accurately model these watersheds. TAGIS arranged for several demonstrations of LiDAR's accuracy and project capabilities, and FATT members unanimously agreed that LiDAR was the only methodology that could be used for these specific watersheds for hydrologically modeling. TAGIS's personnel continued their strong support of the FATT project throughout its life and helped FATT by utilizing the state-of the art technology for the most accurate modeling methods currently available to the public. Without the assistance and direction of TAGIS's personnel, the progress and accuracy of these watershed analyses could not have been achieved to the degree of accuracy obtained and within the time frame mandated.

The primary data sets, which were obtained to perform watershed delineation with DEMs, were elevations, and flow directions. WMS can read digital elevation in standard USGS grids, Environmental Systems Research Institute (ESRI) ArcInfo grids, A(merican) S(tandard) C(ode for) I(nformation) I(nterchange) or ASCII grids, and Geographic Resources Analysis Support System (GRASS) grid formats. Flow direction data for DEM points were computed using the version of TOPAZ especially created for distribution with WMS. This version of TOPAZ, created for use with WMS, only requires an elevation grid as input and produces a flow direction grid as output. The TOpographic PArameteriZation program (TOPAZ) was developed by the USDA-ARS, Nation Agricultural Water Quality Laboratory. A modified version of the program is distributed with WMS for the purpose of computing flow directions for use in basin delineation with DEMs directions. TOPAZ is capable of DEM elevation processing, including raster smoothing, flow accumulation computations, basin and stream delineation and ordering, and development of other watershed parameters. TOPAZ uses a form of the eight-point pour model to determine the direction of flow. This model specifies that the flow will be directed toward the neighboring (in a structured grid there are eight neighbors for each point) DEM point with the lowest elevation. The algorithms typically include functionality for eliminating pits and resolving ambiguities with the lowest elevation is shared by more than one neighboring point.

With the flow directions assigned for each DEM point, the flow accumulation at each DEM point can be computed. The flow accumulation for a given DEM point is defined as the number of DEM points whose flow paths eventually pass through that point. With the aid of the flow accumulations, the location of the watershed outlet was determined and an outlet feature point created there. A minimum threshold is then defined and all of the DEM points "upstream" from the defined outlet(s) are connected together to form a stream network of feature arcs lines.

The watershed was subdivided into sub-basins, and then nodes along the stream feature arcs were converted to “outlet” nodes. As these nodes are converted, the hydrologic modeling tree is automatically updated. Using the outlets on the stream network and the flow directions, the contributing DEM points for each outlet are assigned the proper basin ID.

As with the stream vectors, the boundaries between DEM points with different basin IDs were converted to feature polygons. Once the boundaries of the sub-basins were determined, geometric properties important to hydrologic modeling were computed from the DEM data.

WMS utilized DEMs to define watershed models. Developing watersheds from DEMs involves the use of both feature objects and DEMs. An elevation source is required for creating a model with WMS. The watershed outlets and streams were defined manually in order to confirm key drainage features, such as streams, to the watershed geometry. By default there may only be a single outlet point for the watershed defined, or perhaps only a portion of the stream network. WMS was used to add additional outlet points (representing sub-basin, culverts, etc.) and stream branches.

The watershed network and basin boundaries defined by FATT included several important watershed geometric parameters that were computed by WMS. These parameters (i.e., drainage area, slope, length, etc.) automatically tie into the HEC-1 hydrologic model by WMS. Along with the watershed definition on the DEM, an accompanying topologic model is created. FATT interacted with the model of the watershed to complete input for and begin the development of hydrologic analyses.

All gridded elevation data imported into WMS was in the ESRI ASCII grid format. Grid files were used as DEMs in WMS. Flow directions and flow accumulation grids were compiled by TOPAZ to define an elevation source within the watershed limits. After importing the computed flow direction and flow accumulation grids, all of the remaining watershed parameters were developed by WMS. The USGS and LiDAR elevation DEM or DEMs were used as the background elevation map when creating the watershed models.

Shape files created by DEP and the DEP TAGIS unit provided the method for FATT to import GIS data into WMS and create a watershed model directly.

In order to import shape files into WMS, the following conditions were met:

- A point coverage containing watershed and sub-basin outlet, with the appropriate type (outlet point) attribute defined must exist
- An arc (or line), coverage containing streams in the watershed with the appropriate type (i.e., stream) attribute defined must exist
- A polygon coverage containing watershed boundaries must exist
- There cannot be any overlapping arcs
- Stream arcs must be created from a downstream to upstream direction for all arcs

3. Feature Objects Used in the Watershed Modeling by FATT

   Feature objects in WMS have been patterned after Geographic Information systems (GIS) objects and include points, nodes, arcs, and polygons. Feature objects can be grouped together into coverages, each coverage defining a particular set of information. The use of feature objects is determined by the coverage, or attribute set, to which they belong, but were separated into three categories:

   i. Basin polygons and stream networks of pre-delineated watersheds as a shape file where the basin delineation and attribution has already taken place
   ii. A conceptual model or layout of features in the watershed, such as its rough boundaries and streams
   iii. Soil types, land use, or other data that can be used to define important hydrologic modeling parameters such as curve number (CN)

4. Development and Utilization of Hydrologic Modeling Techniques for Watersheds Used by FATT

   With GIS and other digital data, delineated stream networks and basin boundaries for a given watershed exist. FATT used WMS to build hydrologic models from three different features of the WMS map module: polygons representing basin boundaries, arcs representing stream networks, and nodes representing watershed and sub-basin outlet points.

   Data imported from a shape file was used to set up the hydrologic model in HEC-1. Attributes from the shape files were input and other hydrologic data developed with GIS was used to define input parameters of the given hydrologic model. A geo-referenced TIFF image map was used to establish the boundaries of the watershed at the proper scale so that lengths and areas determined from the feature objects were correct. The feature objects included the mine boundaries, timbering property, urbanized areas, etc.

A DEM was used as a background elevation map for interpolating elevation values to newly created vertices of the model.

5. NRCS Curve Numbers and Other FATT Model Analyses Input Parameters

Beside the creation of stream networks, and sub-basin boundaries, feature objects were used in WMS by FATT to define polygonal zones representing soil types, land use, etc. These polygons were then overlaid with the basin boundaries to determine composite curve numbers, pre-dominate soil type, and other parameters required by the supported hydrologic models. This information for soil types, land use, etc., was obtained from the NRCS publications and verified by correspondence with the NRCS soil scientists for each county that the watersheds were located. The NRCS land uses and their associated curve numbers were field verified by the DEP and the DOF personnel in each watershed subbasin by on-the-ground observation, aerial observation and mapping, and remote imagery techniques. The field information was categorized for each subbasin within each watershed. Then, the field verified land use categories and soil types areas were compared with the published NRSC (SCS) data. Utilizing published NRCS land use definitions, cover and treatment descriptions, and soil type data that matched the FATT field verified field data, allowed the curve numbers to be assigned for each specific area. FATT then used WMS and calculated a composite weighted runoff curve number for each site-specific subbasin within the watershed. The composite curve number that was calculated was then used in WMS in the development of the hydrological modeling of the watersheds.

6. Model Coverages

Feature objects can be grouped together into coverages. Each coverage represents a particular set of data. For example, one coverage, can be used to define line use, and another coverage can be used to define soil type. A common use for coverages is defining NRCS soil type and land use for NRCS (SCS) Curve Number (CN) computation from polygons. Separate coverages must be used for the land use and soil type polygons, since polygons may not overlap within a given coverage. (Table 5)

A common method for the determination of losses due to interception and infiltration makes use of the SCS curve number. Curve numbers were computed by FATT from a NRCS hydrologic soil group in combination with a specified NRCS land use. A hydrologic soil group was assigned to selected polygon(s) belonging to a soil type coverage. The soil group was specified as either A, B, C, or D. Once hydrologic soil groups and land use definitions were assigned, composite curve numbers for each sub-basin were computed for the watershed.

Because of availability of elevation data in gridded format, gridded elevation data was used as a background elevation map when creating DEMs. The United States Geological Survey (USGS) 30 meter and 10 meter DEMs, and 3-meter grids processed from LiDAR data were imported from TAGIS and used as background elevation maps. DEMs were contoured and used as a guide for the placement of boundary, stream, and ridgelines. DEMs or grids were created from the feature polygons and arcs with elevation extracted from the background DEM.

7. Drainage Analysis Performed by FATT in Modeling Watersheds

A DEM was used to provide background elevation sources for the creation of feature objects and to perform drainage analyses using information derived from the elevation points. Data, such as flow directions, flow accumulations, and basin ID's were computed and stored as "attributes" of the DEM at the given location. Connected DEM points that comprised a stream branch were converted to arcs. Groups of DEM points that make a sub-basin within the watershed were converted to polygons for further hydrologic model definition. Beside the elevation DEM, flow directions for each elevation point in the DEMs were required in order to perform drainage analysis. Elevation and flow direction are the essential data from which all of the other drainage computations were made. Flow directions were computed with TOPAZ

A flow direction grid consists of a flow direction value for each DEM point. The flow direction identifies which neighboring point has the lowest elevation. A flow accumulation grid consists of an integer value for each DEM point that represents the number of "upstream" DEM points whose flow path passes through it. High accumulation values indicate points in the stream, whereas low values represent areas of overland flow. Flow directions and accumulations were determined by use of TOPAZ. Resulting grid files were imported into WMS.

If all DEM points had one and only one lower neighbor, the process of determining flow directions would be simple and the requirement to use other programs would not exist. However, there are many problems dealing with depressions and flat areas that make the algorithm for determining flow directions complex. Computations of flow accumulations were fairly straightforward once the flow directions were determined within the watershed. At this point, computations of flow directions cannot be done directly by WMS. A version of the TOPAZ program, modified specifically to work with WMS, creates as output the flow direction and flow accumulation grids. These grids were then imported as DEM attributes and used for basin delineation. FATT used TOPAZ for computing flow direction and flow accumulation grids. Once flow directions had been imported into WMS, flow accumulations were computed. Flow accumulations were computed by counting, for each DEM point, the number of DEM points whose flow paths pass through the DEM point. Streams were identified by large accumulation values since the flow paths of many points pass through the stream points.

The elevation and flow direction values for each DEM point are the primary data required for performing basin delineation and watershed characterization with DEMs. Once these data are imported and flow accumulations computed, stream networks and basin boundaries are defined with the aid of feature objects. Arcs representing streams and feature points or nodes representing basin outlets must be present in order to define basins. Once basins were defined, watershed and sub-basin boundaries were converted to feature polygons. All of the ties to the hydrologic models are made available through these feature objects with geometric values such as area, slopes, lengths, etc. being populated from the DEM data.

An arc vertex is created for each DEM point that has a flow accumulation value greater than the threshold entered. Consecutive stream DEM points are then joined together as arcs with nodes created at junction points where the stream splits. By default, stream arcs are created for all DEM points that have a flow accumulation larger than the threshold. Outlet feature points/nodes are created at DEM points, which pass the accumulation threshold and do not have a neighboring point with a higher accumulation. The stream is "traced" upstream by noting the neighboring DEM point with the next highest accumulation. This process was repeated until no neighboring point had an accumulation larger than the threshold. Outlet points were created at specified DEM points. The outlet point or node has a high enough flow accumulation to pass the threshold.

Each time a feature outlet point is created a sub-basin for each upstream feature arc is created for the hydrologic modeling tree. This means that the stream arcs themselves are associated with a basin. The DEM points intersected by the stream arcs are assigned the basin ID already given to the arcs. The procedure continue by tracing the flow paths of the remaining DEM points until a point which had already been assigned a basin ID was intersected. The result was that each DEM point was assigned the ID of the sub-basin it belongs to within the watershed.

Once the desired sub-basin delineation from the DEM points had been defined, the basin boundaries were converted to feature polygons. This was done by tracing the boundaries between sub-basins to generate arcs. After all of the boundaries had been defined the arcs were converted to polygons and the polygons assigned the appropriate basin ID. After defining basin boundaries, attributes such as basin areas and slopes and stream lengths and slopes were computed. These are all geometric parameters used in defining basins and routing networks in HEC-1 made within WMS. If the basins are changed in any way, the drainage data must be recomputed. When computing basin data the model units and the parameter units must be specified.

The primary objective of WMS is to delineate stream networks and drainage basin boundaries using a DEM terrain model. Since the terrain model is an accurate geometric description of the watershed, parameters such as areas, slopes, and flow distances can automatically be computed. This terrain model then serves as a map to guide entry of all data necessary to run HEC-1.

The first process in performing drainage analysis is to edit the model where necessary. Flat triangles, flat channel edges, and flat ridge edges must all be eliminated before trying to delineate stream networks and basin boundaries. Filtering and removal of flat objects was used. Manual insertion of break lines, the addition of new points, and edge swapping aid in removing anomalies that are introduced into the model. With the model properly edited, stream networks and drainage basins defined in preparation for defining a complete hydrologic analysis are processed.

8. Lag Time and Time of Concentration Used by FATT in Watershed Modeling

Lag time (T_{LAG}) and time of concentration (T_c) are variables FATT used when computing surface runoff using unit hydrograph methods available in HEC-1. These variables indicate the response time at the outlet of watershed for rainfall event, and are primarily a function of the geometry of the watershed. Many different equations have been developed for different watersheds, and most of these equations are a function of the geometric parameters computed by WMS. WMS has implemented many of these equations and allows you to choose from the ones listed to automatically compute lag times / time of concentrations in HEC-1. By default no equations are defined, but once an equation is specified, the lag time and time of concentration will be computed automatically each time that basin data are computed, or when the curve number changes.

Because the equations were developed for specific watersheds (i.e., size, land cover, etc.) FATT considered the assumptions made about a given equation, and match identifies one that used watershed conditions similar to the ones, studied. The following was the WMS equation used by FATT to develop the hydrologic models for the watersheds. FATT chose to use the SCS equations. SCS found that from many field investigations and cases, the lag time of a specific watershed or basin could be related to the concentration time of flow by the following equation:

$$T_{LAG} = 0.6 * T_c$$

This relationship is always used by WMS to determine lag time when a method of computing time of concentration is chosen, or to compute time of concentration when a method for lag time is chosen.

The Soil Conservation Service (SCS, 1975) suggested that

$$T_c = 1.67\ T_{LAG}$$

Where T_{LAG} is defined with the peak discharge of direct runoff. When the other definition of T_{LAG} based on centroids is used, then

$$T_C = 1.42\ T_{LAG}$$

These equations are only valid when the time of concentration is reached.

The NRCS (SCS) (1972) developed an equation using the curve number method to estimate watershed lag time, T_{LAG}, (from the center of mass of the effective rainfall to the time of the peak runoff) that can be expressed as

$$T_{LAG} = (L^{0.8} (S_P + 1)^{0.7}) / (1900 * S^{0.7})$$

Where T_{LAG} is in hours, L is the hydraulic length of the watershed in feet, s is the average watershed landslope in percent, and S_P is the potential watershed storage in inches = 1000 / (CN –10), CN=hydrologic soil – vegetative cover complex number.

In modeling watersheds, WMS creates HEC-1 files compatible with any version of HEC-1. FATT computed the peak discharges and hydrographs with the HEC-1 module within WMS. Once an HEC-1 simulation had been run, FATT reviewed the resulting hydrographs.

After viewing the hydrographs, FATT repeated the previous steps in order to calibrate the watershed model and to look at different scenarios

In WMS an outlet point is used to represent locations where hydrographs are both combined and then routed. Precipitation, base flow, loss rates, and unit hydrograph methods for each hydrograph were specified before a complete HEC-1 file was created. Data for one or more basins was entered by selecting the basins, if no basins are selected, the information entered is applied to all basins.

9. Precipitation Patterns Within Watersheds Modeled by FATT

Precipitation patterns for the July 8, 2001, storm event, a 25-year/24-hour storm event, and a 100-year/24-hour storm event were assigned to basins. If multiple basins were selected then the defined parameters applied to all selected basins. If no basins are selected, the parameters were applied to all basins. FATT assumed uniform distribution of the precipitation for the time interval modeled.

10. Model Hydrology Loss Methods Considered by FATT

One of several different loss methods can be chosen when generating synthetic hydrographs. A loss method is assigned to a basin by first selecting the basin and then choosing the Loss Method.

FATT used the NRCS (SCS) (LS) Loss Method

The SCS curve number method uses the following parameters:

- Initial rainfall abstraction in inches for snow-free ground
- SCS curve number for rainfall/losses on snow-free ground. Note: Composite Curve Numbers were computed automatically when this method for computing losses was chosen.
- Percentage of drainage basin that is impervious

11. Unit Hydrograph Method Used by FATT in Watershed Modeling

One of several different unit hydrograph methods can be chosen when generating synthetic hydrographs. A method is assigned to a basin by first selecting the basin and then choosing the Unit Hydrograph Method in WMS. FATT used the SCS Dimensionless Unit Hydrograph Method. Parameters for generating a unit hydrograph using the SCS dimensionless method include:

- T_{LAG} = SCS lag time in hours

12. Stream or Drainage Routing Data Used by FATT

Outlet points are used to define locations where hydrographs are combined and then routed downstream. The appropriate combined hydrograh stations are generated automatically when writing a HEC-1 file. Routing data was entered in order to simulate the movement of a flood wave through the river reaches. The effects of storage and flow resistance are accounted for in the shape and timing of the flood wave. In addition to these changes, volume may be lost due to channel infiltration. Routing methods available in HEC-1 are based on the continuity equation and the relationship between flow and storage or state.

13. Basin Outlet Names Used by FATT

Outlets are used for both types (combining and routing) of hydrograph stations in the HEC-1.

14. No Routing at Basin Outlet Nodes Determinations by FATT

By default there is no routing at an outlet point. This allows for hydrographs to be combined without considering routing effects.

15. Muskingum Routing Equation Method Used in the Watershed Modeling by FATT

FATT chose the Muskingum routing method to be used in the HEC-1 module of WMS. The Muskingum method is dependent primarily upon an input-weighting factor. The Muskingum method is one of the most popular methods of channel-flow routing. The parameters along with a short description of their meaning are as follows:

- The number of integer steps (equal to the number of subreaches for the stream or drainage area) for the Muskingum routing
- Muskingum's k coefficient is the average reach travel time. Its dimension is in time.
- Muskingum's x coefficient is a dimensionless coefficient used to weigh the relative effects of inflow and outflow on reach storage. x is known as a weighing factor. Theoretically, x can vary from 0 to 1 (Singh, 1992).

16. Storage Considerations Used by FATT

Storage-discharge routing can be used to define either channel or reservoir routing. The following parameters must be defined regardless of the storage routing option specified.

- Number of steps to be used in the storage routing
- Storage in acre-feet
- Discharge in ft^3/sec (cfs)
- Elevation in feet
- Storage, discharge, or elevation corresponding to the desired starting condition at the beginning of the first time period

17. Channel Routing Used by FATT

Channel routing used by FATT was with normal depths and methods. By using normal depth method, the following parameters must be defined:

- Manning's coefficient (n) - Manning roughness coefficients for the channel, and left and right overbanks
- Length - The length of the river reach
- Slope - The slope of the river reach
- Max Elevation - The maximum elevation for which storage and outflow values are to be computed

In addition to these parameters an eight-point cross-section was defined. The first two points define the left overbank, the third point defines the left bank, the fourth and fifth points define the channel itself, the sixth point defines the right bank, and the last two points define the right overbank.

18. Gages (PG) used by FATT HEC-1 Analysis Within the BOSS WMS Software

Gages can be used to establish the position and rainfall accumulation for rainfall gages. For all watersheds analyzed a uniform precipitation event over the watershed was assumed.

I. FATT's Utilization of HEC-1 Analyses with WMS Modeling

Before running an HEC-1 simulation, FATT ran the WMS model checker, which helped identify serious and potential problems that were corrected before a successful run of HEC-1 was made. Model Check in WMS reported any possible errors/inconsistencies in the model so that corrections were made prior to executing. Two types of information are provided as a result of this command. The first type is simply informational and provides things such as the starting time, time step, and total time of the simulation. The second types of information messages are errors and were corrected before an accurate HEC-1 analysis was performed.

1. Computing NRCS (SCS) Curve Numbers and Runoff Coefficients

   NRCS curve numbers are typically determined by using an NRCS table relating land use to hydrologic soil type. The hydrologic soil type can be either A, B, C, or D, as defined by the NRCS country reports. Where the soils infiltration capacity decreases from A to D. The curve numbers for each soil group for a given land use are by the NRCS publications. (Table 1). A composite curve number for a basin can be computed by taking an area-weighted average of the different curve numbers for the different regions (soil type and land use) within a basin. The same thing can be done to compute a composite runoff coefficient, only in this case a table relating soil ID to runoff coefficient is used rather than a table for curve numbers.

   WMS defined a hydrologic soil coverage or grid, and land use coverage or grid that defined boundaries for the different soil types and land uses. These data were then mapped to drainage coverage polygons or TIN triangles and used in the computation of a composite curve number. The following data was used for computing composite CNs:

   - Basin boundaries were defined with feature objects (remember that boundaries defined from a DEM are converted to feature objects)
   - Land use IDs were supplied from land use coverage in the map module or as DEM (a grid) attribute
   - Soil type IDs were supplied from soil type coverage in the map module or as DEM (a grid) attributes

   Combinations of the different data required for computations were used (i.e., drainage coverage, land use grid, soil type coverage, etc.).

2. BOSS'S WMS Modeling Computation Method

   The computation method determines composite CN numbers or composite runoff coefficients. This affects the type of mapping table and also where results are stored. When computing CN's the values are automatically stored with HEC-1.

3. NRCS Soil Types as Published and used by FATT

   The soil type option within BOSS's WMS determines whether NRCS published soil type coverage or a soil type grid will be used. The soil data obtained from published NRCS (SCS) soil type reports for counties of West Virginia has a slightly different meaning depending on the use of CN numbers. For CN numbers the critical attribute is the hydrologic soil type (0-soil A, 1-soil B, 2-soil C, 3-soil D).

4. NRCS Published Land use Types or Classifications used by FATT

   The NRCS land uses as published determine the land use coverage that was assigned by FATT to specific areas within subbasins of each watershed studied. The critical attribute for land use is an ID that can be related to a table of curve numbers, one value for each of the hydrologic soil groups.

5. Channels and Channel Flows as Modeled by FATT

   FATT analyzed the conveyance and other properties of channels using Manning's equation. Channel calculation allowed for the definition of rectangular, trapezoidal, triangular, and circular cross-sectional channels. Once channel input geometry is specified, either depth or flow can be computed after supplying a value for the other. When a hydrograph had been computed using HEC-1, the peak flow for the hydrograph was used as the default flow value.

All calculations (except Froude Number) used Manning's Equation:

$$Q = \frac{1.49}{n} AR^{2/3} S^{1/2}$$

Where:

Q = Flow in cfs
n = Manning's roughness
A = Cross-section area of stream flow
R = Hydraulic radius for stream
S = Slope of stream reach

The Froude number is computed from:

$$F = \frac{V}{g * y}$$

Where:

F - Froude Number (if F<1 then the flow is subcritical, and if F > 1, then flow is supercritical)
V - Velocity
g – acceleration due to gravity
y – equivalent depth of flow for a rectangular channel.

The equivalent depth of flow for a rectangular channel is computed by dividing the cross-sectional area of flow by the top width of the water surface.

6. Precipitation Events Modeled within the Watersheds by FATT

Two different options for defining precipitation are available from the WMS interface. The first is uniform rainfall over the entire watershed and the second allows gage data at specified locations to be defined. Since the watersheds are ungaged watersheds, FATT chose to use a uniform rainfall distribution over the watersheds as derived from NOAA's National Weather Service doplar radar precipitation hourly data.

7. Uniform Rainfall concept used by FATT

The Uniform Rainfall option requires that a single rainfall intensity curve for the entire watershed to be defined. Rainfall intensity values were defined for the given intervals as derived from the National Weather Services radar ranges for the entire storm event on July 8, 2001. For other storm comparisons, FATT chose to use the 25-year/24 hour and 100-year/24 hour storm events evenly distributed over the watershed.

IV. WATERSHED MODEL CALIBRATION by BOSS RiverCAD SOFTWARE

One of the most important steps in any hydrologic modeling problem is calibration. During the calibration phase, an attempt is made to model a set of conditions that have been known to exist at a watershed and for which measured data (surface depth) was available. The geometry, resolution, and input parameters of the model are adjusted until the output computed by the model is reasonably close to the measured data. FATT used actual field surveyed highwater elevations created by the July 8, 2001, flood event to calibrate the HEC-1 model for each watershed.

A. Calibration of Watershed Models with RiverCAD by FATT

To calibrate the results of the hydrologic modeling of all watersheds, FATT used BOSS International RiverCAD software. BOSS RiverCAD (RCAD) incorporates all of the advanced technology available. There is no other river modeling software package with this much capability. Boss RiverCAD is a completely self-contained packaged, providing complete support for both the U.S. Army Corps of Engineers HEC-2 and HEC-RAS numerical flow analysis models. Boss RiverCAD computes water surface profiles for modeling bridges, culverts, spillways, levees, bridge scour, floodway delineations, floodplain reclamations, stream diversions, channel improvements and split flows. FATT utilized the HEC-RAS modeling software to model the watersheds due to the mixed flow variables in the watershed. The benefit of using HEC-RAS over HEC-2 is that it can accommodate mixed flow conditions, i.e., subcritical and supercritical, while HEC-2 cannot.

A BOSS RCAD HEC-RAS model was developed by defining cross-section locations and the corresponding ground geometry using digital contour maps, digital terrain models, XYZ field coordinate data, USGS DEM (Digital Elevation Map) data, on-screen digitizing, manual data entry, and the XYZ coordinate data obtain from LiDAR.

RiverCAD uses Manning's formula to compute the conveyance of each roughness subarea for the current cross-section. It then sums together all roughness subarea conveyances to determine the total conveyance for the cross-section.

In computing the normal or critical flow depth for a specified discharge, an iterative process is used to compute the flow depth to the specified accuracy.

In computing the average flow velocity, RiverCAD assumes a uniform velocity distribution across the entire cross-section. This value is determined by dividing the discharge by the total flow area. The velocity of each roughness subarea is also determined. However, only the maximum velocity is reported to the user.

The program will automatically determine an energy gradient value to use when the program uses the minimum elevation at the current and adjacent upstream cross-sections and the channel flow length to compute an approximate energy gradient. The computed energy gradient is then checked to determine whether it is a reasonable value.

When computing normal depth or normal discharge, the reported critical slope is the channel bed slope that would cause critical depth to occur for the specified (or computed) discharge value.

RiverCAD considers the entire cross-section geometry as available for flow in its computations. RiverCAD cannot address ineffective flow areas, channel improvements, floodplain encroachments, split flow reaches, or overbank areas in which divided flow has been restricted.

If either the starting or ending cross-section stations is below the computed (or specified) water surface elevation, the program automatically extends wetted vertical walls to contain the computed flow. However, no attempt was made to adjust the wetted perimeter to account for the addition of these vertical walls.

A known water surface elevation corresponds to a known water surface elevation (i.e., high water mark) at the cross-section. This value is used to back-calculate a standard and a length-weighted Manning's roughness coefficient using the average friction slope equation. This entry must be specified in Manning's roughness coefficients are to be computed at every cross-section.

Note that an iterative method in determining roughness coefficients may be required due to the uncertainty sometimes associated with high water marks. The back-calculated roughness coefficients can be used with another friction loss equation to compute new water surface elevations. The validity of the computed roughness values can then be verified by comparing the computed water surface elevations with the originally specified high water marks. FATT utilized this technique to calibrate the hydrologic analyses of all watersheds.

B. HEC-RAS Methodology as Used in the Watershed Modeling by FATT

BOSS RiverCAD (referred to hereafter as BOSS RCAD) is based upon a highly optimized version of the U.S. Army Corps of Engineers Hydrologic

Engineering Center (HEC) water surface profile computation model HEC-RAS.

C. Hydrological Assumptions and Conditions Assumed by FATT in Watershed Modeling in RiverCAD Software

The current version of HEC-RAS only supports one-dimensional, steady flow, water surface profile calculations. This section specifically documents the hydrologic capabilities of the steady flow portion of the HEC-RAS. HEC-RAS is designed to perform one-dimensional hydraulic calculations for natural and constructed channels. The following is a description of the major capabilities of HEC-RAS as used or considered by FATT in the watershed analyses:

1. Steady Flow Water Surface Profiles

   This component of HEC-RAS is intended for calculating water surface profiles for steady gradually varied flow. The steady flow component is capable of modeling subcritical, supercritical, and mixed flow regime water surface profiles.

   The basic computational procedure is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction (i.e., Manning's equation) and contraction/expansion (i.e., coefficient multiplied by the change in velocity head). The momentum equation is utilized in situations where the water surface profile is rapidly varied. These situations include mixed flow regime calculations (i.e., hydraulic jumps), hydraulics of bridges, and evaluating profiles at river confluences (i.e., stream junctions).

   The effects of various obstructions such as bridges, culverts, weirs, and structures in the flood plain may be considered in the computations. However, whenever FATT did not have sufficient accurate data concerning the stream flow through the structure, then FATT did not model the structure as being in place during the flood. The steady flow system is designed for application in flood plain management and flood insurance studies to evaluate floodplain encroachments. Also, additional special features include multiple profile computations, multiple bridge and/or culvert opening analysis, and modeling of levees.

   This component of HEC-RAS is capable of simulating one-dimensional unsteady flow through a full network of open channels. This unsteady flow component was developed primarily for subcritical flow regime calculations.

Note that this component of the HEC-RAS modeling system is currently being developed by the Army Corps of Engineers Hydrologic Engineering Center and is not yet available.

2. Sediment Transport and Movable Boundary Computations

   This component of HEC-RAS is intended for the simulation of one-dimensional sediment transport/movable boundary calculations resulting from scour and deposition over moderate time periods (i.e., typically years, although applications to single flood events are possible).

   Note that this component of the HEC-RAS modeling system is currently being developed by the Army Corps of Engineers Hydrologic Engineering Center and is not yet available.

3. Steady Flow Water Surface Profiles

   Calculations for steady gradually varied flow in natural or constructed channels. Subcritical, supercritical, and mixed flow regime water surface profiles can be calculated.

4. Cross-Section Subdivision for Conveyance Calculations

   The determination of total conveyance and the velocity coefficient for a cross-section requires that flow be subdivided into units for which the velocity is uniformly distributed. The approach used in HEC-RAS is to subdivide flow in the overbank areas using the input cross-section value break points (locations where values change) as the basis for subdivision. Conveyance is calculated within each subdivision.

   The program sums up all the incremental conveyances in the overbanks to obtain a conveyance for the left overbank and the right overbank. The main channel conveyance is normally computed as a single conveyance element. The total conveyance for the cross-section is obtained by summing the three subdivision conveyances (left, channel, and right). Field surveyed cross sections were acquired by FATT in order to more accurately represent the stream channel reaches and characteristics.

5. Basic Data Requirements Used by FATT to Model the Watersheds with RiverCAD

   The following sections describe the basic data requirements for performing the one-dimensional flow calculations within HEC-RAS. The basic data are defined and discussions of applicable ranges for parameters are provided.

The main objective of the HEC-RAS program is quite simple---compute water surface elevations at all locations of interest for given flow values. The data needed to perform these computations are divided into the following categories:

- Geometric data
- Steady flow data
- Unsteady flow data (unknown - not readily attainable)
- Sediment data (unknown - not readily attainable)

Geometric data are required for any of the analyses performed within HEC-RAS. The other data types are only required if you are going to do that specific type of analysis (i.e., steady flow data are required to perform a steady flow water surface profile computation). The current version of HEC-RAS is limited to steady flow computations, therefore, geometric data and steady flow data are the only available data categories.

The basic geometric data consist of cross-section data, reach lengths, and energy loss coefficients (i.e., friction losses, contraction and expansion losses). Hydraulic structure data (i.e., bridges, culverts, etc.), that are also considered geometric data, will be described in later sections.

Boundary geometry for the analysis of flow in natural streams is specified in terms of ground surface profiles (cross-sections) and the measured distances between them (reach lengths). Cross-sections are located at intervals along a stream to characterize the flow carrying capability of the stream and its adjacent floodplain. They should extend across the entire floodplain and should be perpendicular to the anticipated flow lines (approximately perpendicular to the ground contour lines). Occasionally it is necessary to lay out cross-sections in a curved or dog-legged alignment to meet this requirement. Every effort should be made to obtain cross-sections that accurately represent the stream and floodplain geometry. However, ineffective flow areas of the floodplain, such as stream inlets, small ponds or indents in the valley floor, should generally not be included in the cross-section geometry.

Cross-sections are required at representative locations throughout a stream reach and at locations where changes occur in discharge, slope, shape, or roughness, at locations where levees begin or end and at bridges or control structures such as weirs. Where abrupt changes occur, several cross-sections should be used to describe the change regardless of the distance. Cross-section spacing is also a function of stream size, slope, and the uniformity of cross-section shape. In general, large uniform rivers of flat slope normally require the fewest number of cross-sections per mile. The purpose of the study also affects spacing of cross-sections. For instance, navigation studies on large relatively flat streams may require closely spaced (e.g., 500 feet) cross-sections to analyze the effect of local conditions on low flow depths, whereas cross-sections for sedimentation studies, to determine deposition in reservoirs, may be spaced at intervals on the order of miles.

The choice of friction loss equation may also influence the spacing of cross-sections. For instance, cross-section spacing may be maximized when calculating an M1 profile (backwater profile) with the average friction slope equation or when the harmonic mean friction slope equation is used to compute M2 profiles (draw down profile). The HEC-RAS provides the option to let the program select the averaging equation.

A stream station label identifies each cross-section in a HEC-RAS data set. The cross-section is described by entering the station and elevation (X-Y data) from left to right, with respect to looking in the downstream direction. The stream station identifier may correspond to stationing along the channel, mile points, or any fictitious numbering system. The numbering system must be consistent, in that the program assumes that higher numbers are upstream and lower numbers are downstream within a reach.

Each data point in the cross-section is given a station number corresponding to the horizontal distance from a starting point on the left. Up to 500 data points may be used to describe each cross-section. Cross-section data are traditionally defined looking in the downstream direction. The program considers the left side of the stream to have the lowest station numbers and the right side to have the highest. Cross-section data are allowed to have negative stationing values. Stationing must be entered from left to right in increasing order. However, more than one point can have the same stationing value. The left and right stations separating the main channel from the overbank areas must be specified. End points of a cross-section that are too low (below the computed water surface elevation) will automatically be extended vertically and a note indicating that the cross-section had to be extended will show up in the output for that cross- section. The program adds additional wetted perimeter for any water that comes into contact with the extended walls.

Other data that are required for each cross-section consist of downstream reach lengths, roughness coefficients, and contraction and expansion coefficients. This data will be discussed in detail later in this chapter.

6. Stream Reach Lengths

The distance between successive cross-sections is referred to as the flow length or reach length. There are two methods of defining flow length between cross-sections. The first method is to simply allow the program to use the difference in cross-section grid identifiers. The program will then use this difference distance for the left overbank, right overbank, and main channel flow lengths.

A second method requires that individual flow lengths between successive cross-sections for the left overbank, right overbank, and main channel be specified. This method permits the user to use cross-section grid identifiers that do not necessarily reflect actual flow distances.

Channel flow lengths are typically measured along the channel centerline (sometimes called the thalweg). Overbank flow lengths should be measured along the anticipated path of the center of mass of the overbank flow. Often the channel and overbank flow lengths will be equal. There are, however, conditions in which they will differ, such as at river bends, or where the channel meanders considerably and the overbanks are straight. Where the channel and overbank flow lengths are different, the program based upon the discharges in the main channel and left and right overbanks determines a discharge weighted flow length. This discharge weighted flow length is then multiplied by the average conveyance in the energy loss computations for the reach being analyzed.

In a meandering stream, the channel's effect on flow direction and its contribution to total conveyance may lessen as flow depth increases. Once the channel is submerged and water is flowing in the floodplain, the majority of flow may travel along a shorter path. The amount of flow that becomes overbank flow depends upon many factors, including the channel size relative to the overbank area as well as the channel roughness relative to the overbank roughness.

7. Energy Loss Coefficients Used in the Modeling

Four types of loss coefficients are utilized by the program to evaluate energy (head) losses:

- Manning's roughness coefficients for friction loss
- Contraction and expansion coefficients to evaluate flow transition losses
- Bridge loss coefficients to evaluate losses related to weir shape, pier configuration, and pressure flow conditions
- Culvert entrance loss coefficients to evaluate losses due to flow entering a culvert

8. Manning’s Roughness Coefficients

When three Manning roughness values, n, are sufficient to describe the channel and overbank roughness, the Manning roughness data entries were used. These values were changed at any other cross-section, when required, to reflect changes in roughness.

Often, three Manning roughness coefficients are insufficient to adequately describe the lateral roughness variation in a cross-section. The horizontal roughness data entries in can be used to describe roughness encountered by flow through defined cross-section subareas. These roughness coefficients remain in effect until changed at a subsequent cross-section. They should be redefined for each cross-section that has different ground geometry stationing specified.

Selection of an appropriate value for Manning's n is very significant to the accuracy of the computed water surface profiles. The value of Manning's n is highly variable and depends on a number of factors including:

- Surface roughness
- Vegetation
- Channel irregularities
- Channel alignment
- Scour and deposition
- Obstructions
- Size and shape of the channel
- Stage and discharge
- Seasonal change
- Temperature
- Suspended material and stream bed load

In general, Manning's n values should be calibrated whenever observed water surface profile information (gaged data, as well as high water marks) is available. When gaged data are not available, such as were all three studied watersheds, then values of n computed for similar stream conditions or values obtained from experimental data should be used as guides in selecting n values. Each stream cross section that was surveyed was documented with a digital photograph. These stream cross section photographs were compared by FATT with known Manning values for similar photographed streams by the USGS, and other agencies.

There are several references FATT modelers accessed that show Manning's n values for typical channels. An extensive compilation of n values for streams and floodplains can be found in Chow's book, Open Channel Hydraulics (Chow, 1959) or Singh’s book, Elementary Hydrology (Singh; 1992).

Although there are many factors that affect the selection of the n value for the channel, some of the most important factors are the type and size of materials that compose the bed and banks of a channel, and the shape of the channel. Cowan (1956) developed a procedure for estimating the effects of these factors to determine the value of Manning's n of a channel.

A detailed description of Barnes' method can be found in Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains (FHWA, 1984). This report was developed by the U.S. Geological Survey (Arcement, 1989) for the Federal Highway Administration. The report also presents a method similar to Barnes' for developing Manning's n values for flood plains, as well as some additional methods for densely vegetated flood plains.

Limerinos (1970) related n values to hydraulic radius and bed particle size based on samples from 11 stream channels having bed materials ranging from small gravel to medium size boulders.

Limerinos selected reaches that had a minimum amount of roughness, other than that caused by the bed material. The Limerinos equation provides a good estimate of the base n value. The base n value should then be increased to account for other factors, as shown above in Cowan's method.

V. AGENCY ROLE AND OBSERVATIONS

Information gained from first-hand observation and professional assessments of the impacts on and behavioral factors of watersheds during the July 8, 2001, event provided important input that enhanced the technically gathered data. Additionally, it is necessary to understand the fundamental regulatory framework that governs the activities of the coal and timber industry and the agencies that administer these laws. The combination of these factors provides a framework from which to draw conclusions about the event and recommendations to mitigate damage from future flooding.

A. Mine Drainage System Regulation Overview

The State of West Virginia has regulated the West Virginia coal industry since the 1930's. In 1977, the Federal Surface Mining Control and Reclamation Act, as amended (SMCRA), was passed by Congress and made law. This led all states, including West Virginia, to increase the regulation and enforcement of surface mining laws, as necessary, to be at least equal to the SMCRA laws and regulations. The West Virginia Legislature noted that the diverse terrain, climate, biological, chemical, and other physical conditions required laws and regulations that were specific to this State. Accordingly, the West Virginia Legislature developed and put into effect the West Virginia Surface Coal Mining and Reclamation Act (Act).

Surface coal mining, including the surface effects of underground mines, has many dynamic aspects that have the potential for causing adverse impact on the safety and well being of the public and the environment. The West Virginia DEP through its Division of Mining and Reclamation (DMR) is responsible for the administering the mandates of the Act, and the rules and regulations promulgated thereunder (Regulations).

One aspect of surface coal mining that may result in significant damage to the safety and well being of the public, and the environment is the unregulated discharge of water. The unregulated discharge of water can cause or contribute to the following:

- Channel scouring
- Stream alteration
- Erosion of soil
- Mass transfer of suspended solids
- Alteration of the chemical and physical characteristics of the receiving stream
- Flooding
- Change of water quantity and quality in watersheds impacted by mining

- Adverse impact to environmentally sensitive areas
- Adverse impact to private and public property, and the health and safety of the public

All applicants for mining permits are required to manage water discharge from the permit area through drainage control structures or systems. All systems or structures used in association with the mining operation shall be designed, constructed, located, maintained, and used in accordance with the Act and the Regulations, and in such manner as to minimize adverse hydrologic impacts in the permit and adjacent areas, to prevent material damage outside the permit area, and to ensure safety to the public. All water discharged from the permitted area is to comply with State and Federal water quality standards and meet effluent limitations as specified in a National Pollutant Discharge Elimination System (NPDES) permit.

The primary sediment and water control structures or systems currently used by the regulated surface coal mining industry in West Virginia are:

- Constructed impoundment structures (permanent & temporary)
- Sediment ditches (permanent & temporary)
- In-pit storage
- Diversion ditches, (permanent & temporary)

  (Note - Temporary impoundment structures or water control structures are structures/systems that are replaced by permanent structures and/or systems, or structures or systems that will be removed when the disturbed permitted area is reclaimed and the reclamation bond has been released by the DMR).

Current regulated surface coal mine water control and sediment control structures, or systems used in association with the regulated surface mine shall:

- Be constructed in accordance with the plans, design criteria, and specifications set forth in the approved and issued DMR permit
- Be located as near as possible to the disturbed mining area
- Comply with applicable State and Federal water quality standards
- Meet effluent limitations as set forth in an NPDES permit for all discharges
- Be designed to have a settling basin capacity designed to store 0.125 acre/ft. of sediment for each acre of disturbed area in the controlled watershed
- Be equipped with a non-clogging dewatering device
- Be designed, constructed and maintained to prevent short-circuiting

- Be cleaned out when the sediment accumulation reaches sixty percent (60%)
- All embankment type structures be designed to safely pass a twenty-five (25) year, twenty-four (24) hour precipitation event peak discharge. The combination of both the principal spillway and/or emergency spillway shall be designed to pass this same peak discharge event.
- Provide adequate freeboard to resist overtopping by waves or sudden increases in volume and adequate slope protection against surface erosion and sudden draw down
- Provide that an impoundment meeting the size or other criteria of 30 CFR 7.216(a) or W. Va. Code § 22-14 et seq., or located where failure would be expected to cause loss of life or serious property damage shall have a minimum safety factor of 1.5 for a normal pool, and a seismic factor of at least 1.2. Impoundments not meeting the size or other criteria of the aforementioned laws and regulations, except for a regulated coalmine waste impounding structure, and located where failure would not be expected to cause loss of life or serious property damage shall have a minimum static safety factor of 1.3 for a normal pool.
- Control water discharges by the use of energy dissipaters, riprap channels or other devices
- All embankment type water control or sediment control structures shall be designed, constructed and maintained according to the applicable State and Federal safety standards for such structure

Diversion and sediment ditches shall have the capacity to pass safely the peak discharge from a twenty-five (25) year, twenty-four (24) hour precipitation event. However, permanent diversion ditches associated with valley fill, side hill fills, and durable rock fills used in the disposal of excess spoil shall be designed and constructed to safely pass the peak runoff from a one hundred (100) year, twenty-four (24) hour precipitation event.

Another notable fact derived from the study was that the July 8, 2001, storm event approached, but did not exceed the 25 year / 24 hour design standard for sediment pond discharges commonly used in the mining industry. FATT observed that the emergency spillways of all the surface coal mine related sediment structures in both Seng and Scrabble Creeks accommodated the July 8, 2001, flows without overtopping. From this fact, FATT concluded that the 25 year/24 hour design standard was not exceeded. The primary purpose of sediment control structures is to treat sediment discharges from permitted areas. The design intent does not encompass flood control.

DMR reviews the Surface Mine Application (SMA) and determines if the SMA is accurate and complete and whether it complies with the Act and Regulations. The agency will also determine if the applicant has demonstrated in the SMA that reclamation as required by the Act and Regulations can be accomplished. The applicant will demonstrate this in the probable hydrologic consequences (PHC) analysis, the hydrologic reclamation plan, the drainage section, and other sections of the permit application.

The PHC is the applicant's statement describing the probable hydrologic consequences of the proposed mining operation with respect to the hydrologic balance, on both the permit area and the adjacent area. The PHC is based on baseline information developed from sampling and analysis of surface and groundwater at monitoring sites established both on the permit area and adjacent areas. The PHC will include findings on:

- Whether adverse impacts may occur in the hydrologic balance
- Whether acid-forming or toxic-forming materials are present that could result in the contamination of surface or groundwater, and whether the proposed operation may proximately result in the contamination, diminution or interruption of an underground or surface water source of water within the proposed permit or adjacent areas which is used for domestic, agricultural, industrial, or other legitimate purpose, and what impact the operation will have on:

    - Sediment yield from the disturbed area
    - Acidity, suspended and total solids, and other important water quality parameters
    - Flooding or stream flow alterations
    - Groundwater and surface water availability
    - Other characteristics as required by the Director of DMR

The applicant for a permit shall submit with the application, all available data and analysis described in the Act and Regulations for use in preparing the cumulative hydrologic impact assessment (CHIA). The DMR shall perform a separate CHIA for the cumulative impact area for each application. This CHIA shall be sufficient to determine whether the proposed operation has been designed to prevent material damage to the hydrologic balance outside the permit area.

DMR then completes the facts and findings which shall include a CHIA of the hydrologic regime associated with the proposed coal mining permit. The Agency also determines if the applicant has demonstrated that reclamation as required by the Act and Regulations can be accomplished. Based upon those facts and findings concerning the proposed mining operations, the permitting staff will recommend to the Director of the DMR that the application be approved or denied. After consideration of the facts and findings, public input, and recommendation of the DMR professional staff, the Director will make a determination to approve or deny the permit.

The permit contains all designs, construction details and specifications for the release or discharge of any water from the mine site. Using this data and making field measurements of water quality and discharge characteristics, the DMR inspector can monitor the permitted coal mine operation water discharges to ensure that they are in compliance with applicable laws, rules, and regulations.

B. Overview And On-Site Summary Of Inspection And Enforcement Program

DMR employs approximately 80 inspectors, inspector specialists and inspector supervisors that are responsible for enforcing the West Virginia Mining and Reclamation laws and rules at coal mining and non-coal mining operations throughout the State. During calendar year 2001, they conducted nearly 20,000 inspections on coal mine facilities and approximately 1,000 inspections on non-coal mining facilities.

DMR inspection staff necessarily become intimately familiar with not only the permitted areas they regularly inspect, but also with the watersheds and terrain in the vicinity of these permitted operations. In times of natural disaster such as the flood of July 8, 2001, they are called upon to immediately respond to their areas of responsibility. They evaluate the situation relative to the permitted facilities, render assistance as necessary and initiate remedial and enforcement actions as the conditions warrant. DMR's activities during and immediately after the July 8, 2001, flood resulted in 24 notices of violation issued for conditions the agency found were caused by or contributed to by mining operations. Firsthand observation from inspection personnel is an important element in analyzing the contribution of mining practices to flood damage.

The FATT conducted interviews of inspection personnel assigned to operations in the impacted regions. Questions asked during these interviews focused on observations made by these individuals both on and off permitted operations, as well as general observations involving the remainder of the watershed. They were asked to describe impacts from other non-mining related operations or facilities in the vicinity as well. They were also asked to provide recommendations relative to the conduct of existing and future mining operations that may minimize or prevent future problems related to precipitation events.

This information is noteworthy in that it reflects the observation and comments from trained personnel intimately familiar with the operations and watersheds in their assigned territories. Information was collected from nine individuals, including supervisory personnel. These individuals include those employees that had operational responsibilities in the most impacted regions of the State.

A general summation of information obtained during this process indicated that:

- Most damage that occurred regarding permitted mining facilities was confined within the permit boundaries and consisted of erosion on the faces of valley fills/unvegetated regraded areas and sediment clogging and filling sediment control structures
- Damage or problems observed off of the permitted area consisted of sediment deposition resulting from breached sediment ditches and sediment being pushed through ponds that were already full from the precipitation event
- Damage related to non-mining related facilities centered on debris clogging road culverts and bridge underpasses, material washing from logging operations and skid roads acting as a focal point for runoff
- Additional questions involved stream obstructions and the constituent make-up of flooding debris. Much of the material observed backed up against culverts and low bridges and consisted of assorted trash and debris, including woody material.

The remaining questions addressed recommendations that could minimize damage in future heavy precipitation events. These recommendations are contained in Section IX-A.

C. Overview of Division of Forestry Regulatory Program

West Virginia has been active in developing and applying practices designed to protect water quality on forestlands. A booklet titled "West Virginia Forest Practice Standards" was published in 1972 prior to implementation of the Federal Water Pollution Control Act. Guidelines to protect soil and water resources during harvesting operations were provided in this booklet. Since then, the West Virginia DOF has been publishing a manual titled "Best Management Practices For Controlling Soil Erosion and Sedimentation From Logging Operations in West Virginia" (see Appendices of Part III). Forest management practices designed to minimize or prevent non-point source water pollution are called Best Management Practices (BMP). Many of the practices outlined in the manual were developed by researchers working at the Fernow Experimental Forest located near Parsons, West Virginia. Best

Management Practices include topics related to streamside management zones, logging debris, road/log landing construction and maintenance, seeding, and pipe installation. The BMP are reviewed every three years by a committee convened by the DOF Director under West Virginia Code Section 19-1B-7(h). The Director of the DOF may then adjust BMP based upon suggestions of the committee.

In 1992, West Virginia moved from a voluntary program to a regulatory program with passage of the 1992 Logging Sediment Control Act (LSCA). The DOF was designated by the Legislature as the agency responsible for carrying out the mandates and provisions of the Logging Sediment Control Act.

The West Virginia Code Section 19-1B-4 requires that anyone, with certain exceptions, conducting a logging operation, buying timber or buying logs for resale is required to be licensed by the Division of Forestry. Acceptance of the license implies that the operator will protect environmental quality through the judicious use of silvicultural BMP.

According to West Virginia Code Section 19-1B-7(g), all timbering operations shall be guided by the silvicultural BMP in selecting practices appropriate and adequate for reducing sediment movement. Failure to use a particular best management practice which causes or contributes, or has the potential to cause or contribute, to soil erosion or water pollution constitutes a violation. West Virginia Code Section 19-1B-5(b) and (c) empowers the Division of Forestry to issue compliance orders to correct problems and, when necessary, to suspend a logging operation until specified corrections are made to bring the operator or operation into compliance with the law. Instances that may result in suspension include when human life is endangered, uncorrectable soil erosion or water pollution, an operation is not licensed, or when a certified logger is not supervising the operation. Licenses may be suspended if the person is found to be in violation twice in any two-year period, and they may be revoked if the logger is found in violation for a third time in any two-year period.

VI. Summary of Citizens Concerns and Observations

During November 2001, a series of public meetings were conducted in five counties with representation from both the Advisory Committee and FATT.

A. Public Meeting 1 – No vember 5, 2001, Whitesville Junior High School, Boone /Raleigh counties, WV.

The November 5, 2001, Boone/Raleigh combined public meeting was the first of a four-county tour. The meeting was held in Whitesville at the Whitesville Junior High School.

Those in attendance were asked to share with members of FATT and the members of the Advisory Committee what they saw and what they experienced during the flooding of July 8, 2001.

There were approximately eighty citizens at the Boone/Raleigh meeting and many shared their accounting of that July day. Many of the speakers spoke of a tidal wave-type wall of water with debris carried on top. Various residents spoke of living in their respective communities for twenty to thirty-plus years and never experiencing anything close to this magnitude of flooding. Additionally, numerous residents mentioned a diesel or gasoline odor and others just a strong stench to the waters. There was mention of the water being yellow then turning gray.

One resident of Whitesville commented, "there's enough coal in my yard to heat the hollow for four years. I mean coal, lumps of coal, sludge and stuff in my yard." The same resident spoke of logging trucks running in and out of the hollow, all day and all night, without resting at all. This went on for three years. She states: "To me, that's what's happened. They have logged and logged, and it's not just them." Many commenters spoke of seeing logs and boulders the size of cars washing off the hillsides.

Several residents from Round Bottom, in Sylvester, spoke about the "bridge" jamming up with rock and debris. The debris backed up from the dam causing an overflow onto residents' property. The water could not get through and under the bridge nor through the dam but overflowed onto the banks of the river and onto residents' property.

One resident of White Oak in the Clear Fork area spoke about logging and mining activity in June, 1997. He stated that there was an increase in water runoff after logging activity began on the right-hand fork of Clear Fork and mining activity began in the left-hand fork of Clear Fork. He also said that two of his neighbors had lost their lives. The resident said that of the three floods that took place in 2001, July 8^{th} was the worst, with water coming out of the hollow just "black as black gets, and it was swift. It was capping up, real rough water." The creek had been cleaned out three times this summer (2001), each time "they went in the creek and started digging them a little deeper." "Then after July the 8^{th} they took our creek bed down six foot, and everybody in the left-hand fork immediately we lost all of our water. We're still using water out of tanks filled by the fire department."

B. Public Meeting 2 – November 8, 2001, Falls View Grade School, Fayette County, WV.

The second public meeting was held November 8, 2001, in Fayette County at the Falls View Grade School with approximately eighty citizens in attendance.

Much like the residents of Boone and Raleigh counties, the committee heard more personal experiences from the Fayette county residents regarding the July 8, 2001, flooding. The majority of residents spoke of seeing a yellow thick mud. The yellowing is believed to be, by some residents, a result of mining. Many addressed logging activity and associated red water since logging began in their communities.

One speaker commented that oil and gas and utility companies were also responsible for the flooding as they have cut roads up and down the hillsides and across the roads.

Another speaker stated that the railroad was also responsible for the flooding. "Well, a lot of that problem was caused by the railroad not having adequate drains and the water came under the railroad, through the banks and washed out on the other side and washed into people's property, and if it had the right drains in there, a lot of that water wouldn't have done that." "There was drains that had been clogged up since I was a kid, and they finally come in there and halfway cleaned them out, the railroad did, after this flood."

One resident of the Charlton Heights area complained that the Department of Highways has inadequate drainage lines in that area. He said that he has been dealing off and on with the DOH since about 1986.

C. Public Meeting 3 – November 19, 2001, Mt. View High School, McDowell County, WV.

The third of four meetings was held November 19, 2001, in McDowell County at Mt. View High School with approximately 45 people in attendance.

Residents reported much the same damages and experiences as did other residents in the previous county meetings. Reports of the diesel smell and rainbow film in and on the waters, oil spots that had washed off the hill, tidal waves, black mud after the water subsided, heavy coal dust, trees washing down and clogging up drains and bridges and several references to a slate dump in Carswell Hollow and inadequate drain pipes from the mine site nearby. There were many references to the flooding of 1986 but, according to the residents, this flood was much worse.

One resident of Welch commented that Welch got the rains and flooding later, mid to late afternoon, and that it took longer to rise, but within two to three hours, it was gone. "I had fifty-eight inches of water in my basement. Our flooding was caused by debris that floated down the river and lodged itself against the bridge that goes over to the city park, and that had that not occurred, most of our homes on Lake Drive would never have even been affected." "My observation was that most of that debris was natural debris. I didn't see any cars floating down there. It was tree limbs, you know, tree trunks and that sort of thing that lodged in the bridge and the water backed up from that."

D. Public Meeting 4 – November 26, 2001, Wyoming East High School, Wyoming County, WV.

The fourth and final meeting of the five county tours was held November 26, 2001, in Wyoming County at Wyoming East High School with approximately eighty people in attendance.

A resident of Mullens stated, "I'm a lifelong resident of Mullens. I've lived there for sixty years. I've been through floods there. I've got brothers and sisters there. We've never been flooded like we have this time. I've never seen water come so quick, come so high. I do know that all the mountains around Mullens have been logged out and I went back in those mountains and it looked like a bomb went off back in there."

Another resident said that, "there were no warnings of an anticipated flood. We had four very hard rains in a six hour period but no harder than we had many times in the past." "I heard something and looked, and it looked like a tidal wave coming. That thing was thirty feet high and looked like a surfer could be underneath it, an ocean wave."

This resident spoke of a chemical smell in the air and a sheen that could be seen on the water. The resident commented that she smelled this same chemical odor when they de-gassed the holes on her property and that it burned her throat and caused her difficulty with breathing.

The resident also stated that a "mine blowout right below the Hilton Strip caused a big tidal wave which never touched the ground until it hit the creek in Indian Creek. There it met one just like it coming down Indian Creek and it was just unreal, and it will happen again."

One individual stated that he has surveyed almost all of the watersheds affected. “We’re surveying these watersheds where there are disturbances such as mountaintop removal, valley fills, steep slope logging, old gob piles, old strip mines and possibly mine blow-outs maybe filled by water being gathered up by old strip mines. The old strip mines, particularly in this county, are everywhere.”

“Where you are closer to these disturbances the flooding is much, much, more severe, and that I think is just about unquestioned. I was at the 4-H camp on Glen Fork below some of the worst steep slope logging I can imagine. There is no question as to how and why logs ended up in the swimming pool of the 4-H camp, and ironically the cabin furthest up the hill, it was pointed out to me, had the worst damage because it was below logging and it came down a little hollow and bashed up the cabin.”

“On the other side of Clear Fork, the entire watershed of Sycamore has been totally clear-cut. Above Mullens, there is tremendous timbering in the Rhodell area, and that caused water to roar down the Guyandotte River.”

“I’d also like to comment about the watersheds that have been chosen for this study. There is more in common between the Scrabble Creek watershed and the Seng Creek watershed than there is the control. Seng Creek and Scrabble Creek are both long, rather somewhat short, narrow watersheds with steep headwater. Anyhow, those two watersheds are very similar.” The control watershed at Sycamore at Colcord is a large watershed and is shaped like a funnel. It does have steep headwaters, but it is a very large basin of water that converges to a very small point which is where the community unfortunately was located. I don’t know where, it’s so hard to find undeteriorated watersheds in southern West Virginia, I don’t really know where you look for a control, but you’re comparing two apples to one orange.”

Many of the residents at this county meeting spoke directly to timbering/logging issues associated with the flooding.

Residents at all the public meetings spoke of the devastation and loss of lives had this flooding occurred during the nighttime hours versus the daytime hours. Neighbors were able to warn and help each other and, in most cases, could see the flooding coming.

VII. FLOOD ANALYSIS TECHNICAL TEAM RESULTS

The results contained in this report can be applied throughout southern West Virginia's steep slope topography. While this report concentrated mainly on runoff analyses during the storm event, other issues of concern such as stream hydraulic jumps or energy transitions, stream constrictions, random stream blockages, stream bed loading and transport, sediment deposition, and sediment transport were considered based mainly on observation and/or comments. These issues are reflected in the recommendations to further protect these watersheds and others in the future.

The results reached in this report are based on proven scientific, engineering, and hydrological modeling techniques.

Through modeling calibration and validation of the physical and hydrologic characteristics in each studied watershed (i.e., Seng Creek, Scrabble Creek, and Sycamore Creek) FATT's watershed methodologies have proven to be accurate in establishing hydrologic modeling similitude. The accuracy standards are accepted in both scientific and engineering disciplines for model validation. Application of these validation techniques indicates that the characteristics of the watershed, as modeled, are sufficiently accurate to produce meaningful results.

Using this methodology, FATT determined the degree of impact from mining and logging activities under different scenarios for each watershed. FATT decided that only two watersheds would be analyzed to assess impacts associated with mining and logging, as present on July 8, 2001. For this modeling, Seng Creek and Scrabble Creek were chosen.

FATT determined that no current mining and/or logging industry activities had occurred in Sycamore Creek. Moreover, significant, observable, and measurable flooding had occurred in this watershed. Therefore, Sycamore Creek was chosen to be the control watershed. This watershed would be representative of a limited industry impacted area, and would serve as a comparative watershed for perspective purposes only.

Five scenarios were developed for the analyzed watersheds (Seng and Scrabble Creeks). These scenarios would include modeling specific types of mining and logging activities, as they existed in the watersheds on July 8, 2001. Due to the lack of relevant data, such as stream gage information, precipitation measurements and current industry data, certain conditions relative to the watersheds and the industry activities were assumed in the FATT models. These include:

- Existing urbanized areas would remain constant in cover type and area throughout each scenario for each watershed model.
- No industry impoundment and/or drainage structure were allowed to attenuate water flows. All water would flow through as though the structures were at their maximum storage volume.
- No forest areas were assumed to be "burned" or associated with any major forest fires within the last 10 years.
- No other industries (oil, gas, highway, power line, utility lines, etc.) activities were addressed as having any impact of the physical and/or hydrologic characteristic of each watershed.
- Bridges, low water crossings, stream crossing culverts that were known to allow the flood waters to pass through were included in the FATT hydrologic model. For those structures where it was not known how long, how much, or if all stream flow was blocked, it was assumed that the structure did not cause a constriction that would create a pooling effect and was not included in the model for the specific watershed.
- Back pooling from major tributaries that the modeled watersheds flowed into were not considered unless validated stream gages located on the main stream at the confluence were available. It was determined that no valid gaging stations were available at the confluence of any of the modeled watersheds and the next tier tributary into which it discharged. Therefore, the backwater effect of the next tier tributary was not considered as being of significance unless the model watershed validation nodes were influenced by this backwater or pooling. FATT determined that none of the validation nodes were impacted or influenced by such conditions.
- Based upon information obtained from the NWS and the NRCS, antecedent soil moisture condition II was used for all watersheds analyzed.
- Based on information obtained from NOAA's NWS and NRCS, storm distribution Type II was used for all precipitation models.

The scope of this analysis is the determination of runoff volume differences of the mining and logging impacts versus those of a non-disturbed watershed condition. Although this study modeled stream flow differences to determine whether impacts occurred, the evaluation of water surface elevations relative to such impacts was not studied. To do so, would require extensive data collection and further study, including an investigation of every reach of stream in the impacted watersheds, the damaged residences and every natural and manmade stream constriction that could influence water level.

FATT established modeling scenarios for Seng Creek and Scrabble Creek to determine the potential impact of mining and logging industries that occurred on July 8, 2001. The scenarios are:

SENG CREEK WATERSHED MODELING SCENARIOS

- Scenario 1: All mining and all logging activities as existed on July 8, 2001, were modeled in the watershed. NRSC (SCS) soil groups and types, CNs, land types, land descriptions were identified and validated by FATT. This data is inserted into the base hydrologic modeling methodology to model the watershed. LiDAR 3 meter x 3-meter horizontal grid data was used to create the ground topography for this model. FATT surveyed stream cross-sections at approximately every 500 feet are used to increase the accuracy of the stream cross-sections and stream profiles within the watershed.

- Scenario 2: All mining activities but no logging activities were modeled in the watershed. NRSC (SCS) soil groups and types, CNs, land types, land descriptions were identified by FATT. This data was inserted into the base hydrologic model. LiDAR - 3 meter x 3-meter horizontal grid data was used to create the ground topography for this model. FATT surveyed stream cross-sections at approximately every 500 feet were used to increase the accuracy of the stream cross-sections and stream profiles within the watershed.

- Scenario 3: All mining with all areas assumed to be reclaimed and bond released, the vegetation has matured for 40 years and is equal to that of the surrounding area. NRSC (SCS) soil groups and types, CNs, land types, land descriptions were identified by FATT. This data is inserted into the base hydrologic model. LiDAR 3 meter x 3-meter horizontal grid data was used to create the ground topography for this model. FATT surveyed stream cross-sections at approximately every 500 feet were used to increase the accuracy of the stream cross-sections and stream profiles within the watershed.

- Scenario 4: No mining and no logging were shown modeled in the watershed. All forest areas were assumed to be mature. However, the mine topography as created by the mining activities as of 2001, and mapped by the LiDAR data was maintained in this model. NRSC (SCS) soil groups and types, CNs, land types, land descriptions were identified by FATT. This data is inserted into the base hydrologic model. LiDAR 3-meter x 3-meter grid data was used to create the ground topography for this model. FATT surveyed stream cross-sections at approximately every 500 feet were used to increase the accuracy of the stream cross-sections and stream profiles within the watershed.

- Scenario 5: No mining and no logging activities were shown in the watershed. All forest areas were assumed to be mature. NRSC (SCS) soil groups and types, CNs, land types, land descriptions were identified by FATT. This data is inserted into the base create the ground topography for this model. FATT surveyed stream cross-sections at approximately every 500 feet were used to increase the accuracy of the stream cross-sections and stream profiles within the watershed.

SCRABBLE CREEK WATERSHED MODELING SCENARIOS

- Scenario 1: All mining and logging activities as existed on July 8, 2001, were modeled in the watershed. NRSC (SCS) soil groups and types, CNs, land types, land descriptions were identified and validated by FATT. This data is inserted into the base hydrologic modeling methodology to model the watershed. LiDAR 3 meter x 3-meter horizontal grid data was used to create the ground topography for this model. FATT surveyed stream cross-sections at approximately every 500 feet were used to increase the accuracy of the stream cross-sections and stream profiles within the watershed.

- Scenario 2: All mining but no logging activities as existed on July 8, 2001, were modeled in the watershed. NRSC (SCS) soil groups and types, CNs, land types, land descriptions were identified by FATT, This data is inserted into the base hydrologic model LiDAR 3 meter x 3 meter horizontal grid data was used to create the ground topography for this model. FATT surveyed stream cross-sections at approximately every 500 feet were used to increase the accuracy of the stream cross-sections and stream profiles within the watershed.

- Scenario 3: All mining with all areas assumed to be reclaimed and bond released, the vegetation has matured for 40 years and is equal to that of the surrounding area. No logging activities were shown in the watershed. NRSC (SCS) soil groups and types, CNs, land types, land descriptions were identified by FATT. This data is inserted into the base hydrologic model. LiDAR 3 meter x 3-meter horizontal grid data was used to create the ground topography for this model. FATT surveyed stream cross-sections at approximately every 500 feet were used to increase the accuracy of the stream cross-sections and stream profiles within the watershed.

- Scenario 4: No mining and no logging were shown modeled in the watershed. All forest areas were assumed to be mature. However, the mine topography as created by the mining activities as of 2001, and mapped by the LiDAR data was maintained in this model. NRSC (SCS) soil groups and types, CNs, land types, land descriptions were identified by FATT. This data is inserted into the base hydrologic model. LiDAR 3 meter x 3-meter grid data was used to create the ground topography for this model. FATT surveyed stream cross-sections at approximately every 500 feet were used to increase the accuracy of the stream cross-sections and stream profiles within the watershed.

- Scenario 5: No mining and no logging activities were shown in the watershed. All forest areas were assumed to be mature. NRSC (SCS) soil groups and types, CNs, land types, land descriptions were identified by FATT. This data is inserted into the base hydrologic model. USGS 10 x 10-meter grid data was used to create the ground topography for this model. FATT surveyed stream cross-sections at approximately every 500 feet were used to increase the accuracy of the stream cross-sections and stream profiles within the watershed.

SYCAMORE CREEK WATERSHED MODELING SCENARIO (CONTROL WATERSHED)

Scenario 1: No mining and no logging were shown modeled in the watershed. All forest areas were assumed to be mature. NRSC (SCS) soil groups and types, CNs, land types, land descriptions were identified by FATT. This data was inserted into the base hydrologic model. LiDAR 3 meter x 3-meter grid data was used to create the ground topography for this model. FATT surveyed stream cross-sections at specific locations in the stream necessary to calibrate and validate the model.

Because Sycamore Creek was designated the control watershed with no logging or mining influences, FATT modeled only one scenario, based upon the July 8, 2001, storm event. The model results concerning watershed performance was certified and then validated by FATT as being accurate and precise in its representation of the hydrologic and physical characteristics of the watershed during the storm event on July 8, 2001.

Certain physical conditions associated with mining and logging influences on runoff were input into the modeling analysis to ensure accurate depiction of these activities. Some of these conditions were:

- Type of terrain and slope of natural undisturbed ground
- Type of mining activity - Approximate Original Contour (AOC) versus Regrade Variance
- Extent of mining
- Degree of reclamation

- Type of logging activity – Select-cut or clear-cut methods
- Extent of logging activity
- Extent of post-timbering regrowth
- Location of industry activity within the watershed

Upon assembly of all pertinent research, data, and factors of influence concerning the subject watersheds, the modeling analysis was completed. After calibration and validation of model accuracy, the following results were obtained. For a more detailed comparison of watershed effects, refer to Parts II and III of this report.

The scenario comparisons yielded the following results. The results represent the percentage increases or decreases in flow volumes (ft^3/sec) at various locations within each study watershed.

Seng Creek

SENG CREEK WATERSHED - (July 8, 2001 event)								
PEAK DISCHARGE STREAM FLOW VALUES AND PERCENTAGE DIFFERENCES IN WATERSHEDS COMPARED WITH UNDISTURBED WATERSHED								
NODE LOCATION	**Scenarios 1:2** Total Logging Influence		**Scenarios 2:4** Total Mining Influence		**Scenarios 4:1** Total Logging & Total Mining Influence		**Scenarios 4:3** Mining with Reclaimed Topography Influence & No Logging	
Node 1C at mouth of watershed	144 cfs	5.9%	-6 cfs	-0.2%	138cfs	5.6%	-78 cfs	-3.3%
Node 2C	126 cfs	5.8%	-19 cfs	-0.9%	107 cfs	4.9%	-93 cfs	-4.4%
Node 3C	112 cfs	5.9%	55 cfs	3.0%	167 cfs	9.1%	-18 cfs	-1.0%
Node 4C	76 cfs	5.6%	-10 cfs	-0.7%	66 cfs	4.8%	-81 cfs	-6.3%
Node 5C near toe of Valley fill	27 cfs	3.9%	-19 cfs	-2.8%	8 cfs	1.1%	-87 cfs	-14.1%

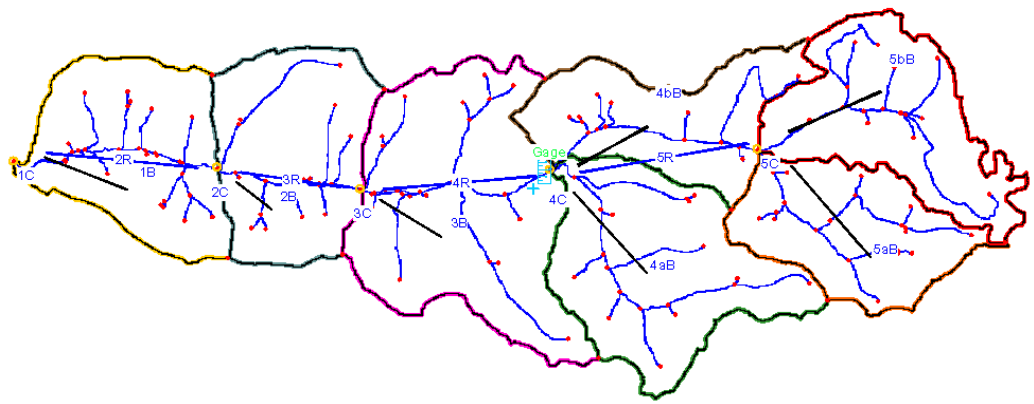
In the Seng Creek watershed at the 1C node (near mouth of the receiving stream), FATT determined that logging had a 5.9% flow increase and mining had a 0.2% flow decrease.

Logging in Seng Creek occurred fairly recently (within 1 – 5 years) and had minimal regrowth opportunity. Mining operations were ongoing and the actual regrade designs allowed a regrade variance from AOC. Specifically, the mined areas were regraded to a configuration having flatter slopes than the original pre-mining topography. This alteration of the topography by the surface mine to lesser slopes had a beneficial effect and produced less of an overall impact or influence outcome relating to surface runoff volumes and stream peak discharges.

Seng Creek Hydrology Analysis

Seng Creek Watershed Hydrology Analysis	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
	With Logging (CN 70 & 73) With Mining (CN 75 & 87) Topography w Mining (LIDAR Data)	Without Logging (CN 70) With Mining (CN 75 & 87) Topography w Mining (LIDAR Data)	Without Logging (CN 70) With Reclaimed Mining (CN 70) Topography w Mining (LIDAR Data)	Without Logging (CN 70) Without Mining (CN 70) Pristine Topography (USGS DEM Data)	With Logging (CN 70 & 73) Without Mining (CN 70) Pristine Topography (USGS DEM Data)

Watershed Delineation and Basin / Outlet / Routing Naming



Scrabble Creek

SCRABBLE CREEK WATERSHED - (July 8, 2001 event)								
PEAK DISCHARGE STREAM FLOW VALUES AND PERCENTAGE DIFFERENCES IN WATERSHEDS COMPARED WITH UNDISTURBED WATERSHED								
NODE LOCATION	Scenarios 1:2 Total Logging Influence		Scenarios 2:4 Total Mining Influence		Scenarios 4:1 Total Logging & Total Mining Influence		Scenarios 4:3 Mining with Reclaimed Topography Influence & No Logging	
Node 1C at bottom of Scrabble Creek	75 cfs	3.8%	168 cfs	9.3%	243 cfs	13.5%	-139 cfs	-8.4%
Node 2C	65 cfs	3.7%	205 cfs	13.4%	270 cfs	17.6%	-107 cfs	-7.5%
Node 3C	10 cfs	1.1%	110 cfs	13.4%	120 cfs	14.7%	-51 cfs	-6.6%
Node 4C Downstream of Valley Fill	0 cfs	0%	30 cfs	17.3%	30 cfs	17.3%	-2 cfs	-1.2%
Node 5C Downstream of Valley Fill	0 cfs	0%	59 cfs	21.1%	59 cfs	21.1%	-1 cfs	-0.4%
Node 6C Downstream of Valley Fill	0 cfs	0%	22 cfs	19.6%	22 cfs	19.6%	1 cfs	0.9%
Node 7C	23 cfs	4.0%	68 cfs	13.5%	91 cfs	18.1%	-33 cfs	-7.0%

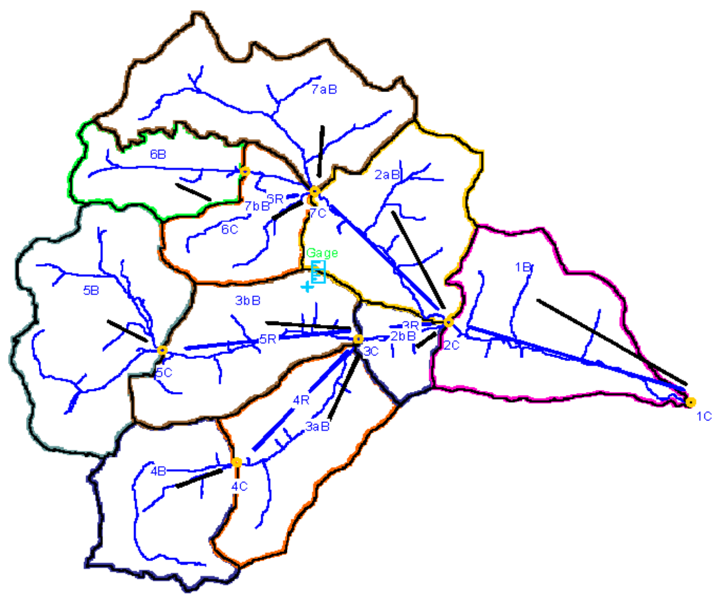
In the Scrabble Creek watershed at the 1C node (near mouth of the receiving stream), FATT determined that logging had a 3.8% flow increase and mining had a 9.3% flow increase.

In this study watershed, both current and recent logging occurred, but affected a lesser fraction of the watershed area than in Seng Creek. Much of the mining area was in some form of reclamation, but the average regrade slopes closely approximated those of the pre-mining topography when compared to Seng Creek. The mine reclaimed steeper slopes created faster surface runoff and retarded less flows than that of the surface mine in Seng Creek that had less reclaimed topographic slopes.

Scrabble Creek Hydrology Analysis

Scrabble Creek Watershed Hydrology Analysis	Scenario 1 With Logging (CN 70 & 73) With Mining (CN 75 & 87) Topography w Mining (LIDAR Data)	Scenario 2 Without Logging (CN 70) With Mining (CN 75 & 87) Topography w Mining (LIDAR Data)	Scenario 3 Without Logging (CN 70) With Reclaimed Mining (CN 70) Topography w Mining (LIDAR Data)	Scenario 4 Without Logging (CN 70) Without Mining (CN 70) Pristine Topography (10m DEM Data)	Scenario 5 With Logging (CN 70 & 73) Without Mining (CN 70) Pristine Topography (10m DEM Data)

Watershed Delineation and Basin / Outlet / Routing Naming



Sycamore Creek

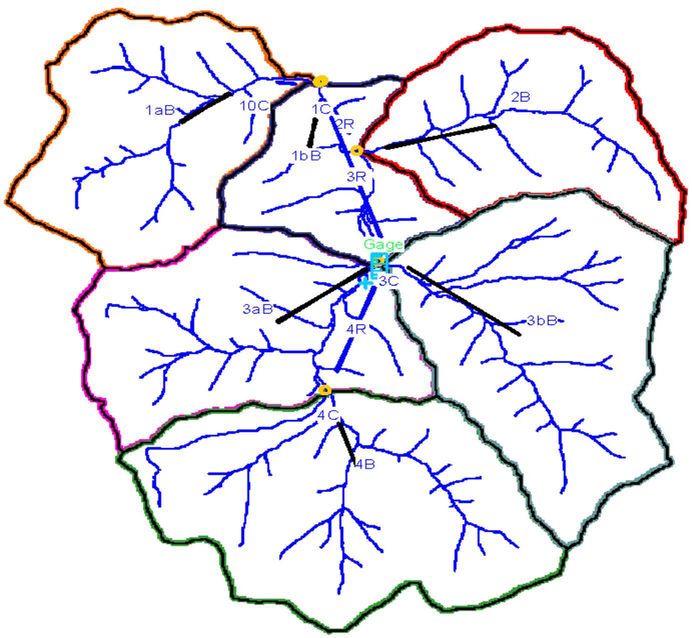
Sycamore Creek was observed to have extensive surface water runoff impacts with negligible logging and mining disturbances. No current logging or mining operations were identified in this watershed. Surface mining had been conducted many years ago (estimated 20 or more years) along a small contour operation near the head of the watershed. Over the years, natural revegetation of this mining disturbance had occurred. For modeling purposes, this watershed was assumed to be undisturbed.

The assimilated design storm in Sycamore Creek, representing the July 8, 2001, event consisted of 2.6 inches of rainfall over an approximate 5-hour period. This amount of rain was less than the 3.9 inches and 4.1 inches observed in Seng and Scrabble Creeks, respectively. Nevertheless, the impacts to the Sycamore Creek watershed by the "out-of-bank" flows were severe, especially when considering the damages caused to the community of Colcord, located near the mouth of Sycamore Creek. Because of these runoff impacts in the watershed, Sycamore Creek was chosen by FATT to provide a perspective analysis focusing upon the July 8, 2001, precipitation event and its associated surface water runoff effects in the watershed.

Sycamore Creek	LIDAR (wo Mining & wo Logging)		
Outlet Node	Event	25 yr	100 yr
1C	1211	4378	6078
2C	198	901	1255
3C	840	3374	4737
4C	333	1513	2109

9 fps

Watershed Delineation and Basin / Outlet / Routing Naming



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WMS Peak Discharge Values.xls

VIII. FLOOD ANALYSIS TECHNICAL TEAM CONCLUSIONS

The Flood Analysis Technical Team in conjunction with the Flood Investigative Advisory Committee both enacted by Governor's Executive Order No. 16-10 undertook an extensive investigation into the scientific and hydrologic cause of the July 8, 2001 floods. The investigation focused on any impacts that current and past practices of the timbering and mining may have had or contributed to the aforementioned flooding events. The investigation made extensive use of information obtained from numerous Federal agencies, other West Virginia State agencies, and West Virginia University. Additional information was gained through agency consultations, individual interviews and public meetings.

The study concentrated on runoff analysis. The results reached in this report provide an indication of the impacts of mining and forestry practices and the consequent behavior of the watersheds throughout the July 8th storm event. This report may form the basis for more analyses in the future. Although time did not allow for additional watersheds to be studied, the results contained in this report are applicable to most steep slope topographic regions associated with most of southern West Virginia. While this study was based upon runoff analysis comparative methods, other issues of concern such as sediment deposition were considered based mainly on observation and/or comments. References to these types of issues are presented in the recommendations to provide further downstream protection.

In general, the percentage contributions of mining and timbering were relatively small when compared to the total stream flow volumes and the associated cross-sectional areas <u>at the mouths</u> of the selected watersheds, i.e., Seng Creek and Scrabble Creek. However, at evaluation points further upstream and closer to the industry disturbances, the calculated runoff volumes often increased and the associated effects became more pronounced. These effects intensified primarily because the topography is more restrictive and provides less cross-sectional area to accommodate flows and the closer proximity to industrial activities provides less runoff attenuation.

In the modeled watersheds, flows were "out-of-bank" for all scenarios, including the undisturbed scenario assuming no industry influences. Even without the exacerbating effects from the industry operations, significant "out-of-bank" flows would have resulted.

Any increase in runoff contributions must be considered potentially significant. However, it would be presumptuous of FATT to draw conclusions regarding significance without further long-term investigation and analyses, including (as previously mentioned) an investigation of every reach of stream in the impacted watersheds, the damaged residences and every natural and manmade stream constriction in those watersheds that could influence water level. What can be concluded, however, is that mining and timbering impacts did influence the study watersheds by increasing surface water runoff and the resulting stream flows at various evaluation points.

IX. FLOOD ANALYSIS TECHNICAL TEAM RECOMMENDATIONS

These recommendations are meant to foster enhanced runoff control for logging and mining operations. Most of the recommendations contained herein will have to be implemented through rulemaking or, in the case of forestry, formal changes to the Best Management Practices, while others pertaining to forestry can be implemented through policy or programmatic development, as indicated.

As noted below, a number of these recommendations are the result of the technical analysis conducted for the development of this report. Others came as a result of field observations made by agency professionals and information developed from the public meetings that were conducted as part of this effort.

A. FATT RECOMMENDATIONS FOR MINING AND RECLAMATION OPERATIONS

1. Recommendations Resulting from the Technical Analysis

a. Revise regulations to enhance Hydrologic Reclamation Plans for all existing, pending and future permits to prohibit any increase in surface water discharge over pre-mining conditions.
b. Revise regulations so that the post-mining drainage design of all existing and future mining permits corresponds with the permitted post-mining land configuration.
c. Revise regulations to enhance contemporaneous reclamation requirements to further reduce surface water runoff.

2. Recommendations Resulting Primarily from Observations

a. Revise regulations to require that each application for a permit contain a sediment retention plan to emphasize runoff control and minimize downstream sediment deposition during precipitation events.
b. Revise regulations to require durable rock fills be limited to “bottom up or incremental lift construction” methods for enhanced runoff and sediment control.

c. Revise regulations to require the condition of the total watershed be reviewed prior to any approved placement of excess spoil material. Conditions that should be considered include the proximity of residents, structures, etc., to excess spoil disposal structures.
d. Revise regulations to require that valley fill designs minimize erosion within the watershed during precipitation. The permittee shall consider the total disturbance of the disposal area.
e. Revise regulations to prohibit “wing dumping” of spoil in excess spoil disposal structures.
f. Revise regulations to prohibit placement of windrowed material in areas that encroach upon natural drainageways.
g. Revise regulations to limit areas allowed for clearing/grubbing of operations in excess spoil disposal areas.
h. Revise regulations to maximize reforestation opportunities for all types of post mining land uses.
i. Revise regulations to require rain gages be located on all mine sites and that monitoring and reporting schedules be developed.

B. FATT RECOMMENDATIONS FOR FORESTRY OPERATIONS

Agency observations and comments by the public indicated substantial movement of logging debris and sediment from logging operations into streams during the flood event. Transport of this material was caused in part by concentration of flow by logging and skid roads. In addition, disposal of slash near streambeds also contributed material that may have increased flood damage. Erosion of material from roadways was evident from aerial overflights after the July 8 storm.

FATT recommends that the forestry oversight committee, established under the Logging Sediment Control Act, W.Va. Code 19-1B-7, include the foregoing recommendations as revisions to the West Virginia Best Management Practices to enhance sediment and runoff control. We further recommend increased staffing to aid in: forest fire prevention and suppression, forest hydrology, and field inspection and verification of the use of existing and proposed BMPs. While research shows the value of using BMPs, close field verification and vigorous enforcement are necessary to provide the benefits associated with proper timbering methods.

1. Recommendations

a. Revise BMPs to limit logging activities within the total area of a watershed based upon acreage, basal area removed, silvicultural methods or any combination so as to minimize runoff velocities and channelization of flows due to total watershed disturbance.

b. Revise BMPs to prohibit the use of lopped slash as a substitute for seeding on skid roads, require out-sloping and seeding of all roads prior to a post-operational site inspection or within sixty days of the end-date in the timber harvesting notification.
c. Revise BMPs to require a slash disposal plan be included in all timber harvesting notifications to provide for the removal of slash from roadways and landing areas. The BMPs should be revised to prohibit placement of large woody vegetation in intermittent and perennial stream channels.
d. Revise BMPs to require that the past history of uncontrolled burning in the watershed be taken into account in designing timbering operation plans to reduce runoff from these areas. The committee should investigate increased staffing for forest fire prevention and suppression with the long-term goal of eliminating forest fires as a contributor to increased runoff.
e. The Division of Forestry should conduct pre-operational site inspections to review proposed timbering operation plans, sediment control practices, and BMPs to be used by operators.
f. The Division of Forestry should implement a routine inspection regime to monitor and enforce BMPs and timbering notification requirements during active operations.
g. The Division of Forestry should conduct a post-operational site inspection at the end-date of the timbering operation to insure that all BMPs and sediment control practices have been met prior to removal of equipment from the site.
h. The Division of Forestry should provide increased technical assistance to timber operators in training and field verification, specifically with regard to road construction, stream-crossing construction, log landing location, and sediment control measures.

C. ADDITIONAL AREAS OF CONCERN EXPRESSED BY THE GENERAL PUBLIC AND RECOGNIZED BY FATT

FATT recognizes the following areas as appropriate for study to prevent or minimize storm-related flood damage. While assessments of these issues were beyond the scope of the instant analysis, FATT understands that most, if not all, of these matters are being addressed by the statewide flood protection task force.

1. Undersized road culverts in streams.
2. Inadequate flow areas under bridges and failure to maintain the bridge stream flow area.
3. Stream encroachment from land development.
4. Littering and placement of debris into streams and their flood plains.
5. Oil, gas, and other large scale earth disturbance projects.

D. FATT RECOMMENDATIONS FOR FURTHER STUDIES

1. Follow-up studies on any implemented recommendations resulting from this report to analyze effectiveness.
2. Additional studies to determine effectiveness of current logging BMPs and possible enhancements.

Table 1

Nation Weather Service precipitation measurements on July 8, 2001

Location	Amount of Precipitation
NWS Charleston station	**1.87” of precipitation**
Clay	**2.33” of precipitation**
Madison	**0.65” of precipitation**
Tornado	**0.80” of precipitation**
South of Beckley	**6.77” of precipitation**
Beckley	**4.56” of precipitation**
Dry creek	**3.91 of precipitation**
Babcock	**3.26” of precipitation**
Hawks Nest	**5.12” of precipitation**
Oak Hill	**4.78”of precipitation**
Page	**5.00” of precipitation**

National Weather Service Rainfall Data

LOCATION	COUNTY NAME	NORMAL JULY RAINFALL	RAINFALL ON JULY 8TH
Mullens, WV Oceana, WV Pineville, WV Kopperston, WV Wolf Pen, WV Clear Fork, WV	Wyoming	4.80 inches	5.32 inches 5.19 inches 4.79 inches 3.49 inches 2.56 inches 1.53 inches
Hawks Nest SP, WV Page, WV Oak Hill, WV Gauley Mountain, WV Mann Lookout Tower	Fayette	4.80 inches	5.02 inches 5.00 inches 4.78 inches 3.78 inches 2.38 inches
Beckley VA, WV Crab Orchard, WV Dry Creek, WV Grandview, WV Beckley AP, WV	Raleigh	5.50 inches	4.56 inches 4.05 inches 3.91 inches 3.42 inches 2.64 inches
London Lock, WV Marmet Lock, WV Latuna, WV Charleston AP, WV Charleston RLX, WV	Kanawha	4.80 inches	4.02 inches 2.49 inches 2.15 inches 2.05 inches 1.87 inches
Elkhorn, WV War, WV Welch, WV	McDowell	4.60 inches	4.05 inches 3.07 inches 1.20 inches
Elk Run, WV Williams Hill, WV Madison, WV	Boone	4.60 inches	1.88 inches 1.79 inches 0.65 inches

Table 2

U.S. ARMY CORPS OF ENGINEERS RAINFALL COMPARISON 2001

Gage	July 8th Storm (4 hour event)	July 27th (24 hour event)
Beckley, WV	4.56 inches	5.31 inches
Pineville, WV	4.75 inches	1.30 inches
Oceana, WV	5.19 inches	1.15 inches
Mullens, WV	5.37 inches	2.36 inches
Oak Hill, WV	4.78 inches	2.81 inches
Hawks Nest, WV	5.72 inches	2.38 inches
Wolf Pen, WV	2.56 inches	1.51 inches
Kopperston, WV	3.49 inches	1.74 inches

U.S. Army Corps of Engineers – Huntington District
Precipitation Comparison - 2001

Gage	May 16-18**	July 8*	July 26	July 29	July 30	Total all Storms
LOCATION						
Bartlick, VA	NA	0.41”	2.45”	0.25”	1.53”	4.64”
Beckley, WV	NA	4.56”	5.31”	1.28”	0.96”	12.11”
Beech Fork Lake, WV	3.10”	0.14”	1.43”	0.81”	0.84”	6.32”
Bluestone Lake, WV	3.55”	1.55”	3.48”	1.52”	1.29”	11.39”
Clintwood, VA	NA	NA	2.86”	NA	NA	2.86”
Craigsville, WV	NA	1.49”	3.74”	3.20”	2.03”	10.46”
Dewey Lake, WV	1.44”	0.58”	2.82”	2.12”	0.95”	7.91”
East Lynn Lake, WV	4.05”	0.32”	2.15”	0.94”	1.39”	8.85”
Frametown, WV	NA	2.38”	0.42”	0.63”	1.04”	4.47”
Georges Fork, VA	NA	0.65”	3.00”	0.41”	0.54”	4.60”
Grayson Lake	2.05”	0.40”	0.39”	1.19”	1.49”	5.52”
Hawks Nest, WV	NA	5.72”	2.38”	2.00”	NA	10.10”
Haysi, VA	NA	0.42”	3.13”	0.27”	1.67”	5.49”
John Flannagan Lake	2.23”	0.44”	4.00”	0.30”	1.90”	8.87”
Kopperston, WV	NA	3.49”	1.74”	0.88”	0.92”	7.03”
Madison, WV	NA	NA	3.80”	NA	NA	3.80”
Mt. Lookout, WV	NA	1.82”	3.22”	2.07”	2.34”	9.45”
Mt. Nebo, WV	NA	NA	2.75”	2.08”	NA	4.83”
Mullens, WV	NA	5.37”	NA	0.92”	1.51”	7.80”
Oak Hill, WV	NA	4.78”	2.81”	1.10”	NA	8.69”
Oceana, WV	NA	5.19”	NA	1.27”	NA	6.46”
Pikeville, KY	NA	NA	2.26”	0.47”	0.81”	3.54”
Pineville, WV	NA	4.75”	1.30”	0.63”	NA	6.68”
Queen Shoals, WV	NA	2.47”	0.69”	1.04”	0.70”	4.90”
R. D. Bailey Lake, WV	2.18”	0.62”	1.77”	0.74”	1.47”	6.78”
Richlands, VA	NA	NA	3.25”	NA	NA	3.25”
Summersville Lake, WV	3.30”	1.09”	4.18”	2.83”	2.96”	14.36”
Sutton Lake, WV	2.26”	0.44”	1.06”	0.77”	2.01”	6.54”
Wayne, WV	NA	NA	2.22”	0.88”	1.66”	4.76”

*July 8, 2001– an estimated 4-hour storm event

** May storms - all observed values from COE projects.

Table 3

USGS Provisional recurrence interval of July 2001 flood in West Virginia from High Water Marks compared to Flood Insurance Study

Location	Elevation	Recurrence Interval
Tug Fork at mile 153.1 (Downtown Anawalt)	1686.9	50
Tug Fork at mile 151.8 (West side of Anawalt)	1653.7	>500
Tug Fork at mile 150.2	1603.6	100
Tug Fork at mile 145.2	1471.7	100
Tug Fork at mile 141.4 (Downtown Gary)	1404.9	10
Tug Fork at mile 136.3 (East side of Welch)	1317.4	10-50
Elkhorn Creek at mile 13.7 (East of Keystone)	1664.4	10
Elkhorn Creek at mile 8.25 (East of Kimball)	1491.0	10
Elkhorn Creek at mile 7.0	1465.6	10-50
Elkhorn Creek at mile 0.5	1307.5	50
Browns Creek at mile (North side of Welch)	1448.0	
Guyandotte River at mile 167.2	1567.2	>500
Guyandotte River at mile 159.7 (Mullens)	1427.8	>500
Slab Creek at mile 0.3 (Mullens)	1423.3	100
Guyandotte River at mile 157.5	1408.3	>500
Guyandotte River at mile 149.1	1338.9	100-500
Guyandotte River at mile 147.6	1330.1	100
Guyandotte River at mile 143.8 (approximate)		>100
Pineville Upstream of Park Street	1288.3	
Pineville Downstream of Park Street	1286.3	
Guyandotte River at mile 142.6 (In loop of river)	1272.0	>500
Guyandotte River at mile 138.5	1224.2	500
Guyandotte River at mile 131.7	1171.25	>500
Clear Fork at Oceana (2.8 miles above State Route 10)	1257.6	50
Clear Fort at mile 12.3	1238.1	100
Paint Creek 14,200 ft. above confluence of town of Pax	1629.8	100

Table 4

Provisional discharge of the July 2001 flood in West Virginia and estimated recurrence interval from USGS gaging stations
[Drainage area in square miles, peak stage in feet, peak discharge in cubic feet per second, and recurrence interval years.]

USGS station number and name	County	Drainage Area	Peak Stage	Peak Discharge	Recurrence interval
03177100 Payne Branch near Oakvale	Mercer	8.64	2.86	--	--
03178000 Bluestone River near Spanishburg	Mercer	199.00	18.30	6,000	2
03178500 Camp Creek near Camp Creek	Mercer	32.00	7.15	4,800	25-50
03179000 Bluestone River near Pipestem	Summers	395.00	11.44	9,110	2-5
03185000 Piney Creek at Raleigh	Raleigh	52.20	9.40	--	--
03190100 Anglins Creek near Nallen	Nicholas	23.50	No HWM	--	<2
03190500 Meadow Creek near Summersville	Nicholas	4.22	No HWM	--	<2
03191400 Laurel Creek near Summersville	Nicholas	4.28	No HWM	--	<2
03198350 Clear Fork at Whitesville	Raleigh	62.80	28.47	--	--
09199300 Rock Creek near Danville	Boone	12.20	6.45	380	<2
03200500 Coal River at Tornado	Kanawha	862.00	18.83	15,400	<2
03202245 March Fork at Maben	Wyoming	4.85	15.38	Indirect Q	--
03202400 Guyandotte River at Baileysville	Wyoming	306.00	31.25	Indirect Q	--
03202480 Briar Creek at Fanrock	Wyoming	7.34	No HWM	--	<2
03202490 Indian Creek at Fanrock	Wyoming	40.70	17.11	4,940	50
03202750 Clear Fork at Clear Fork	Wyoming	126.00	15.60	Indirect Q	--
03212750 Tug Fork at Welch	McDowell	174.00	19.77	Indirect Q	--
03212980 Dry Fork at Beartown	McDowell	209.00	10.13	7,180	5-10
03213000 Tug Fork at Litwar	McDowell	505.00	13.17	19,000	5
03213620 Tug Fork at Vulcan	Mingo	778.00	17.00	19,500	--
03213700 Tug Fork at Williamson	Pike (Ohio)	936.00	20.01	13,000	<2

Table 5

NRCS Runoff Curve Numbers (ref. TR-55 Appendix) for Cultivated Agricultural Lands[1]

			Curve numbers for			
Cover type	**Treatment[2]**	**Hydrologic Condition[3]**	**A**	**B**	**C**	**D**
Fallow	Bare soil	-	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row	Poor	72	81	88	91
		Good	67	78	85	89
	Straight row + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	Contoured + (CR)	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	68	74	80	82
		Good	62	71	78	81
	Contoured & terraced + CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	Straight row	Poor	65	76	84	88
		Good	63	75	83	87
	Straight row + CR	Poor	64	75	83	88
		Good	60	72	80	84
	Contoured	Poor	63	74	82	85
		Good	61	73	81	84
	Contoured + CR	Poor	62	73	81	84
		Good	60	72	80	83
	Contoured & terraced	Poor	61	72	79	82
		Good	59	70	78	81
	Contoured & terraced + CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded	Straight row	Poor	66	77	85	89
or broadcast		Good	58	72	81	85
legumes or	Contoured	Poor	64	75	83	85
rotation		Good	55	69	78	83
meadow	Contoured & terraced	Poor	63	73	80	83
		Good	51	67	76	80

[1] Average runoff condition.
[2] Crop residue cover (CR) applies only if residue is on at least 5% of surface throughout the year.
[3] Hydrologic condition is based on combination of factors that affect infiltration and runoff, including:
(a) density and canopy of vegetative areas

(b) amount of year-round cover
(c) amount of grass or close-seeded legumes in rotation
(d) percent of residue cover on the land surface (good > 20%), and
(e) degree of surface roughness.

Poor: Factors impair infiltration and ten to increase runoff.
Good: Factors encourage average and better than average infiltration and tend to decrease runoff.

Table 5, con't – NRCS Runoff Curve Numbers for other Agricultural Land[1]

Cover Description		Curve numbers for hydrologic soil group			
Cover type	**Hydrologic Condition[3]**	**A**	**B**	**C**	**D**
Pasture, grassland, or range – continuous forage for grazing.[2]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow – continuous grass, protected from grazing and generally mowed for hay.	-	30	58	71	78
Brush – brush-weed-grass mixture with brush the major element[3]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30[4]	48	65	73
Woods-grass combination (orchard or tree farm).[5]	Poor	57	73	82	88
	Fair	43	65	76	82
	Good	32	58	72	79
Woods[6]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30[4]	55	70	77
Farmsteads – building, lanes, driveways and surrounding lots.	-	59	74	82	86

[1] Average runoff conditions.
[2] Poor: < 50% ground cover or heavily grazed with no mulch.
Fair: 50% to 75% ground cover and not heavily grazed.
Good: > 75% ground cover and lightly or only occasionally grazed.
[3] Poor: < 50% ground cover.
Fair: 50% to 75% ground cover.
Good: > 75% ground cover.
[4] Actual curve number is less than 30; use CN = 30 for runoff computations.
[5] CNs shown were computed for areas with 50% woods and 50% grass (pasture) cover.
Other combinations of conditions may be computed from the CNs for woods and pasture.
[6] Poor: Forest, litter, small trees, and brush have been destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

Table 5, con't. - NRCS Runoff Curve Numbers for Arid and Semi-Arid Rangeland[1]

Cover Description		Curve numbers for hydrologic soil group			
Cover type	**Hydrologic Condition[2]**	**A**	**B**	**C**	**D**
Herbaceous – mixture of grass, weeds, and low growing brush, with brush the minor element.	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Oak–aspen – mountain brush mixture or oak brush, Aspen, mountain mahogany, bitter brush, maple, and other brush.	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48
Pinyon-juniper –pinyon juniper, or both; grass understory.	Poor		75	85	89
	Fair		58	72	80
	Good		41	61	71
Sagebrush with grass understory.	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
Desert shrub – major plants include saltbrush, greasewood, creosotebruse, blackbrush, bursage, palo verde, mesquite, and cactus.	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	88	79	84

[1] Average runoff conditions. For rangelands in humid regions, use table 2-3b.
[2] Poor: < 30% ground cover (litter, grass, and brush overstory).
Fair: 30% to 70% ground cover.
Good: > 70% ground cover.
[3] Curve numbers for group A have been developed only for desert shrub.

Table 5, con't. – NRCS Runoff Curve Numbers for other Urban Areas[1]

Cover Description		Curve numbers for Hydrologic soil group			
Cover type and hydrologic condition	**Average percent Impervious area[2]**	**A**	**B**	**C**	**D**
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, etc.)[3];					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right of way).		95	98	98	98
Streets and roads;					
Paved; curbs and storm sewers (excluding-right-of-Way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only)[4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, dessert shrub with 1 – 2 inch sand or gravel mulch and basin borders.)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
¼ acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
½ acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no Vegetation)[5]		77	86	91	94
Idle lands (CNs are determined using cover similar to those in table 2-2a)					

[1]Average runoff condition

[2]The average percent impervious area shown was used to develop the composite CNs. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition.

[3]CNs shown are equivalent to those of pasture. Composite CNs may be computed for other combinations of open space cover type.

[4]Composite CNs for natural desert landscaping should be computed based on the impervious area (CN = 98) and the previous area CN. The pervious area CNs are assumed equivalent to desert shrub in poor hydrologic condition.

[5]Composite CNs to use for the design of temporary measures during grading and construction should be computed using the degree of development (impervious area percentage) and the CNs for the newly graded pervious area.

Table 5, con't. – NRCS Runoff Curve Numbers for Porous Pavement & Surface Mined Areas[1]

Cover Description		**Curve numbers for hydrologic soil group**			
Cover type and hydrologic condition	**Gravel Subbase Thickness**	**A**	**B**	**C**	**D**
Porous pavement					
Properly maintained	10 inches	57	66	69	75
Properly maintained	12 inches	56	64	68	74
Properly maintained	14 inches	55	63	67	72
Properly maintained	16 inches	54	62	65	70
Properly maintained	18 inches	53	61	64	69
Properly maintained	20 inches	52	60	63	68
Properly maintained	24 inches	52	58	61	66
Properly maintained	30 inches	49	55	57	61
Properly maintained	36 inches	47	52	55	58
Not properly maintained	10-36 inches	98	98	98	98
Disturbed surface mined areas					
Raw spoils (gob piles)		88	88	88	88
Graded spoils		84	84	84	84
Top-dressed spoils		82	82	82	82
Vegetated spoils		75	75	75	75

[1]Average runoff conditions, $I_a = 0.2S$.

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Peer Review Addendum

As provided by the executive order, the Flood Advisory Committee recommended that this study be evaluated by impartial experts. Consequently, the committee chose Dr. Rhett Jackson and Dr. Wayne Swank to perform independent peer reviews of the FATT study. Their comments/recommendations and corresponding FATT responses are as follows:

Comments from Dr. Rhett Jackson

MEMORANDUM

To: Jim Pierce, John Ailes, and the West Virginia Flood Analysis Technical Team (FATT)

From: Rhett Jackson, P.E., Ph.D., Assistant Professor of Hydrology, Warnell School of Forest Resources, University of Georgia

Date: May 29, 2002

RE: Review of Draft Flood Analysis Technical Team Report

Introduction:

This memorandum provides a summary of my comments, observations, and suggestions regarding the draft flood analysis technical team report. Due to perceptions that mining and timber management activities may have contributed to the magnitude of the summer 2001 floods experienced in southern West Virginia, the Governor of West Virginia commissioned the Flood Analysis Technical Team (FATT) to assess the floods and the contribution of mining and timber management to these floods. The FATT has produced a draft report and has contracted for external review of the report before it is released to the public. This memorandum documents the findings of the review I have performed. The draft report is a substantial and important contribution to the understanding of the summer 2001 floods, and my comments are meant to help improve the document as a resource for the public and for State agencies.

Recommendations for Direct Analysis of Flood Related Data:

It is my opinion that the report in its current form relies too much on the hydrologic/hydraulic modeling to characterize the floods and their causes. Although the observational data is probably insufficient to support rigorous statistical analysis of the floods and their causes, the observational data can be better used to understand and explain the floods of summer 2001. It is my experience that the public and agency personnel will be more receptive to conclusions or inferences drawn from raw data than to conclusions drawn from modeling. It is best when data analysis and modeling are complementary. I have a number of suggestions for direct analysis of flood related data.

Land use in the study area, and the relationship of land use to flood magnitude, need to be explored in maps and tables. I suggest creating a map, or possibly a series of maps, illustrating the hydrography and land use in the study area as well as the spatial distribution of available data. An ideal map would show:

- stream network,
- land use roughly categorized as forest, recent harvest, active mine, closed mine, agricultural, and residential/commercial,
- locations of flood damage,
- rain gages and precipitation amounts on the day in question,
- USGS flow gages and recurrence interval of flow on the day in question, and
- locations and recurrence intervals of flows estimated from high water marks.

I suggest supporting this map with a land use table for each basin where flow has been measured or estimated. The table should include the following information:

- location,
- basin area,
- percent of basin in forest cover,
- percent of basin recently logged,
- percent of basin mined,
- percent of basin developed,
- precipitation depth during the storm, and
- recurrence interval of resulting flow.

From the map and the table, readers can infer whether mining and timber mangement appear to be correlated to flood magnitude, or whether flood magnitude seems to be independent of these land uses. The map and the table would also allow technical reviewers to understand what data are available and what data analysis is possible. For instance, one question that occurred to me while reviewing the report was why there were so few large flows reported at the existing USGS gages? Where are these gages located with respect to the high precipitation amounts experienced in the summer of 2001?

If there are enough locations in the study area where flood flows were measured or estimated from water levels, I suggest running a multiple regression of flow recurrence (or the ratio of the peak flow to the basin's mean annual flow) against basin area, precipitation depth, percent of basin recently logged, and percent of basin mined. The regression would discover whether there are significant relationships between the logged and mined areas and the magnitude of the resulting floods. If there are insufficient data for a multiple regression, I suggest grouping basins by basin size, and conducting a graphical analysis of mining and timber harvest. Specifically, create graphs of relative flood magnitude versus percent of area mined, percent of area recently harvested, and the summation of the area mined and recently harvested. The problems with such an analysis are that each basin received a different amount of precipitation, the amount of precipitation received often must be estimated based on spatial extrapolation, and the antecedent moisture conditions for each basin were different. That is why a regression analysis would be better. If there is a strong relationship to precipitation depth, it might be possible to conduct a simple graphical analysis of the residuals from the precipitation relationship versus mined and logged areas.

Another possible avenue for addressing the effects of logging and mining is analysis of long-term peak flow time series from the USGS gages. If there are gages on streams with little or no influence of mining and logging, these stations can serve as controls. Then, the ratios of peak flows in logged and mined basins to the peak flows in the control basins can be analyzed over time, and the pattern can be compared to the time series of logging and mining activities. There are established procedures for this type of analysis.

A literature review on the hydrologic effects of timber management and mining would also help support this analysis. There is a lot of scientific literature on the effects of timber harvest and management on stream flows. I would be happy to provide a short review of the literature on timber harvest and hydrology, and I could also provide a bibliography of such literature. I am not familiar with hydrologic literature concerning coal mining, but if any such studies exist, they should be described in the report as well.

I also suggest analyzing the types of damages that occurred during the flood. How were people killed? Were flooded structures within the mapped 100-year floodplain? Were they new structures built in areas where flooding was previously experienced? The types and mechanisms of flood impacts might guide policy changes to help minimize the damages incurred in future floods.

Comments on the flood modeling:

There is nothing inherently wrong with the analysis that was conducted, but the presentation suggests that the modeling effort was something more than it was. In essence, the SCS Curve number model has been run under various logging and mining scenarios to estimate the relative impact of these activities on the floods experienced in the summer of 2001 based on the principles of the SCS model. This exercise allows the comparison of predicted storm runoff for a hypothetical fully forested condition and the actual land use composition of 2001, as well as other scenarios that allow the predicted effects of logging and mining to be separated. If the proportion of land in these activities is relatively small, or if the post-mining topography temporarily captures stormflow, then the SCS method will not predict a major change in downstream flows. If the proportion of land in these activities is large, the SCS method will predict major changes in downstream flows. This is basically a way of filtering a land use analysis through a hydrologic model. The argument would be much stronger, however, if a graphical and tabular land use analysis accompanied the effort (see comments above).

Throughout the report there are comments that the BOSS modeling system provides accurate and precise results. Actually, the SCS method that is the basis for HEC-1 and BOSS modeling is inherently inaccurate. There is a very good reason that the textbooks and guidance documents for the SCS method do not show the original scatter plots from which the curve numbers were derived - such plots would erode the user's confidence in the results of the model. While the curve number for a mature forest on a certain type of soil may be 70, the actual runoff behavior of such a land/cover combination is actually quite variable due to differences in soil depth, bedrock conditions, topography, landscape position, and landscape history. For these reasons, uncalibrated hydrologic models, including the SCS model and others, are notoriously inaccurate. They may do a good job of predicting average relative differences between land uses, but describing them as accurate is not a fair statement, and if they are not accurate, their precision is basically meaningless. The models should simply be described as representing standard practice in the engineering and hydrologic communities, and that experience has shown these models represent the relative effects of land use change reasonably accurately.

There are other reasons that the BOSS modeling system cannot be described as accurate without more verification data. The input data itself is not highly accurate. The soil maps have precise lines showing where one soil ends and another begins, but these maps are developed from spot checks and aerial photographs, and while they are generally accurate, the errors in these maps may exceed the scale of the effect being modeled. Furthermore, the SCS method is not well suited for describing the hydrologic behavior of the highly modified landscape of a mine or a closed mine. Finally, the precipitation data put into these models is not very accurate. The high spatial variability of convective rainfall makes it very difficult to accurately assess how much rainfall fell on a basin during a single storm.

These qualifications about the accuracy of the model do not mean that the modeling effort is not worthwhile, but they should affect how the modeling is presented and how it is supported by other direct analysis of available data (see comments above).

Another caveat about the modeling is that the calibration that was conducted was not a true calibration as hydrologists use the term. The available data are not extensive enough to support a true calibration. A calibration data set must include a large number of different types of storms so that model parameters can be developed to provide robust simulation over a broad range of hydrologic and flow conditions. Matching a single peak from a single storm does not constitute a calibration.

Comments on the Organization and Content of the Report:

I am not sure what audience is being targeted with this report, but I think the report needs to be reorganized and shortened in order to reach a larger and more relevant audience. Much of the information on the details of the SCS, HEC1, and BOSS modeling belong in an appendix. This information is not informative to engineers and hydrologists familiar with the workings of these models, and it is not interesting to non-engineering audiences. The details need to be included in an appendix, so the analysis could be reproduced by others, but the details do not belong in the report.

I suggest restating the objectives (Section II) as follows:

1. Conduct a general hydrologic and hydraulic analysis of the floods of May and July 2001.

2. Determine the extent to which timber management and mining contributed to the magnitudes of these floods.

3. If the effects of timber management and mining on these floods is found to be unacceptable, explore how such effects could be reduced or managed in the future.

4. Make hydrologic policy recommendations to the Secretary of the DEP.

These objectives are more specific and better guide the analysis.

I would give section III a title such as, **Public and Agency Perceptions of the 2001 Floods**, and I would move much of the current section V into the new section III. This section would describe how the public viewed the floods and how the agencies have responded to the floods. This would help motivate the analysis.

I would create a new section IV, **Current Hydrologic and Water Quality Regulation of Mining and Timbering**. This section would describe current mitigations required or suggested of these activities. I would pull the appropriate material from the current section V into this section.

I would create a new section V, **Hydrologic and Hydraulic Review of the 2001 Floods**. In this section I would present the map discussed in my comments, the land use assessments, and any direct data analysis of flood flows or precipitation.

Section VI would be **Analysis of Flood Scenarios Using Hydrologic and Hydraulic Modeling**. This section would describe what models were use, why these models were run, and what the models indicated. This section would have a brief summary of how the models were set up. The vast majority of the supporting information in the current section III would be moved into an Appendix.

The PDF file for the supporting information needs to be split into two smaller files for easier access. Once I acquired the file, I had no trouble using it, but accessing a file of this size via email or via the web is problematic. Since many computers have 128 Megs of RAM or less, and since the operating software and Adobe must use a part of the RAM, a 98 Meg file is too large to be accessible to many potential users.

I hope these comments are helpful and useful to the FATT. Please contact me if you have questions, comments, or concerns regarding this review.

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FATT’s Responses to Dr. Jackson’s Comments

Dr. Jackson stated, “It is my opinion that the report in its current form relies too much on the hydrologic/hydraulic modeling to characterize the floods and their causes.”

FATT from the onset recognized the weaknesses associated with hydrologic modeling of natural, open systems (watersheds) and worked diligently to identify any and all key parameters that could not be accurately modeled for the storm event. These unknown parameters were documented and are available if additional in-depth flood routing analyses are required for these watersheds.

The FATT model input parameters were developed by FATT by field collecting data, recording site specific soil, land uses, cover types, geology, geomorphology, vegetation type and density, reviewing various types of remote images, personal interviews with flood victims, and many other pertinent data for each watershed evaluated in the FATT study. This information was complemented with many hours of telephone and personal conversations with hydrologists, hydrologic engineers, civil engineers, mining engineers, soil scientists, research scientists, and other professionals concerning the methodology of modeling and the importance of gathering actual field observation data and interviews of the flood victims. This wealth of information specific to the watersheds assisted FATT in the choice of the modeling technique and the importance of specific parameters critical to the development of an acceptable method to model the July 8, 2001 flood event and quantify its associated effects.

Because of these conversations, review of different modeling techniques, and personal accounts of the flood event by victims of the flood, FATT’s hydrology model for each watershed relied on accurate site-specific empirical data to enter in the watershed models. Later, the results were calibrated and validated for each watershed model.

Jackson suggests that land use in the study area and the relationship of land use to flood magnitude needs to be explored in maps and tables. He further suggests creating a map, or possibly a series of maps, illustrating the hydrography and land use in the study area…

The information Dr. Jackson is seeking is available in the contents of the detailed FATT modeling input, output parameters, and is associated with maps and other illustrations within the detailed FATT study. This information was specifically developed by FATT based upon a sub-basin spatial distribution of all certified data collected for analyses of the watershed and the events of July 8, 2001. This information is found within and throughout the many sections of the FATT report. Additional maps have been included in the narrative report showing the land use patterns used by FATT in the analysis.

Dr. Jackson states, "I suggest creating a map, or possibly a series of maps, illustrating the hydrography and land use in the study area as well as the spatial distribution of available data. An ideal map would show:

Stream network, land use roughly categorized as forest, recent harvest, active mine, closed mine, agricultural, and residential/commercial, locations of flood damage, rain gages and precipitation amounts on the day in question, USGS flow gages and recurrence interval of flow on the day in question, and locations and recurrence intervals of flows estimated from high water marks.

The FATT watershed report and study addresses all available information for the determination of the input parameters for each watershed modeled. FATT recognized from the beginning that these were ungaged watersheds with no site-specific meteorological stations, stream gaging stations, etc., in existence within the near proximity to the study watersheds. The concept of modeling the watersheds with a modeling technique based upon spatial variable distribution of its input parameters was not possible due to the lack of information.

Jackson suggests supporting this map with a land use table for each basin where flow has been measured or estimated. He also suggests that the table include the following information:

location,
basin area,
percent of basin in forest cover,
percent of basin recently logged,
percent of basin mined,
percent of basin developed,
precipitation depth during the storm, and
recurrence interval of resulting flow.

The information requested by Dr. Jackson is included within the FATT watershed detailed study. The necessary information to develop any tables necessary for presentation can be achieved with minimal efforts by the members of FATT, or other parties, if so desired.

Dr. Jackson states, "…I suggest running a multiple regression of flow recurrence.…That is why a regression analysis would be better."

FATT does not totally agree with Dr. Jackson's suggestion of utilization of regression analyses for these ungaged, rural watersheds to be "better". Several studies were conducted by qualified professionals of similar ungaged, rural watersheds in West Virginia utilizing several different regression techniques for the determinations for peak discharges for the small watersheds. In almost every watershed evaluated with or by the regression analyses the accuracy associated with the results were less than acceptable. In one specific report, the range of "acceptable values" generated by regression modeling resulted in values that the authors stated were at least plus or minus 150% of actual data when compared to actual measured field data. This high degree of inaccuracy is totally unacceptable to FATT for their modeling results, and as such, FATT could not support the utilization of algorithms, processes of parameters, and modeling techniques which did not yield an acceptable degree of accuracy for the watersheds studied. FATT's input parameters, modeling algorithms, modeling processes, and model results were continually certified, calibrated against actual documented and observed data, and the modeling results were verified or validated by different techniques to maintain modeling accuracy.

Jackson suggests analyzing the types of damages that occurred during the flood.

FATT fully appreciates the concern of Dr. Jackson as to the magnitude of the flood events. However, this type of data collection was not necessary to certify and calibrate the data and results of the FATT watershed models.

Jackson states, "…the SCS method that is the basis for HEC-1 and BOSS modeling is inherently inaccurate".

To a limited degree we [FATT] agree with Dr. Jackson's comments concerning the SCS modeling technique. The SCS technique when used by individuals not familiar with its limitations or with its principles, can create results that are inaccurate and misrepresentative of the watersheds modeled. However, SCS modeling methods, as well as many other modeling techniques, when used by qualified professionals knowledgeable of the particular models algorithms and limitations, strengths and weaknesses, can provide very good results of watershed hydrology. Any modeling technique is only as accurate as the input parameters, the model algorithms applications to the characteristics of the watershed, and the validation methodology of any results calculated by said modeling technique.

Comments from Dr. Wayne Swank

Review of Draft, Flood Advisory Technical Taskforce (FATT)

Detailed Report (May 17, 2002)

Submitted By:

Dr. Wayne T. Swank

Scientist Emeritus, Coweeta Hydrologic Laboratory

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Introduction

The purpose of this document is to provide a summary review of the draft report prepared by FATT as requested by staff of the Department of Environmental Protection, Division of Mining and Reclamation. The draft report addresses the scientific and hydrological causes of flooding events in southern West Virginia in May and July 2001 with a specific focus on assessing the impact of coal mining and timbering practices on flooding in the region. I was requested to focus my review on the hydrologic modeling approach and techniques used in the assessment. Background material was derived from 1) a site visit on May 22-23 to Seng Creek and Scabble Creek, two of these watersheds used in the study, to obtain on-the-ground familiarity with the topography, soils, vegetation, land use practices, and streams; 2) discussions with Jim Pierce, John Vernon (visit hosts), and Mike Reese of DEP and 3) a complete copy of the draft report comprised of three large volumes containing narrative, data output, photographs, and copies of some source materials used in the assessment. Clearly, I was not able to digest and comprehend in detail all of this information within the time frame available for the review.

Hydrologic Modeling Approach & Techniques

A variety of rainfall-runoff models have been developed over the past several decades and a brief description of approaches is appropriate. In general, hydrologic models can be classified as physics-based, conceptual and metric (Beck 1991). Physics-based models utilize mathematical representation of real processes to mimic hydrological behavior of a watershed. The Institute of Hydrology Distributed Model (IHDM) (Beven et al. 1987) is a recent example of this class of model, which is characterized by requiring massive amounts of site-specific data. Conceptual models describe the component hydrological processes perceived to be of importance as simplified conceptualizations. System stores are linked and are recharged and depleted by appropriate hydrological processes. The Stanford Watershed Model (Crawford and Linsley 1966) is an early example of this approach and subsequently, numerous versions of conceptual models have been developed. IHACRES (Jakeman and Hornberger 1993) is an example of a later lumped conceptual model. Parametric uncertainty and over parameterization are risks associated with conceptual of models.

Metric models are constructed with little consideration of hydrological processes and characterize system response by extracting information from existing data. The unit hydrograph theory (Sherman 1932) is the basis of metric rainfall-runoff models and assumes linearity between rainfall excess and streamflow. A major strength of methods using the unit hydrograph is their minimal data requirements.

The FATT team selected the unit hydrograph method and NRCS runoff curves numbers (CN) as defined by soil hydrologic groups, land uses, and cover types to predict peak flow rates for the ungaged study watershed. Given the time and resource constraints, this approach is probably the best available and most tractable method for you to use for the task. Alternative approaches are too data intensive or require extant discharge data which are not available for the study region.

There are important limitations associated with the application of the NRCS CN method as given in Technical Release 55. One critical consideration is that NRCS runoff procedures apply only to direct surface runoff and not conditions of large sources of subsurface flow. Surface or overland flow seldom occurs on undisturbed forested watersheds since infiltration capacity exceeds precipitation intensity. Thus, in forests, subsurface flow is linked to the variable source area to generate channel flow as you note on p.8 of the draft report. Apparently some consideration is given to this condition by assigning lower CN's to forest areas and the user has the option to adjust table CN's based on stream gage records (TR-55). The use of CN's for mining conditions is perhaps more straightforward since surface runoff from diversion ditches & ponds is a dominant process.

A critical question arises: is CN 70 an appropriate index for predicting peak discharge for "pristine" forests? Probably the best approach in addressing this question is to apply the NRCS procedure to experimental forested watersheds with long-term discharge records and compare predicted values with observed values. I am not aware of any citeable reference where this is documented. However, Hewlett et al. (1977) developed simple nonlinear equations (R-Index Method) for predicting stormflow and peakflow for small-forested basins based on data from 11 watersheds from New Hampshire to South Carolina. Tested against the SCS runoff curve method used at that time (SCS-TP-149) on four independent basins, the R-index method was judged considerably more accurate. The runoff curve method gave quite wild predictions and largely over predicted stormflow volumes and peakflow discharge.

A very rough measure of overall basic model performance is a comparison of simulated peakflows with long-term baseline data for gaged forested watersheds. For the pristine scenario (no logging, no mining, i.e., undisturbed forest) simulated unit area peakflows at the outlets of Seng, Scabble, and Sycamore Creeks were 455, 429, and 237 $ft^3/sec/mi^2$ (CSM) respectively. The nearest long-term record of discharge for forested watersheds is the Fernow Experimental Forest in north central West Virginia. The four largest storms during 50 years of research ranged between 4.4 and 5.8 inches of precipitation and average peak discharge from three control (undisturbed) forested watersheds for these storms was 136 CSM with a range of 115-170 CSM (personal communication, James Kochenderfer). Thus, peak discharges simulated for the FATT watersheds are 2-3 fold greater than documented at Fernow. Discharge has been measured from 17-forested watersheds for 68 years at the Coweeta Hydrologic Laboratory in the Nantahala mountains of western North Carolina, including seven control watersheds. The maximum peak discharges recorded for the largest storms (15-20 inches in 7 days) averaged 132 CSM for five of the control watersheds (3125-4056 ft. max. elevation), 450 CSM for two of the control watersheds (4770-5250 ft. max. elevation) and 189 CSM for the two fourth-order streams (average area of 2.9 $mi.^2$) which drain a mix of disturbed and undisturbed forest land (Swank et al. 1988). Peak discharge rates for two of the FATT watersheds are very similar to values for the two high elevation Coweeta watersheds with steep slopes (70% average) and thin soils. However, storm events were more than 3-fold greater for Coweeta than for the study area.

Of course, in the above comparisons, there are many differences between sites in watershed attributes which control peak discharge. From a perspective of the large body of knowledge about peak discharges for forested watersheds in the central and southern Appalachians, those simulated for the FATT study sites are among the maximum recorded. If you have any field estimates of peak discharge for the study watersheds (you mentioned a culvert site), it is important to show a comparison with simulated values. Although the study site streams show evidence of high hydrologic response, it is my feeling that CN 70 is somewhat high for the forested condition.

With regard to techniques and modeling software used in the hydrologic analyses, FATT employed current, state-of-the-art methods used by other hydrologic modeling groups. This appears to provide an excellent data base of watershed attributes and techniques used in the modeling effort.

<u>Streamflow Responses to Disturbance</u>

Decades of research on experimental forested watersheds provide a large body of knowledge on the effects of management on the quantity, timing and quality of streamflow. In particular, a wealth of information is available for the Appalachian mountain range (see Appendix I for a brief historical background of forest hydrology). Based on these carefully conducted long-term panel watershed experiments, several common threads of information relevant to interpretations of the FATT simulation results may be helpful. Some summary references are Hewlett and Helvey (1970); Hewlett (1982); Kochenderfer et al. (1997); Hornbeck (1973); Swank et al. (1988); Lull and Reinhart (1972); Swank et al. (2001).

- On a given watershed, at least 25% of the forest stand basal area must be cut to measure significant changes in annual water yield and even larger harvests are required to measure changes in parameters of the storm hydrograph.
- Hydrologic recovery from forest cutting occurs quickly (4-5 years) due to rapid regrowth of natural regeneration.
- Overland flow seldom occurs in undisturbed forests. Roads, landings or other compacted features are the primary source of surface runoff associated with logging activities. As road density increases, the potential for altering storm hydrograph parameters increases.
- The beneficial effects of forest cover on reducing peak discharge and stormflow volume have been documented over a range of storm events. During major flood-producing storm events the effects of a forest cover on peak discharge are minimal.

Summary & Recommendations

I feel your modeling approach is appropriate in view of the time/resource constraints and mixed land-use associated with the task. These models provide a first approximation for the effects of land use on peak flows for the July 2001 storm. My primary concern is with the CN's used for the undisturbed and logged forest scenarios. I recommend collaboration with Fernow scientists to validate the use of these procedures in predicting peak discharge from forests. You already have excellent techniques available and much of the required data input is available on the Fernow. Of course, this cannot be done prior to the report deadline but I feel your modeling effort is a work in progress. I highly recommend additional follow-up analyses/studies and can suggest some additional approaches that would support this effort. I feel the FATT group should be commended for your efforts on a complex issue.

Appendix I

Historical Background

The roots of forest hydrologic investigations are embedded in basic questions of the relationship between forests and runoff (Swank & Johnson 1994). Forest hydrologic research extends over more than a century with the establishment of two experimental watersheds in Czechoslovakia in 1867 with the purpose to examine the role forests play in surface runoff. Research on the effects of deforestation on flood flows in Switzerland began in 1902 using paired experimental watersheds. In the United States, concern about soil erosion, flood control, sustained flow of streams, and future timber supplies led to establishment of national forests from the public domain lands in the West. The role of forests in regulating the flow of navigable streams was the basis for enactment of the Weeks Act of 1911, which allowed the Federal government to purchase private lands for national forests in the East. Concurrent with these enactments there was considerable debate, but no scientific evidence, concerning the influence of forests upon streamflow regulation and flooding. Thus, the first paired forested watershed experiment in the U.S. was initiated in Colorado in 1909.

Subsequently, the need for scientific studies of factors controlling floods and erosion was accelerated by the disastrous 1927 flood in the Mississippi River Basin. This led to the formal establishment of watershed research by the USDA Forest Service. Three forest hydrology laboratories were established in the east within the Appalachian Highlands Physographic Division: Coweeta Hydrologic Laboratory (1934) in the Nantahala Mountains of western North Carolina; Fernow Experimental Forest (1948) in the Allegheny Plateau of north central West Virginia, and Hubbard Brook Experimental Forest (1955) in the White Mountains of New Hampshire. The research approach at these laboratories has encompassed the hydrologic cycle with studies of basic hydrologic processes on individual experimental basins to determine the principals underlying the relation of forests and their management, to the supply and distribution of water. A large body of knowledge and understanding now exists on the basic hydrologic functions of forested watersheds and responses to management.

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FATT's Responses to Dr. Swank's Comments

Dr. Swank commented that the unit hydrograph theory, of which HEC-1 is an example and used by FATT, is probably the best available and most tractable method to use. However, he questions whether a runoff curve number (RCN) of 70 is appropriate for "pristine" forest areas.

FATT considered the actual forest conditions in the studied watersheds. In reality, much of the forested areas have been previously harvested. In southern West Virginia, an NRCS runoff curve number of 70-77 best reflects the conditions associated with the determination of surface runoff. Such range of curve numbers represents standard engineering practice in this locality.

We feel that a RCN of 70 is appropriate for the "pristine" undisturbed forest areas that we studied. This is primarily due to minimal forest litter, shallow depth of soil, bedrock exposure, forest floor characteristics, and other land alterations caused by previous logging activities or coal prospecting.

Also, it should be noted that the runoff curve numbers used in the FATT watershed models were determined by field investigation of the previous logged and undisturbed forest areas. Before making a final RCN choice, FATT used research and communication with professional foresters to determine appropriate site-specific runoff curve numbers for the study areas. Information relating to the runoff curve number determinations and the delineations of the timbering and undisturbed forest areas was provided by the personnel of the West Virginia Division of Forestry. FATT members certified these runoff curve numbers in conjunction with the efforts and with agreement by the professional foresters within the West Virginia Division of Forestry.

Dr. Swank commented that from a perspective of the large body of knowledge about peak discharges for forested watersheds in the central and southern Appalachians, those simulated for the FATT study sites are among the maximum recorded. He further recommended the use of any field estimates of peak discharge for the study watersheds to compare with simulated values.

For the July 8th event, the peak discharges per area (CSM) are on the high range of what Dr. Swank has experienced in other areas. However, the peak discharges in the subject watersheds represent the actual peak discharges at the watershed evaluation node as determined by indirect measurements from certified field surveyed high water marks produced by the actual flood event. Our data sets are not uncalibrated, unvalidated watershed model simulations, but are certified, calibrated, validated results at specific nodes throughout the study watersheds. The FATT model results agree with numerous field certified and verified observed high water points and flood water boundaries within each specific watershed as documented for the July 8, 2001, flood event in the specific geographic regions of West Virginia.

It should be noted that the NOAA National Weather Service has identified various meteorological regions throughout West Virginia. Also, the United States Geological Survey (USGS) in performing their water research projects have divided West Virginia into two climatic regions. Therefore, the meteorological events and climatic characteristics in the regions studied by FATT are characteristically different than those associated with the forest research centers referenced by Dr. Swank (Fernow in West Virginia and Coweeta in North Carolina). As a result, any research comparisons between those of the Forest Service Research centers and those studied by FATT could only be generalized due to these and other differences. The correct modeling solution would be to include the personnel of the Forest Research Center in a long-term evaluation of the specific watersheds evaluated by FATT. Subsequently, a true comparison of the Forest Research methodology could be applied to the specific watersheds evaluated by FATT. The Forest Research Center personnel then could accurately evaluate the modeling results of FATT for the specific watersheds studied in southern West Virginia for the flood events on July 8, 2001.

Swank references, “The FATT team selected the unit hydrograph method and NRCS runoff curves numbers (CN)…to predict peak flow rates for the ungaged study watershed(s).”

FATT chose to use BOSS international’s software to model the watersheds to determine the impact of mining and timbering on the July 8, 2001, flood event. BOSS International’s software provides many variations of modeling techniques to use. The software chosen by FATT was BOSS’s Watershed Modeling Software (WMS) and RiverCAD. The reasoning that FATT members used for these choices were that the available data required for modeling was limited, the watersheds were ungaged, and the model results would have to be very accurate relative to the FATT evaluation. BOSS’s software modules that were used by FATT to model the watersheds were those developed with the U.S. Army Corps of Engineers (COE) Hydrologic Engineering Center (HEC) HEC-1 and HEC-RAS hydrology and hydraulic modeling software. These HEC programs are accepted internationally, and have been proven to yield accurate results such as was required by FATT for their watershed modeling.

FATT and other qualified professionals made extensive field investigations and research of the specific watershed characteristics and meteorological events of July 8th. Only certified data that FATT or recognized qualified professionals contributed were used to input in the BOSS WMS (hydrology modeling software) for the watersheds. This information was certified by FATT and the associated qualified professionals for these specific watersheds prior to any of the modeling computer hydrology runs. Upon completion of the hydrology runs, FATT ran the hydrologic results through the BOSS RiverCAD software utilizing the COE HEC-RAS software and all certified observable field surveyed highwater marks of the July 8th flood event to calibrate the hydrologic modeling results. This reiteration of the watershed’s hydrologic model results continued until the hydrology results for the watershed agreed with the historic field surveyed highwater marks throughout the watersheds. This hydrology model calibration technique utilizing the more advanced hydraulic engineering algorithms and accurate field data is an acceptable technique whenever there are sufficient observed and field surveyed elevations and boundary limits of the actual event to calibrate the hydrologic model.

There were many dynamic parameters associated with the flood event of July 8, 2001, that made the hydrology and hydraulic modeling of the watersheds complex and could possible bias or cause inaccuracy in the results. Therefore, FATT insured that all field surveyed calibration points and boundary limits of the flood event were not unduly influenced by any of these parameters or any model input parameters that could not be certified. After the certified data was input into the computer program and the watersheds modeled, each watershed model was accurately calibrated with numerous field-surveyed points and elevations of the certified highwater marks utilizing certified parameter input into the hydraulic program. When these models were completed, FATT verified the results with all known certified observations. By this process, FATT validated the hydrology modeling of the July 8th flood event in the study watersheds.

Dr. Swank states, "The runoff curve method gave quite wild predictions and largely over predicted stormflow volumes and peakflow discharge."

FATT agrees with Dr. Swank's introduction of the possibility of "wild predictions and largely over predicted stormflow volumes and peak flow discharges." It was for this specific reason that FATT took great care in the certification of all parameters used to determine the curve numbers, and chose modeling techniques to reduce the influence of the possibility of erroneous curve numbers. FATT realized that many research studies incorrectly used the curve numbers and caused erroneous results in their studies. FATT chose to use the curve number method because there are many other studies that have successful results in modeling the hydrologic events. FATT achieved its accuracy in its watershed models by its modeling methodology, parameter certification, model calibration, and model validation. FATT chose a modeling methodology that subdivided the watershed into many sub-basins that would not allow the influence of a singular curve number for an entire watershed to be introduced in the watershed model program. The use of the FATT certified data in the models, such as: soil types and characteristics, antecedent soil moisture, stream roughness and characteristics, stream flow conditions, subsurface flows, base flows, vegetation types and maturity, geologic character, geomorphology, stream and flow networks, precipitation variability, extent of urbanization, extent and type of industry disturbance, and many other measured and quantified observed data for the watershed model, allowed FATT to accurately model the specific watersheds utilizing the NRCS curve number method with the COE software within the BOSS modeling programs. In addition, FATT utilized certified data in their calibration process and FATT was therefore able to not only calibrate the watershed hydrology models within acceptable limits of modeling accuracy, but were also able to validate the subsequent hydrologic results for the watershed study.