The Floods of April

A REPORT ON THE APRIL 1977 FLOOD IN SOUTHEASTERN KENTUCKY

STAFF STUDY
NOVEMBER 1977

COMMONWEALTH OF KENTUCKY
DEPARTMENT FOR NATURAL RESOURCES AND
ENVIRONMENTAL PROTECTION
BUREAU OF NATURAL RESOURCES
DIVISION OF WATER RESOURCES

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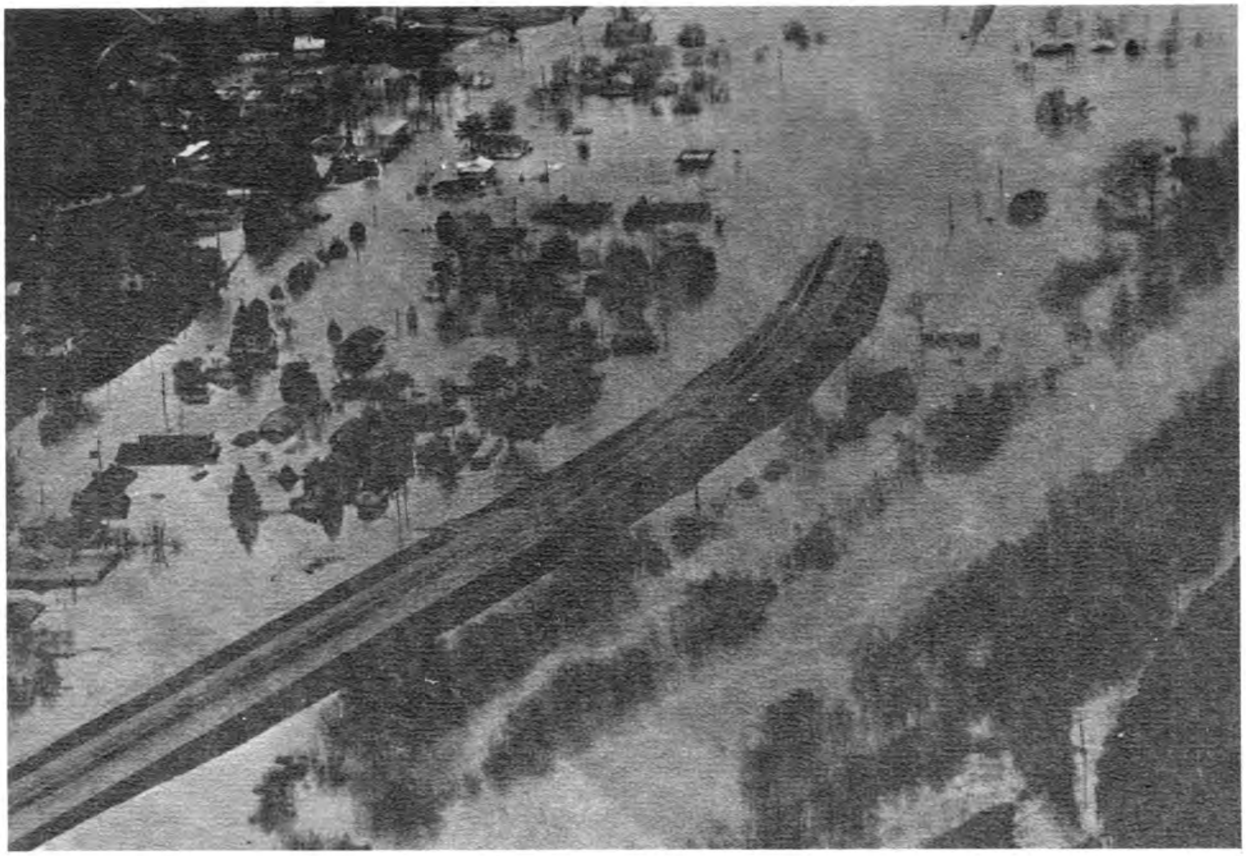

Nature creates floods:
Man creates flood damages.

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FOREWORD

Much of the data used in the preparation of this report was obtained from state and federal agencies. The report staff wishes to express its gratitude to the following for their assistance:

Kentucky Department for Natural Resources and Environmental Protection; Divisions of Forestry and Conservation, Bureau of Surface Mining Reclamation and Enforcement, and the Office of Planning and Research
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U. S. Army Corps of Engineers; Huntington, Louisville, and Nashville Districts
U. S. Tennessee Valley Authority
U. S. Soil Conservation Service
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Bureau of Surface Mining Reclamation and Enforcement
Kentucky Office of Disaster and Emergency Services

The Floods of April

PART I

INTRODUCTION

The April 1977 Flood

In early April, 1977, during record drought in many parts of the nation, a major storm centered over southeast Kentucky, east Tennessee and western Virginia and West Virginia. On April 3 and 4, this storm system deluged this area with record or near-record precipitation. Measured rainfall approached eight inches in Bell and Harlan Counties for the 72 hours of April 3, 4, and 5. Approximate measurements in the Upper Big Sandy River Basin in Virginia indicated total rainfall in excess of fifteen inches. The resulting flood left its indelible imprint on the memory and heart of eastern Kentucky.

Floods approaching or exceeding maximum stages of record swept down the Upper Cumberland, Big Sandy, and to a lesser extent, the Kentucky River. Homes, businesses and public buildings were swept away or damaged severely. Highways and bridges were destroyed. Property representing a lifetime of work was lost in a few short hours. Most tragically, lives were lost to the rampaging floodwaters.

Communities near the headwaters had little time to prepare. Harlan County in the Cumberland River Basin was devastated. Further downstream, at Pineville in Bell County, the floodwall and levee which had given protection from floods since the mid-1950's overtopped. In Middlesboro, past flood records were exceeded. At Barbourville, sandbagging prevented the levee from overtopping. Williamsburg, with more time to prepare, still sustained major damage.

In the Big Sandy Basin, developments constructed in the floodplains of Levisa Fork and Tug Fork were virtually wiped out. Pikeville, Elkhorn City, Prestonsburg, South Williamson, Martin and Inez suffered extensive damage. Paintsville and Louisa were less severely damaged than their upstream neighbors. In the Kentucky River Basin, flood heights were well below record levels; nevertheless, damage was very severe. Tangible damages caused by the April 1977 flood in Kentucky were estimated by the disaster evaluation team to be as much as $175,000,000. The impact on the lives of those affected is beyond estimation.

On April 6, 1977, President Carter declared fifteen counties in eastern Kentucky a federal disaster area, making the area eligible for federal emergency relief and rehabilitation benefits. The counties were:

Bell
Breathitt
Floyd
Harlan
Johnson
Knott
Knox
Lawrence
Leslie
Letcher
Magoffin
Martin
Perry
Pike
Whitley

Background

In 1974 after several decades of declining population and a depressed economy, eastern Kentucky began experiencing significant population growth and increased economic activity. From 1960 to 1970, the fifteen disaster counties experienced a net population decrease of 61,000. As the demand for and price of coal has increased, so has employment opportunity. Eastern Kentucky youths no longer must locate in the northern industrial cities to find jobs. Emigration has been reversed. Many who had left in earlier years returned to work in coal mining or related industries and service. From 1970 to 1976, the fifteen counties had a net population increase of approximately 57,000, a 16.2 percent increase, while the state population increased by only 6.4 percent.

Historically housing and businesses in eastern Kentucky have been located in areas subject to flooding. Recent immigration has created a demand for housing that has encouraged intensified development in the floodplains. Mobile homes, which are particularly susceptible to flood damage, have been sited along rivers and creeks. Commercial facilities to serve the growing population have located primarily in flood-prone areas. All the above factors set the scene for extensive damages experienced during the April 1977 flood.

As floodwaters inundated valleys throughout eastern Kentucky and the adjoining states, and as the toll of damages, suffering and even death mounted, assertions were made from several quarters that the flood was aggravated, or even caused, by man's activities in the mountains. Some asserted that surface mining disturbances had increased runoff and clogged streams and substantially increased flood peaks. Others charged that the federal flood-control projects had not been effective in controlling flooding. Still others charged that other developments or disturbances had caused the flood. Amid such immense destruction and the frenzied efforts to provide critically needed relief to those left homeless, the questions were asked repeatedly: "What caused the flood? What contributed to the flood? What was to blame? Who was to blame? What actions should be taken now?"

This report presents an initial effort to provide answers to the questions raised.

Objectives and Methodology

The Division of Water Resources in the Kentucky Department for Natural Resources and Environmental Protection was directed to study the April 1977 flood. Within the constraints of time, manpower and available data, the division was directed to prepare a report covering:

1. Description, effects and causes of the flood, and
2. Recommendations for further actions.

Fortunately, many agencies previously had conducted studies and collected data that were helpful in understanding the major contributing factors to this and other floods. The assigned staff members set about to identify those sources of information and to secure the available studies, data, documenting photographs and related research information. This report presents only salient and relevant portions of the information. The material set forth below describes the kinds of information sought, sources of the information, assumptions that were made and other limitations of the study.

Information Sought and Sources. Information was sought on all significant aspects of the April 1977 flood as follows:

1. Floods - Definition and information on the causes and control of floods were obtained from authoritative books, publications, and study reports.
2. Rainfall -- April 1977 and Other Floods - Rainfall information was obtained from the National Weather Service at Louisville and Huntington and the Tennessee Valley Authority. Hyetographs (rainfall distribution maps) were obtained from the U. S. Corps of Engineers and from Division of Water Resources staff calculations.
3. Runoff - General information on rainfall runoff was obtained from authoritative books and other reports.
4. Stream Discharges by Time Periods and Peaks for the 1977 and Other Floods - Stream discharge information was obtained from the U. S. Geological Survey and the Corps of Engineers.

5. Developments with Potential to Increase the Heights and Damage of the 1977 Flood:

   a. Agricultural - Agricultural information was obtained from the U. S. Census of Agriculture.

   b. Forestry - Information on forestry was provided by the Kentucky Division of Forestry which consulted the U. S. Forest Service and the U. S. Soil Conservation Service.

   c. Housing and Commercial Construction - Information on construction was secured from the Kentucky Area Development Districts, the U. S. Bureau of the Census Population Estimates, Series P-26, No. 76-17, issued July, 1977 and the Preliminary Population Projections, Urban Studies Center, University of Louisville.

   d. Road Construction - Information on road construction was requested from the Kentucky Department of Transportation and Area Development Districts.

   e. Surface Mining Acreages and Current Stages of Reclamation - Surface mining information was obtained from the Division of Reclamation.

6. Surface Mining Effects upon Rainfall Runoff and Erosion - Various study reports and articles were used to secure information on the effects of surface mining. See the reference lists.

7. The Effect of Erosion and Sedimentation upon Floods - Literature, calculations by the Division of Water Resources, and Division of Conservation staffs and manuals of the U. S. Soil

Conservation Service provided general information on erosion and sedimentation.

8. Photographs of the 1977 Flood and its Damages and Selected Developments in the Area - Photographs and slides were secured from the Corps of Engineers, local newspapers, individuals, the Northeastern U. S. Forest Experiment Station, the Disaster Emergency Services, Division of Reclamation and Governor Carroll's staff.

Limitations of the Study. The Bureau and the division staff found that only a summary study could be made using information readily available. No basic data collection or new information could be developed in the time available.

1. Staff - Two regular staff members of the Division of Water Resources were assigned to the project and asked to give the project top priority among their several assignments.
2. Finances - No special funds were provided for the study. An idea of the economic scale of such a study can be otained by considering that the Huntington District, Corps of Engineers requested $400,000 for a study of the flood in the Big Sandy and Guyandotte basins. A complete and exhaustive study would have required a large, specialized staff and far more funding than was available to the Division of Water Resources.
3. Time - Initially, the report was requested in about 30 days. The study was begun in April. After administrative review of the first draft in early August, deadlines were removed with instructions given to proceed with diligence. The assignment was broadened and a revised report format was determined.

4. Research Information - Limited research results were available on key aspects of the study. For example, there were very few reports existing which examined the effects of strip mining on runoff and those that were available covered watersheds of less than one (1) square mile. Some of these were conducted on nearly level lands as contrasted to the steep hills of eastern Kentucky ravaged by the April, 1977 floods. Data did not exist which listed the acreage of strip mining in various stages of reclamation either by county or watershed. There was very little data on the runoff and erosion control effects of various stages of reclamation. There were very few reports available on the effect of degree of slope and soil depth as factors affecting the runoff from surface mining. Information was lacking also on new housing and how much of this housing was in the floodplains.

CHAPTER I

THE HYDROLOGY OF FLOODING

Introduction

Floods result from a complex interaction between precipitation, land and streams. Because of this complexity, most people have a highly simplified conception of the development of floods. This section of the report explains the factors involved in the progression from rainfall to flood flows under the general headings of Rainfall, Watershed Characteristics, and River Conditions. Snowmelt will not be considered because it is seldom an important factor in floods in Kentucky.

The reader must understand that although the processes involved in the generation of a flood can be identified, the relative importance of each cannot be given a precise value. Therefore, the following discussion will explain what processes occur to create a flood and how they vary, but will not attempt to assign values to the component parts.

Before discussing flood hydrology, it is necessary to define or clarify some terms frequently used in discussions of flooding.

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

Also commonly misused are the terms *floodplain* and *floodway*. The floodplain is the relatively flat area or low lands adjoining the channel of a river or stream which has been or may be covered with flood water. The floodway is the channel of a stream and that portion of the adjoining floodplain designated to provide for passage of flood flows without significant increase in flood level. The relationship between these two terms is illustrated in Figure 1. The floodplain is formed by sediment deposition or removal during those times when the stream flow rises above the banks of its low water channel. For most streams such an event will occur every two or three years.

From the definition of floodway it can be seen that if all of the floodplain outside of the floodway were blocked to flow, the height of a given flood would increase very little. The floodway boundaries vary with the magnitude of the flood and with the definition of significant increase. This means that the floodway for a fifty-year flood is usually much wider than that for a five-year flood; also, the floodway for a two-foot allowable increase in stage for a given flood discharge is narrower than that for a six-inch increase in stage. Therefore, the U. S. Department of Housing and Urban Development and others have specified the floodway to be the stream channel and that part of the adjacent floodplain required to pass the one-hundred-year flood without increasing the water depth more than one foot.

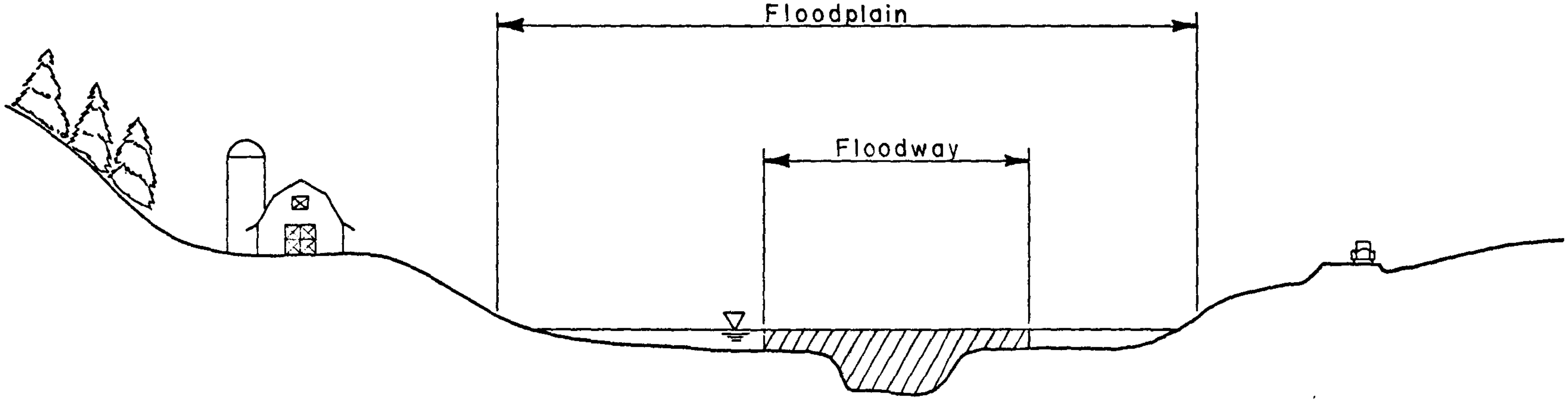


Figure I. Definition sketch of the relationship between floodplain and floodway.

There will be other terms unfamiliar to the reader in the following discussion. These terms will be defined either in the text as they occur or in the glossary.

Rainfall

It is sometimes said that floods result from excessive precipitation. While the relationship is not this simple, it is true that extreme rainfall is a prime requisite for flooding. Some sense of the complexity involved in the generation of a flood event can be obtained by studying the processes of the hydrologic cycle, Figure 2. Most of the variables shown, in turn, have considerable variability, and these will be discussed in later sections. Rainfall itself may be extremely variable in the effects it has on flooding.

The primary factors which determine a rainfall's effect on a flood are its amount and distribution. Because of the network of rainfall gages maintained by the Weather Service, TVA, and others, rainfall amounts can be estimated as an average in inches for most watersheds in this country. The importance of rainfall amount with regard to flooding is obvious. A rainfall averaging six inches over a watershed in twenty-four hours will undoubtedly contribute more runoff than would a two-inch rainfall within the same period, everything else being equal. Certainly, a large rainfall will cause some degree of flooding regardless of the condition of the watershed or stream channel. However, the distribution of rainfall in time and space can make considerable difference in the degree of flooding which occurs from any given rainfall amount.

The effects of distribution in time are associated with the rate of rainfall. A very intense storm, which produces a relatively large amount of rainfall quickly, does not produce the worst flooding, except

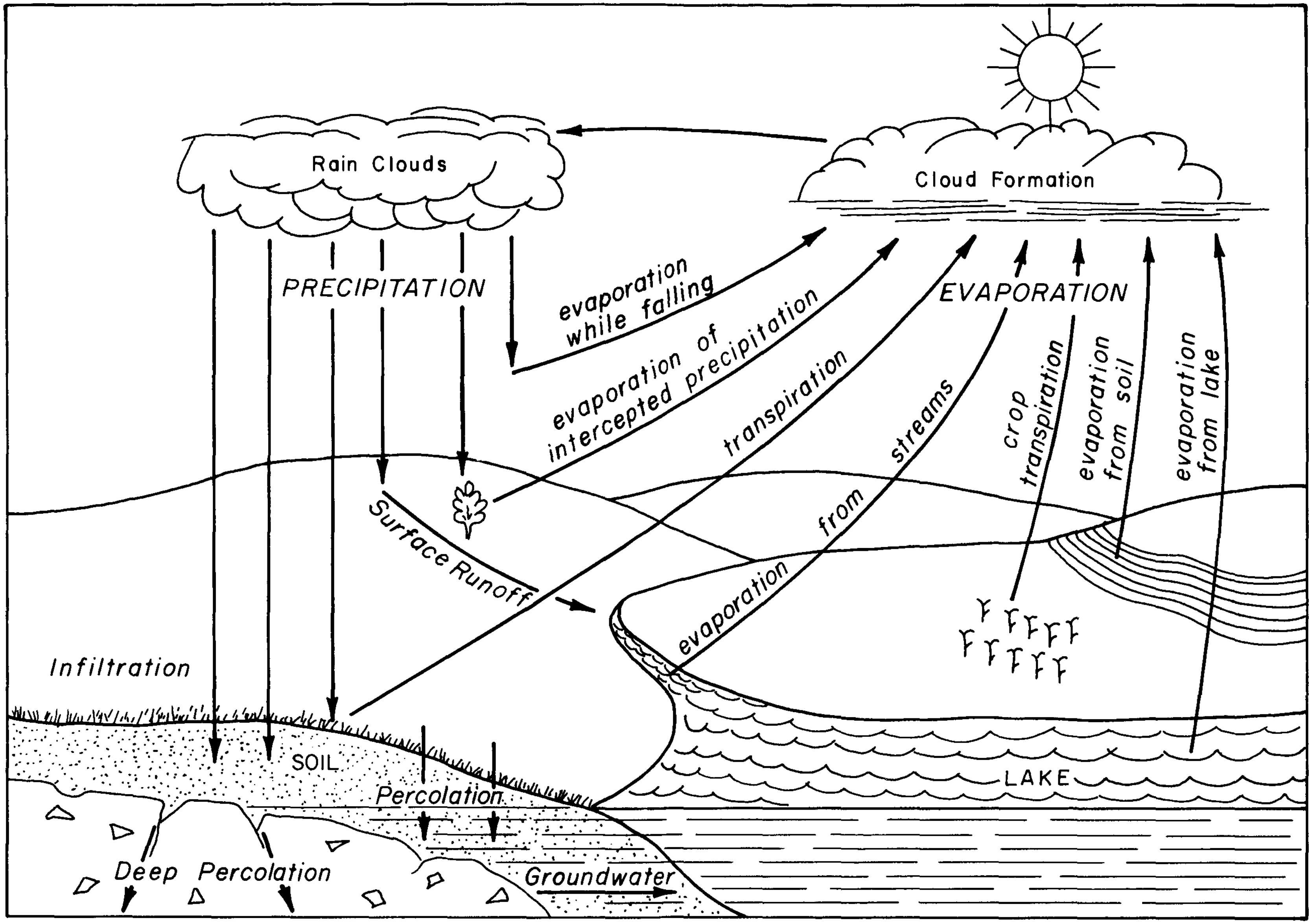


Figure 2. Definition sketch of the hydrologic cycle.

in watersheds of a few square miles or less. Such a heavy rainfall is usually confined to small areas and so will cause flooding on small tributaries, but, except in special watersheds, the arrivals of peak flows from the tributaries will not coincide with each other. The floods from the tributaries thus join the main stream one after the other, forming small pulses of flow which cause minor flooding, if any, on the main stream. On the other hand, if the same rainfall amount were to fall on the watershed but over a longer period of time, the tributary floods, though smaller, accumulate one on the other to create a larger main stream flood.

Spatial distribution of rainfall can also have a considerable effect on the degree of flooding resulting from a given rainfall. A rainfall volume that is uniformly distributed throughout the watershed will create a lesser flood than if the rain were centered over the lower portion of the watershed. Since rainfall falling in the upper portions of the watershed travels farther overland, a larger amount will inflitrate into the soil. Also the upper reaches of most tributaries transport the surface runoff less efficiently than the lower reaches. In the lower portion of the watershed runoff travels a short distance overland either into the lower reaches of the tributaries or directly into the main stream. This means that a higher percentage of the total volume begins contributing to main stream flow earlier and creates the same cumulative increase in flood peak as was discussed regarding temporal rainfall distribution.

The last factor affecting the degree of flooding caused by a given amount and distribution of rainfall is storm direction. If all other factors are the same, a storm which moves down the watershed, that is from the upper portion to the lower, will create a more severe flood than a storm which moves up the watershed. The process responsible for this is shown in a very simplified block diagram in Figure 3. In this figure, the storm on the left drops a block of rainfall near the top of the watershed at Time 1 and then moves down the watershed. For illustrative purposes, it is assumed that the storm moves downstream at the same speed as the block of water. Then at Time 2, another block of rainfall falls on top of the first. This process continues with the blocks building higher and higher. Now consider the right-hand diagram. In this figure the storm is moving upstream at the same speed of the block of water moving downstream, so that, at Time 2, the second block of water falls completely separate from the first.

Watershed Characteristics

The *watershed* above any point on a stream is the area enclosed by a topographic divide such that any precipitation which falls within this area would normally drain by gravity to that point. In the case of heavy rainfall, a variety of watershed characteristics determine the size of flood that reaches the stream. The watershed factors which affect the degree of flooding from a given rainfall are classified in the following discussion as geometry, topography, geology, and surface condition.

The *geometric factors* which affect flooding are size and shape. The size of the watershed is the factor which determines the manner in which flooding occurs. Floods on large watersheds reach their crests slowly, remain at flood stage for a long time, and recede slowly. Floods on small watersheds reach their crests quickly, usually remain there a short while, then recede rapidly. The effect of size was covered partially under the discussion of rainfall duration when it was noted that a rainfall of very high rate and short duration caused larger floods on small watersheds, while a rainfall of lesser rate but of longer duration caused larger floods on large watersheds.

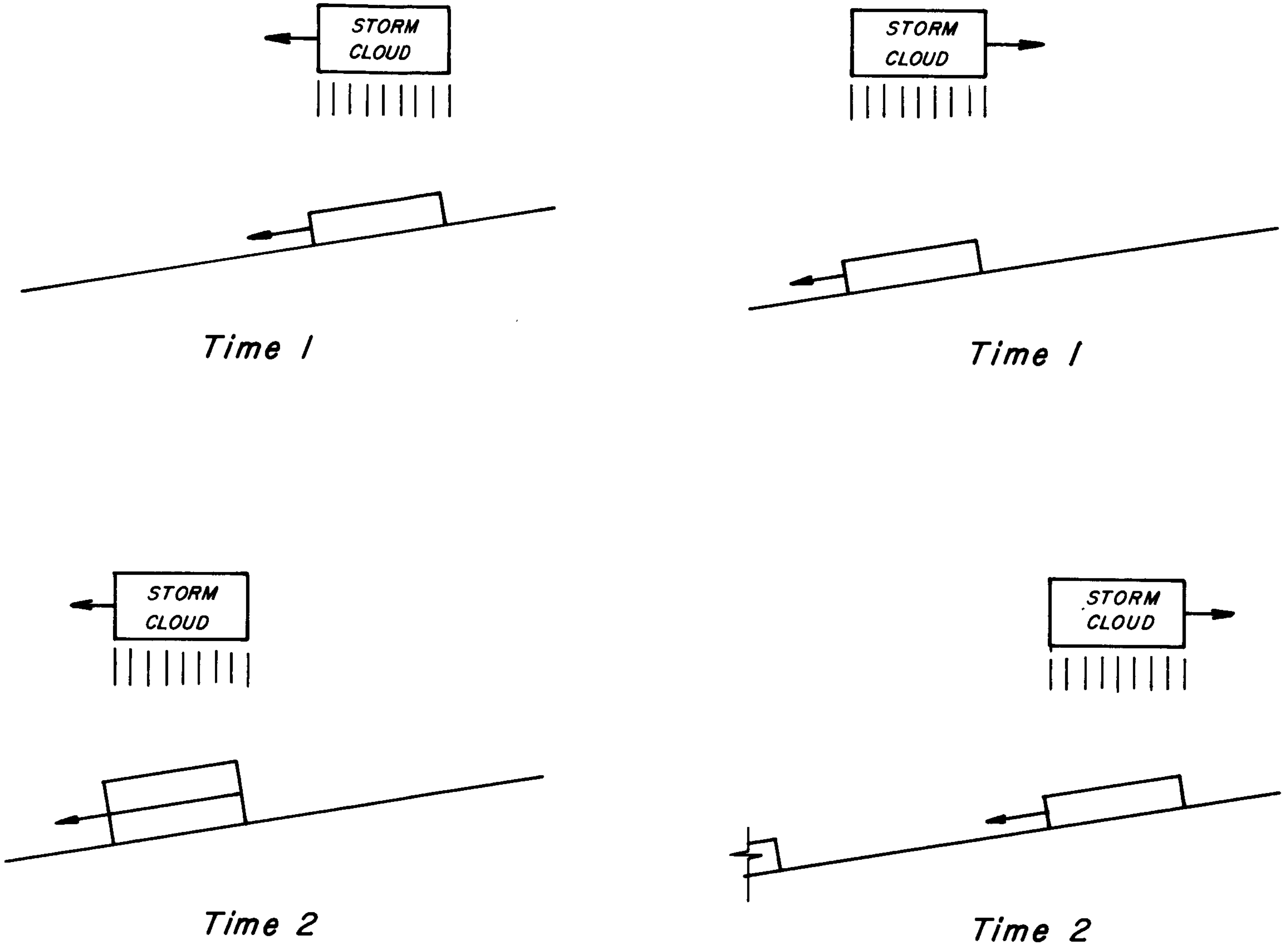
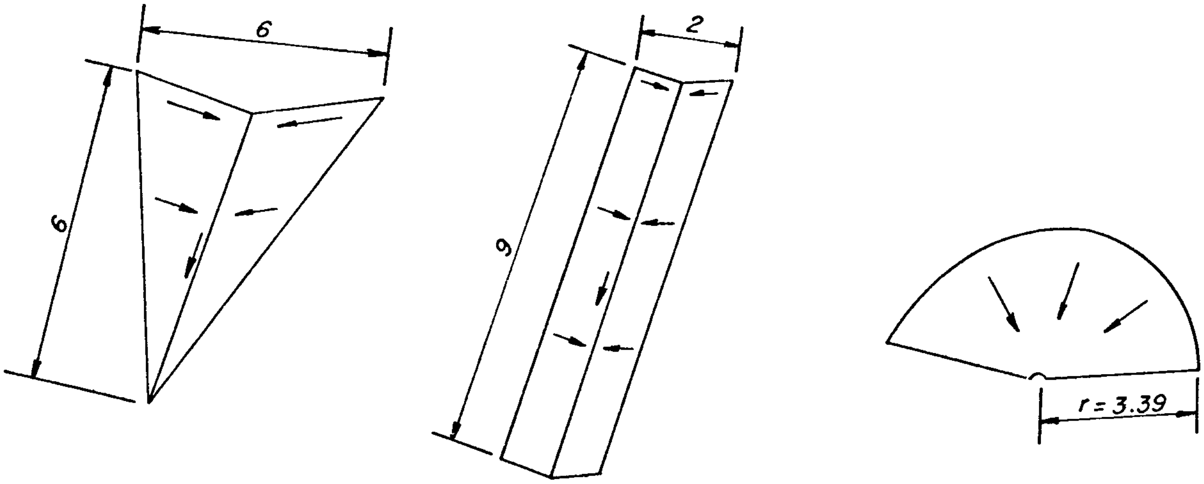


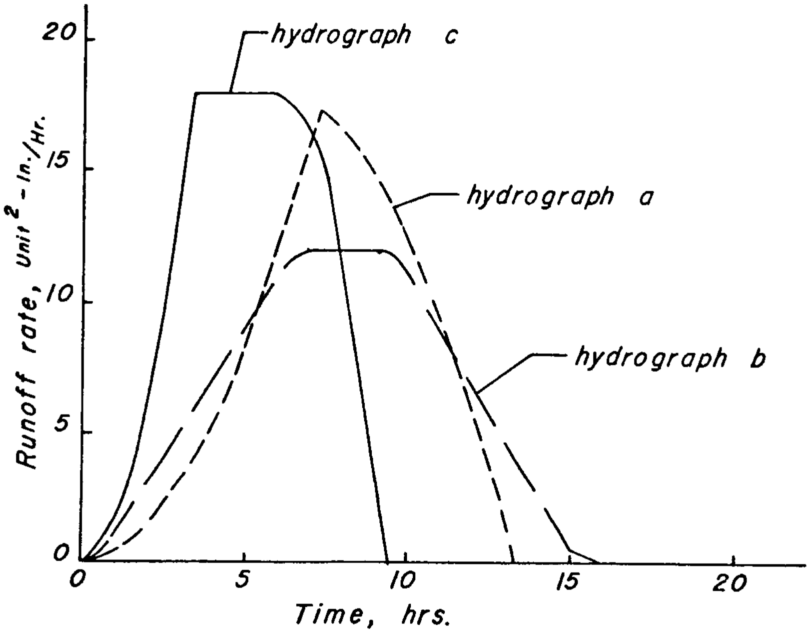
Figure 3. *Block diagram showing effect of a storm moving downstream versus one moving upstream.*

For a given size of watershed and a given rainfall, the degree of flooding is significantly influenced by watershed shape. A long, narrow watershed is more likely to have a lower rate of runoff than a more compact watershed. Figure 4 shows how watershed shape can affect the runoff which results from a given rainfall by comparing curves which show the rate of runoff versus time for three different shapes; these curves are called hydrographs. It is apparent from this comparison that circular watershed, which is the most compact shape, peaks sooner and recedes sooner than either of the other two. In this example, the circular watershed had a higher peak flow because it was the only watershed whose time of concentration (that is the time required for rain falling on the most remote portion of the watershed to reach the outlet end) was less than the duration of the rainfall. This leads to another important consideration with regard to shape: since heavy rainfalls tend to have short durations, a compact watershed is more likely to receive a high rate of rainfall for sufficient time to cause maximum flooding. Also, there is a greater chance a storm will miss part of a long, narrow watershed than for a compact watershed, especially if the storm moves perpendicular to the length of the elongated watershed. *All of these factors indicate that over a long period of record a compact watershed is likely to sustain more frequent and worse flooding than those that are very long and narrow.*

In addition to geometry, the *topography* of a watershed has considerable effect on the amount of flooding from a given storm. The topography influences flood peaks through the watershed slope, tributary arrangement and condition, and the location of mountains, if any.



a. Triangular watershed b. Long rectangular watershed c. circular watershed



d. Runoff hydrographs for three watersheds of different shapes. Assumes 1 in/hr rainfall for 6 hrs, velocity of 1 unit/hr for all slopes, and all rainfall becomes runoff.

Figure 4. *The effects of shape of watershed on rate of runoff.*

Slope of the watershed is one of the most easily understood factors affecting flooding. Obviously, runoff from a steep watershed is faster than runoff from a flat one. This in turn means that there is a higher percentage of runoff from a steep watershed, since there is less opportunity for rainfall to infiltrate into the soil. *Therefore, given similar rainfalls, steep watersheds produce floods more frequently and of greater magnitude than watersheds that are level.*

Other important topographic considerations are the arrangement and the condition of the watershed's tributary network. Since rate of flow in tributary channels is higher than the rate of flow overland, a dense network of tributaries will deliver flow to the main stream more rapidly than a sparsely distributed set of tributaries. For tributary networks of equal density, the slope of the tributaries is important; the steeper the slope, the more rapid the runoff and, therefore, the greater the potential for flooding. Last among the tributary factors is the sinuosity of the channels. If there are a great number of curves in the tributaries, peak flow is lessened for two reasons. First, the length of travel from the top of a watershed to the bottom along a curvy path is longer than along a straight path and, therefore, the overall slope is less which leads to a lower rate of runoff, as just discussed. Also, at each curve in the tributary streams there is a loss in head, or driving force, thus causing further lessening of the peak flow at the tributary outlet.

The location of mountains, if any, is the last of the topographic factors relating to the degree of flooding resulting from a storm. A mountain range in a watershed means a steep slope for the watershed overall and usually indicates a dense and steeply sloped tributary network. In addition, when a storm crosses a mountain range, it may drop a larger amount of rainfall on the windward side of the mountains. Thus, if a mountain range is located on the far side of the watershed from an approaching storm, the watershed may get a higher amount of rainfall than if the range is on the near side. Therefore, the same storm can contribute considerably different amounts of rainfall due to variation in situation of mountain barriers.

Another major factor regarding a watershed's flood potential is its *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 clayey 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.

Another important geological aspect of watersheds, especially in central and western Kentucky, is the presence of sink holes or solution cavities. Sink holes occur in regions where soluble rock, such as limestone, dolomite or calcareous sandstone, underlie the surface. Sink holes are caused by the dissolving of the rock by water percolating down through cracks in the rock or from the collapse of the roof of a cave or tunnel formed by water flowing beneath the surface. Sink holes tend to reduce the effective drainage area of a watershed because flow that goes into them does not necessarily reappear within the watershed. Flow from a sink hole may even be in the opposite direction from surface flow. Also, in areas where sink holes are prevalent, called karst areas, there tends to be relatively few surface streams because a large amount of rainfall is carried in underground channels. For these reasons, the degree of flooding on a stream in a karst area is usually less than on a stream with an otherwise similar watershed, although much depends on where subsurface flow rejoins the surface flow.

The last of the characteristics which determine a watershed's effect on the degree of flooding for a given storm are those related to the *surface conditions:* vegetation, surface storage, soil moisture, and land use.

Vegetation retards overland flow allowing more time for water to enter the soil. It increases the porosity of the soil both through the action of its root system and by the addition of organic matter to the soil when the vegetation decays. The vegetal foliage intercepts a portion of the rainfall before it can reach the ground; however, for large storms this effect may be insignificant due to the small percentage of total rainfall that is intercepted. Vegetation also inhibits flooding by reducing the amount of erosion which might otherwise occur and form gullies, since water collected by gullies would reach the main stream in less time than water flowing over land, as was discussed previously. *Therefore, the primary benefit from vegetation is its reduction in the rate of surface runoff, although there is also some reduction of runoff amount.*

Some part of the rain which falls on any watershed may be caught and stored in lakes, ponds, swamps and surface depressions, all of which are classified as surface storage which is the second surface condition affecting flooding. When one of these storage basins reaches the point of overflowing, it begins contributing to the watershed's runoff, but this outflow is usually at a lower rate than the inflow. *If a watershed has a large amount of surface storage, the degree of flooding then may be considerably lessened both by reduced volume and reduced rate of flow.*

Another surface condition that affects the degree of flooding from a watershed is the moisture in the soil at the beginning of the storm. It is obvious that if the soil is nearly saturated at the beginning of the rainfall, the resulting flood will be greater than if the soil were very dry. Also, if the soil moisture that is present is frozen, then very little additional water can be absorbed resulting in a higher amount of runoff.

The final surface condition, and the one which may have the most effect on the degree of flooding, is land use. In general, forested areas yield the lowest rates of runoff of any lands.[1] Agricultural land is the next higher runoff-producing land use. Of course, agricultural uses vary widely in their runoff yields: meadows producing the least runoff, then pastures (although some pasture treatments produce even less runoff than forests), then croplands, and the highest agricultural runoff classification, fallow lands. Comparable to fallow lands are those construction practices which create large disturbed areas: subdivision or shopping center construction, highway clearing and excavation, surface mining. The highest runoff-producing land use is urban land. *Urban development in an area causes more runoff volume, due to large impervious areas and to the absence of surface storage, and a faster rate of runoff, due to more rapid overland flow over paved areas and to the efficiency of urban storm drainage networks.*

River Conditions

After heavy rains have fallen and tributaries have collected the runoff and funneled it down to the main stream, the flood thus formed begins its journey downstream. The manner and extent of its progression are determined by the channel and floodplain characteristics and by the presence or absence of obstructions and constrictions along the flood's path.

The channel and floodplain characteristics determine the rate of flow for the channel for a given depth of flow. The rate of flow, Q, for a river can be determined from Manning's equation, which is

$$Q = \left(\frac{1.48}{n}\right) \left(AR^{2/3}\right) \left(S^{1/2}\right).$$

In this equation the term enclosed in the first parentheses is a measure of the stream's roughness or resistance to flow. The terms in the second parentheses are cross-sectional area and hydraulic radius. Both of these terms are expressions of the stream's geometry, which means that they are related to the depth of flow. The term in the last set of parentheses is slope. In this case, the slope is that of the energy grade line.

Manning's roughness coefficient, n, is a dimensionless number that is inversely, linearly proportional to the rate of flow. This means that doubling the Manning's coefficient will halve the flow rate, everything else being equal. The primary factors which determine the value of the coefficient are surface roughness, vegetation, and channel irregularities.

Surface roughness resists the flow along the boundary between the water and the bottom and sides of the stream. In streams where the bed material consists of sand, silt, or clay, the retarding effect is not very great; therefore, Manning's coefficient is low. For streams which are lined with coarse gravel or boulders, the retarding effect is higher, and the Manning coefficient is higher.

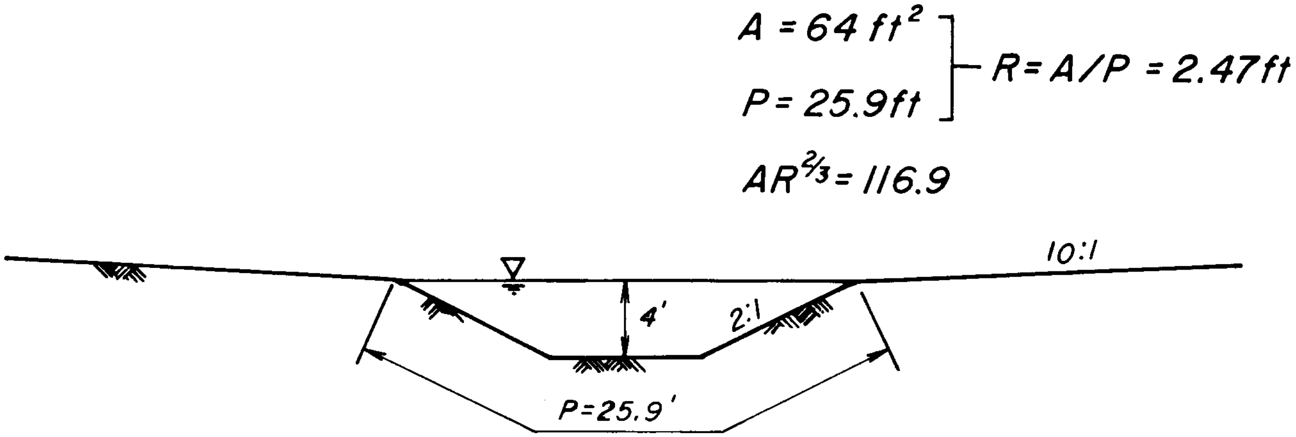
The effect of stream vegetation is to resist flow at points in the flow above the contact boundary. The degree to which vegetation affects flow depends on the height, density, distribution, and type of vegetation. The effect of vegetation also depends on the season. In the summer when it is in full foliage, vegetation offers more resistance to flow than during winter. Since the floodplain is usually more heavily vegetated than the main channel, the roughness coefficient is usually higher in the overbank region.

Even in those portions of a channel where conditions appear to be uniform, there are sand bars, sand waves, ridges, holes and other channel irregularities. These irregularities cause flow disturbance which adds to the effects of surface roughness. Generally, only abrupt changes in cross-section will cause very much change in the roughness value.

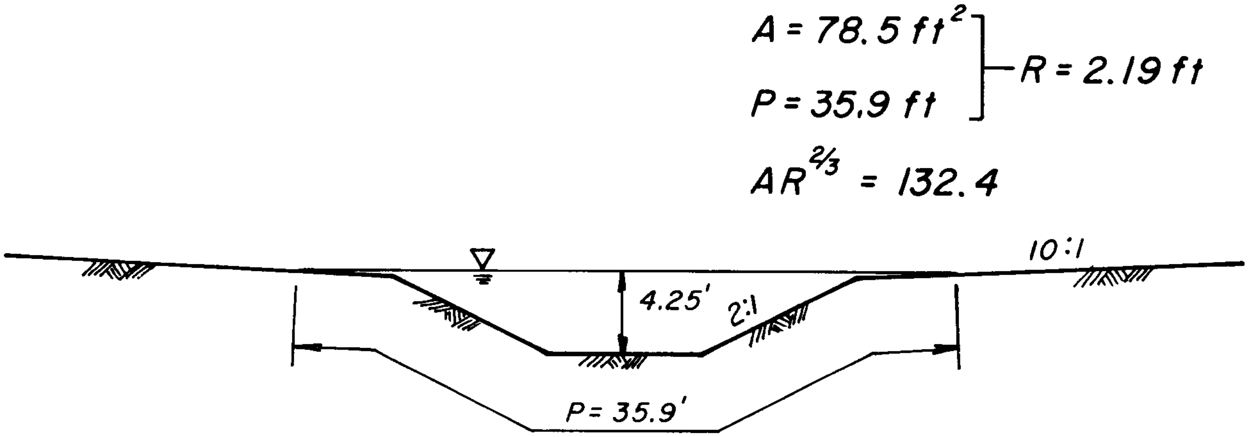
The geometric properties of area, A, and hydraulic radius, R, are directly proportional to the flow rate. This means that if either one or both of these increase the flow rate will increase. For a given cross-section, each of these factors is a function of depth. Obviously, the area of flow always increases with depth of flow. This is not always true, however, for the hydraulic radius.

The hydraulic radius is defined as the area divided by the wetted perimeter, P, which in turn is the length of the line of intersection between the water and stream cross-section, as shown in Figure 5. From Figure 5, it can be seen that although both the area and wetted perimeter are higher for condition 2 than for condition 1, the hydraulic radius is less. This is due to the slope on the overbank portion of the stream being so low that the percent of increase in area is much less than the percent of increase in wetted perimeter. Notice, however, that although the value of the hydraulic radius decreases, the product $AR^{2/3}$ still increases; therefore, the quantity of flow will increase from condition 1 to condition 2.

The final term in Manning's equation is the slope of the energy grade line. The total energy available at any point on a stream is the sum of the potential energy, which is due to elevation, and kinetic energy, due to the motion of the water. As flow progresses downstream, energy is lost due to friction, contractions or enlargements in the channel cross-section, and changes in flow direction. The change in energy along a stream must be equal to or greater than these losses or flow would slow down and eventually stop. In Manning's equation, flow is directly proportional to the square root of the energy slope; so if the energy slope of a channel is made four times greater, the rate of flow for the channel will double. Although this slope can sometimes be roughly approximated by the bed slope or the slope of the water surface, it is important to remember that this slope is neither of these, and that these slopes should not be used in Manning's equation unless there is no way of finding a better approximation of the energy slope.



Condition 1



Condition 2

Figure 5. *Definition sketch of wetted perimeter, P and showing the relationship beteen area, A, hydaulic radius R, and P.*

In addition to channel and floodplain characteristics, stream obstructions are important factors in determining the movement of a flood downstream. Some of the most commonly occuring obstructions are bridges, buildings, fills and levees. All of these constrict the floodplain, and sometimes even the channel, causing increased depth of flow, which means higher stages upstream. As far back as 1941, it was realized that the obstruction of streams was a severe problem; according to George W. Pickels, then professor at the University of Illinois:[2]

> Streams have carved out their channels and floodplains to provide for their flood flows, and any encroachment by man in the way of levees, bridges, buildings, or anything that will constrict the channel is naturally followed by more frequent and greater flood heights. This is becoming one of the most serious causes of floods.

Obstructions are currently a major aggravating factor of flooding. As pointed out in some of the floodplain information studies prepared by the Corps of Engineers, although the effect of each individual obstruction may be negligible, the combined effect of a large number of them may produce a significant raising of the water surface elevation.

Conclusion - The Hydrology of Flooding

Floods occur from major rainfall events or from moderate storm rainfalls falling on a watershed that is saturated by a previous rainfall, frozen, or barren of vegetation, or from a combination of severe rainfall and watershed conditions. The flood height reached at points along the stream depends on the size and condition of the channel and floodplain, the energy slope, and the presence of obstructions. Activities such as deforestation, excavation, and urbanization of the watershed along with construction of bridges, levees, buildings and other obstructions of the channel and floodplain have increased the severity of flooding and have decreased the capability of streams to carry high flows.

Although the detrimental actions of man are difficult to correct once taken, proper planning and evaluation of the factors involved in the process of flooding can keep the severity of future floods to a minimum.

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1. This discussion is based on the Soil Conservation Service's curve number system, see their publication TP-149, p. 6.

2. George W. Pickels, Drainage and Flood Control Engineering; McGraw-Hill Book Co., New York, 1941; p. 66.

CHAPTER II

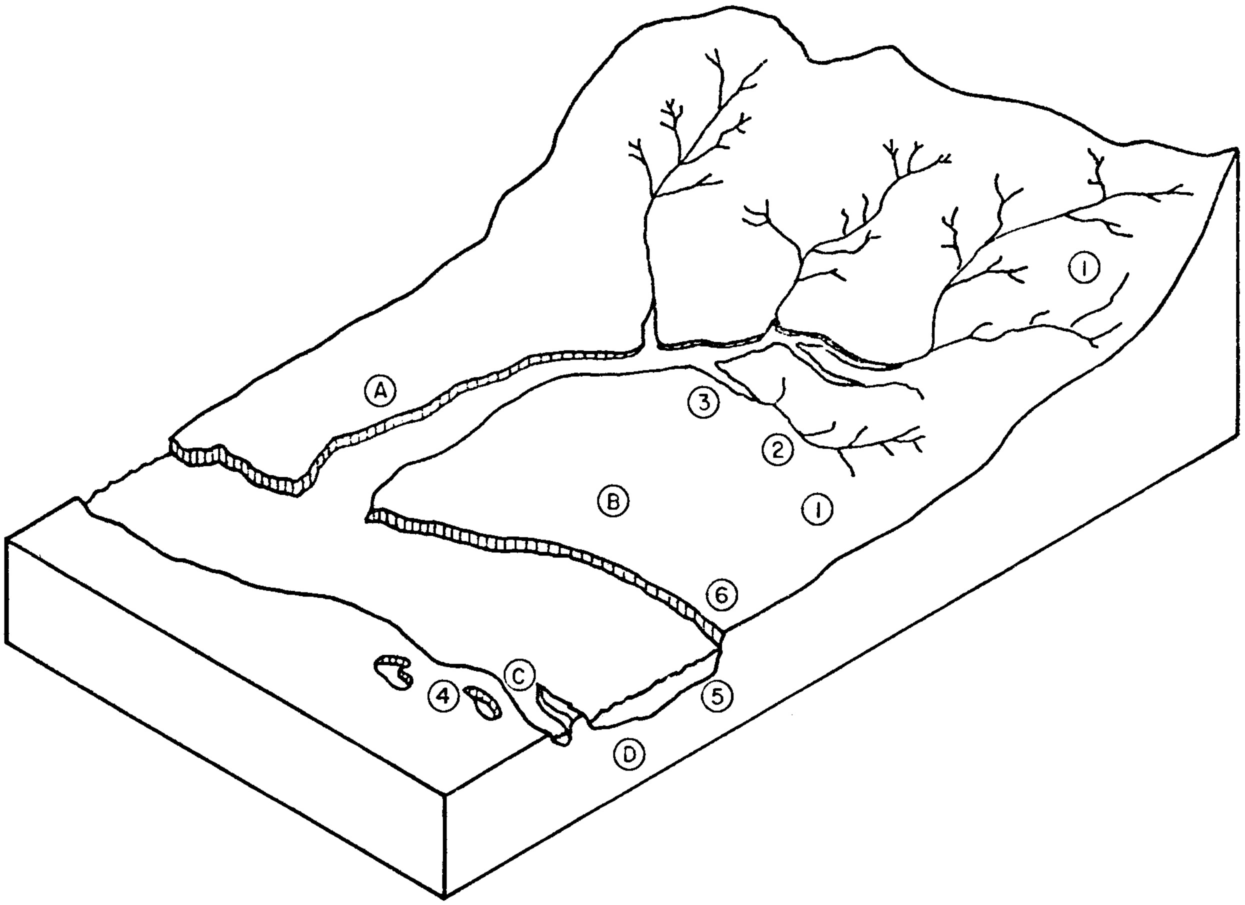
SEDIMENTATION

Introduction

A portion of the economic loss resulting from the flooding of an urban area is due to the large quantity of sediment which is deposited by the receding flood water. In 1948 Brown[1] stated that the total average annual damage resulting from sediment deposition was at least twenty percent of the total flood damage nationally. For this reason and others (such as the filling of lakes and reservoirs, destruction of aquatic habitat, etc.), sediment is often regarded as the major source of water pollution in the United States.

Since sediment-related damage is a primary factor subsequent to flooding, it is desirable to include in this report a general introduction of sedimentation for the reader who is not familiar with the processes involved. The following text gives an overview of the problems and processes related to sedimentation.

Sedimentation as used in this discussion denotes the processes of erosion, transportation, and deposition. These phenomena acting in concert are continuously changing the earth's surface. Figure 1 shows some of the areas where the sedimentation processes to be discussed herein can be expected to occur.



EROSION

① SHEET AND RILL EROSION
② DEGRADATION OF MINOR DRAINAGEWAYS
③ GULLY EROSION
④ FLOODPLAIN SCOUR
⑤ STREAMBED DEGRADATION
⑥ STREAMBANK SCOUR

DEPOSITION

Ⓐ DEPOSITION AT BASE OF STEEP SLOPES (COLLUVIUM)
Ⓑ VALLEY DEPOSITS
Ⓒ POINTBAR DEPOSITION
Ⓓ STREAMBED AGGRADATION

Figure 1. Typical erosion and deposition occurrences. (After Vanoni)

Erosion

The process of *erosion* consists of detaching soil particles and moving them to a channel in which they may be transported. Erosion may be caused by the impact of falling rain drops as shown in Figure 2a or by a combination of drag and lift forces resulting from the fluid's motion, similar to the forces involved in airplane flight, as shown in Figure 2b.

Erosion may be classified as either geologic or accelerated *Geologic erosion* is the erosion of the earth's surface in its natural or undisturbed state. Geologic erosion has been responsible for wearing away mountains and forming vast canyons. In most areas of the eastern United States, geologic erosion is relatively low due to luxuriant vegetative cover. Conversely, in areas of the western United States where heavy rains fall on virtually barren soil, geologic erosion is high.

Accelerated erosion is the increase in the rate of erosion beyond geologic erosion brought on by man's activities. These activities include agricultural activities, urbanization, road and highway construction, mining operations, altering runoff, and stream control works.

Accelerated erosion due to agricultural activities started in the United States when the American colonists began clearing the native forests and burning the grasslands in preparing the land for cultivation. Today about fifty percent of the sediment deposited in streams and lakes is due to erosion from agricultural lands. Cultivation increases the rate of erosion by removing the protective vegetal cover and by breaking up the soil into loose, easily eroded particles, It has been estimated that croplands are subject to about two hundred (200) times as much erosion as forested land.[2] The rate of erosion from

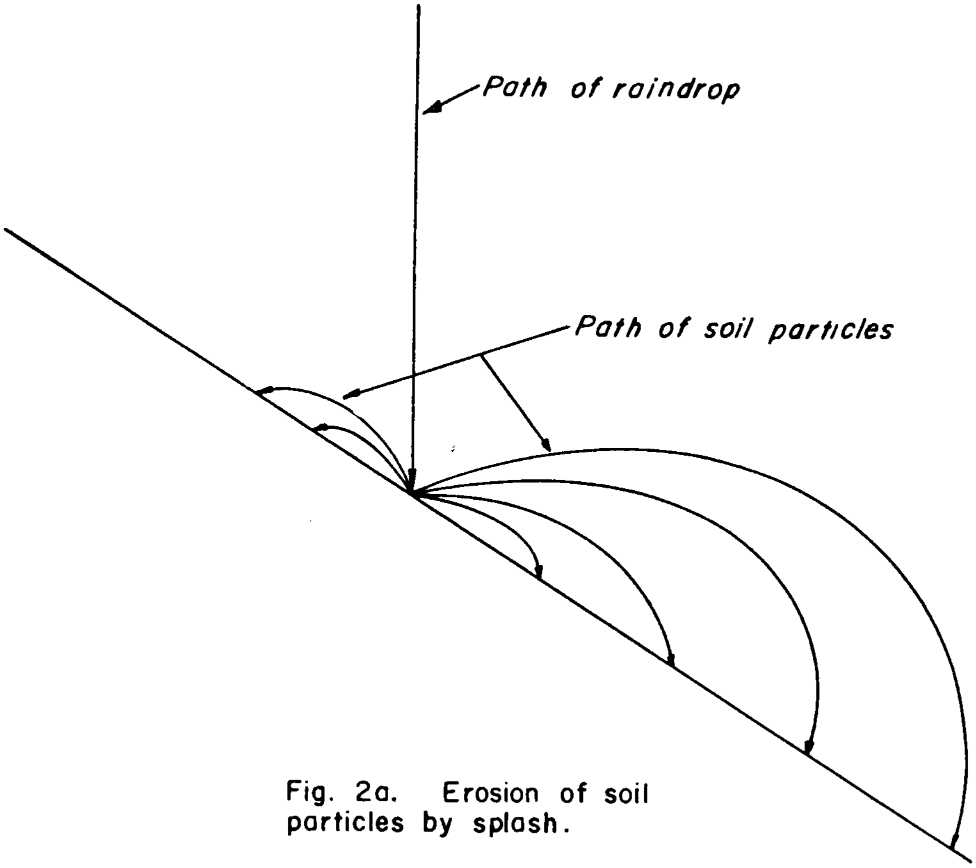


Fig. 2a. Erosion of soil particles by splash.

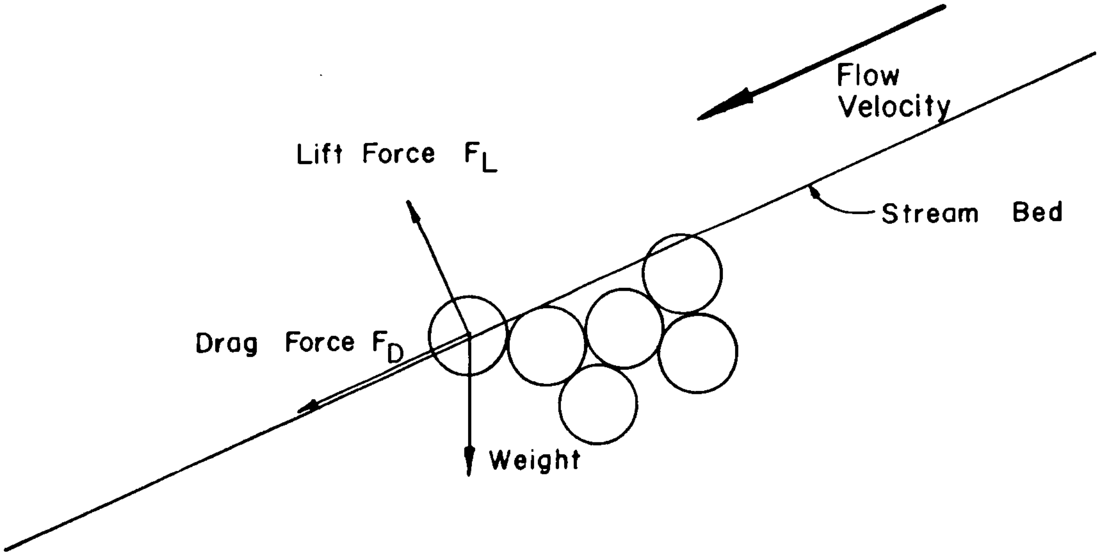


Fig. 2b. Force diagram on particles in a cohesionless soil.

Figure 2. Mechanisms of erosion.

agricultural land is often as much as two hundred (200) tons per acre per year for heavily cultivated areas.[3]

Every year large portions of farmland are transformed by urban development. A fully developed, stable urban area has a much lower sediment production rate than farmland because of the high percentage of land that is protected by roofs, streets, parking lots, and well-kept lawns. However, land that is undergoing urbanization has an erosion rate ten (10) times that of cropland.[4] This is aggravated because appropriate erosion control measures are not taken while the disturbed sites are most susceptible. The period of high erosion is only about three to four months for individual housing construction, since sodding and driveway construction are usually promptly completed. For large subdivisions, and industrial and commercial construction, it may be two to three years before the soil is stabilized once more.

High rates of erosion also result from roadway construction. The rate during construction is about that of urban construction. Most major roadway projects are quickly revegetated so that the peak erosion period is as short as possible. This is not true with many of the local roads which are never effectively stabilized and remain a source of excessive sediment for many years.

Another source of extremely high sediment production is mining, especially strip mining. The major sources of sediment production in strip-mining operations are areas being cleared, grubbed, or scalped; roadways; spoil piles and active mining areas; and areas in very early stages or reclamation. While the actual rate of erosion for active mining operations may be no higher than that for urban or roadway construction,[5] it is often more conspicuous since it occurs in areas that are primarily forest or pasture and since the sediment frequently enters directly into streams. Also, the steepness of the terrain where much strip mining occurs readily allows material that is eroded to be transported from the site.

The erosive energy of flowing water depends on its volume and velocity, so that any change in the volume or rate of runoff will also change the associated erosion potential. Therefore, any activity which increases runoff amount or rate may also increase erosion. For example, some activities related to urbanization that tend to produce these effects include: first, increased runoff amount due to more impervious areas and fewer surface depressions, and, second, quicker runoff due to curbs and gutters, roadway ditches, culverts, and storm sewer systems. There are similar activities associated with all other forms of construction that intensify runoff, and these too tend to increase erosion potential.

The last among those activities which tend to increase erosion are stream control works. The straightening or constricting of channels, for instance, increases flow velocity and thereby increases channel erosion. The construction of dams on a stream can also increase erosion. When water that is completely saturated with sediment enters a reservoir, much of the sediment is deposited, and clearer water flows out below the dam. This rapidly flowing, clearer water will in turn pick up sediment downstream, often causing serious erosion below dams.

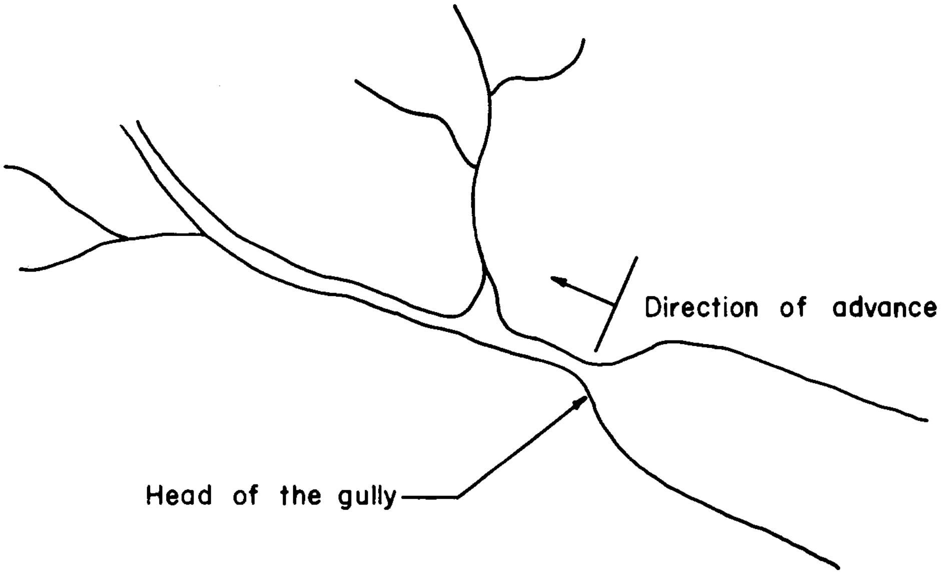
Erosion may also be classified by method of development as either gully, rill, or sheet erosion. *Gully erosion* is the removal of soil by flowing water concentrated enough to form channels that cannot be readily smoothed by normal cultivation practices. *Rill erosion* differs from gully erosion in that there are numerous channels formed, and these can be smoothed by normal cultivation practices. Lastly, *sheet erosion* is the wearing away of a thin layer of the land surface so that no channels are formed. In this report rill and sheet erosion will be considered together.

Gullies develop when overland flow concentrates to form a small channel. The turbulence in this concentrated flow creates enough force to dislodge soil particles from the bed and banks of the channel. As the gully forms, the profile has its steepest slope at the head. Since the flow velocity is more rapid on steeper slopes, this uppermost region erodes most readily, and the gully advances upstream as shown in Figure 3. This type of erosion is most common in areas having steep terrain and thick topsoil. The shape and rate of progression depends upon the soil's erosion resistance.

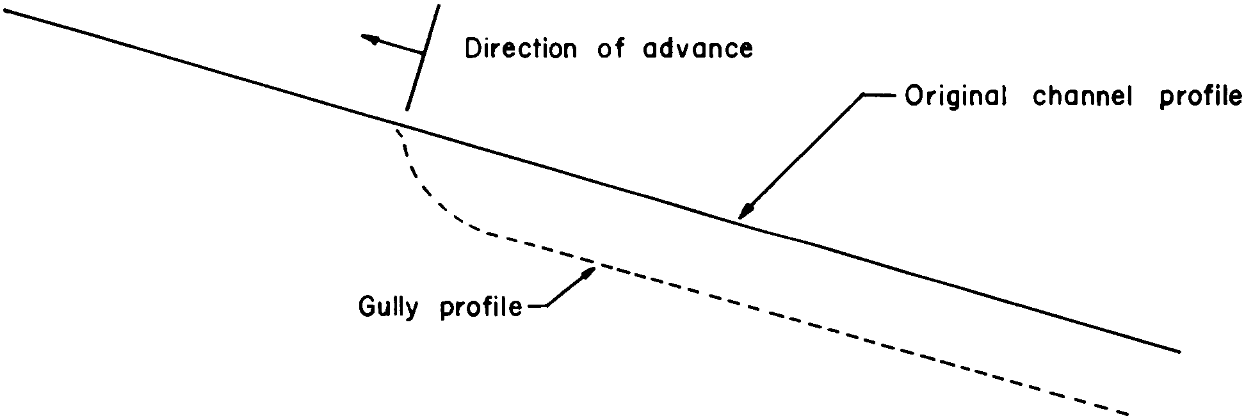
Although the amount of material eroded from an area by gully erosion is large, it is usually less than the amount due to sheet erosion. Sheet erosion occurs on cultivated or unvegetated mining and construction sites with mild slopes when the runoff is not concentrated in well-defined channels. The erosion occurs as successive thin layers of soil are removed uniformly over a large area. The more absorptive, organic-laden topsoil is more resistant to the type of erosion than the less absorptive and less stable subsoil layers beneath. Therefore, it is important to protect the topsoil layer to minimize later sheet erosion.

Sheet erosion varies considerably on unprotected land depending on topography, climate, and most importantly, the inherent erodibility of the soil.

Sheet erosion in an area can be estimated relatively closely by means of the Universal Soil Loss Equation, widely used by the Soil



Plan view of gully development



Profile view of gully development

Figure 3. Schematic illustration of the method by which gully erosion occurs.

Conservation Service. This equation takes into account the primary factors involved in sheet erosion and is of the form

$$E = RKLSCP,$$

where E is the average annual soil loss in tons per acre; R is the erosion index based on the average annual sum of the kinetic energy due to rainfall; K is the soil erodibility factor in tons per acre per unit of R; L and S are topographic factors related to length of slope and degree of slope, respectively; C is the cropping factor; and P is the supporting conservation practice factor.

The factors R, K, C, and P have been evaluated by extensive experimentation and can be obtained for almost any area in the country. The erosion index, R, varies nationally from as little as ten (10) to as much as three-hundred and fifty (350). The R values for Kentucky are shown on Figure 4. The value of the soil erodibility factor ranges from 0.02 to 0.70 tons per acre per unit of R and may vary considerably within a given locality. The value for any given area can be obtained from the Soil Conservation Service. The cropping practice, C, is used as an adjustment for various types of vegetal cover and managment. Land in cultivated row crops is considered to have a C value of one. The values of this coefficient for grassland and forested areas are given in Tables I and II.[6] The conservation practice factor, P, accounts for the reduction of erosion due to the influence of various drainage pattern practices on reducing runoff concentration and velocity. Values of this factor are given in Table III.[7]

The topographic factors, L and S, were determined by statistical analysis of field measurements taken throughout the country. The land slope, S, is given as a percentage while the length of slope, L, is given as the distance measured along the slope in feet. These measured

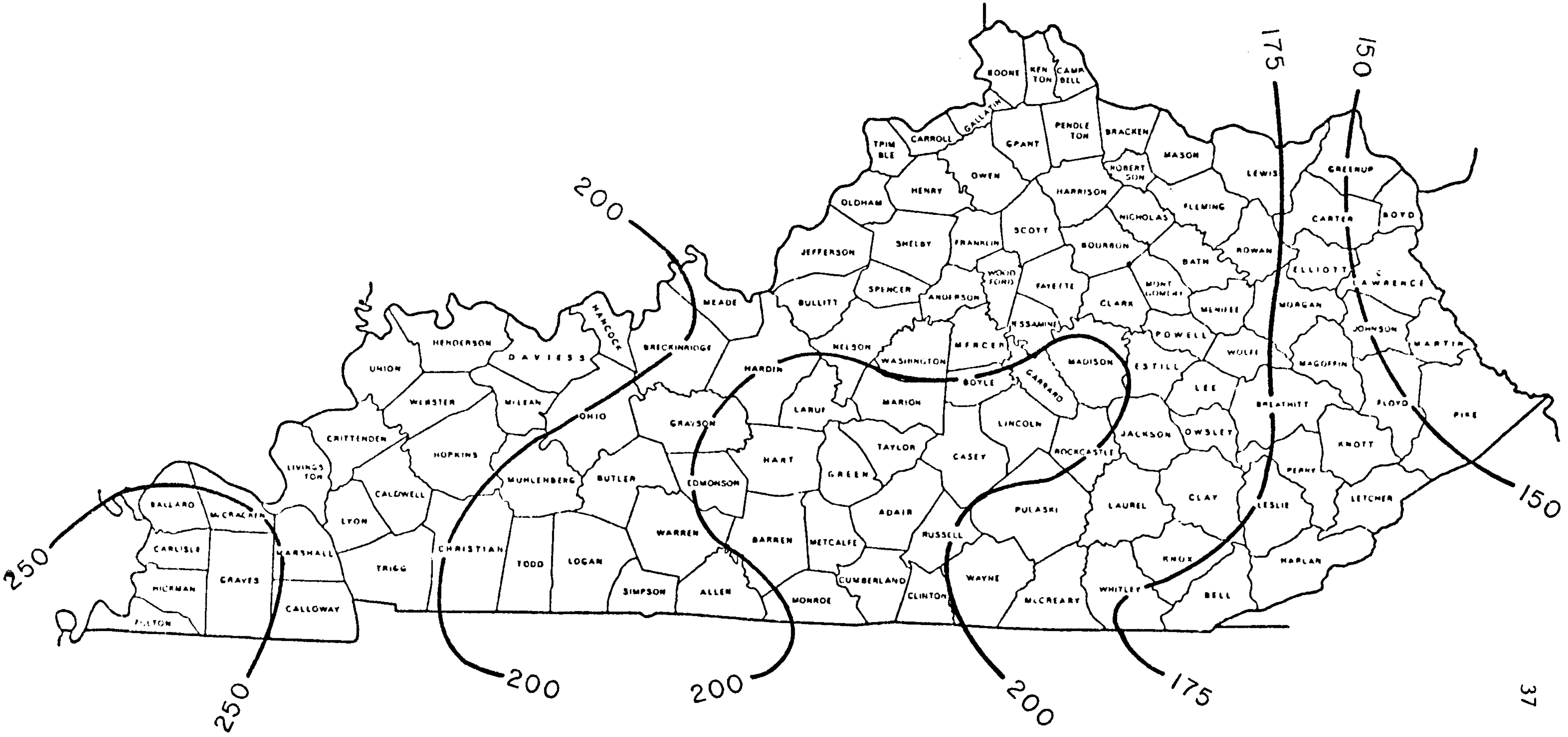


Fig. 4. R values of the Universal Soil Loss Equation for Kentucky.

TABLE I

"C" Values for Permanent Pasture, Rangeland, and Idle Land[a]

Vegetal Canopy		Cover That Contact the Surface						
Type and Height of Raised Canopy[b]	Canopy Cover[c] %	Type[d]	Percent Ground Cover					
			0	20	40	60	80	95-100
No appreciable canopy		G	.45	.20	.10	.042	.013	.003
		W	.45	.24	.15	.090	.043	.011
Canopy of tall weeds or short brush (0.5 m fall ht.)	25	G	.36	.17	.09	.038	.012	.003
		W	.36	.20	.13	.082	.041	.011
	50	G	.26	.13	.07	.035	.012	.003
		W	.26	.16	.11	.075	.039	.011
	75	G	.17	.10	.06	.031	.011	.003
		W	.17	.12	.09	.067	.038	.011
Appreciable brush or brushes (2 m fall ht.)	25	G	.40	.18	.09	.040	.013	.003
		W	.40	.22	.14	.085	.042	.011
	50	G	.34	.16	.085	.038	.012	.003
		W	.34	.19	.13	.081	.041	.011
	75	G	.28	.14	.08	.036	.012	.003
		W	.28	.17	.12	.077	.040	.011
Trees but no appreciable low brush (4 m fall ht.)	25	G	.42	.19	.10	.041	.013	.003
		W	.42	.23	.14	.087	.042	.011
	50	G	.39	.18	.09	.040	.013	.003
		W	.39	.21	.14	.085	.042	.011
	75	G	.36	.17	.09	.039	.012	.003
		W	.36	.20	.13	.083	.041	.011

a. All values shown assume: (1) random distribution of mulch or vegetation, and (2) mulch of appreciable depth where it exists. Idle land refers to land with undisturbed profiles for at least a period of three consecutive years.

b. Average fall height of waterdrops from canopy to soil surface: m = meters.

c. Portion of total-area surface that would be hidden from view by canopy in a vertical projection, (a bird's-eye view).

d. G: Cover at surface is grass, grasslike plants, decaying compacted duff, or litter at least 2 inches deep.

W: Cover at surface is mostly broadleaf herbaceous plants (as weeds with little lateral-root network near the surface, and/or undecayed residue.

Table II. "C" Factors for Woodland

(a) Tree Canopy % of Area	(b) Forest Litter % of Area	(c) Undergrowth	"C" Factor
100-75	100-90	Managed[d]	.001
		Unmanaged[d]	.003-.011
70-40	85-75	Managed	.002-.004
		Unmanaged	.01-.04
35-20	70-40	Managed	.003-.009
		Unmanaged	.02-.09[e]

a. When tree canopy is less than 20%, the area will be considered as grassland, or cropland for estimating soil loss. See Table 1.

b. Forest litter is assumed to be at least two inches deep over the percent ground surface area covered.

c. Undergrowth is defined as shrubs, weeds, grasses, vines, etc., on the surface area not protected by forest litter. Usually found under canopy openings.

d. Managed - grazing and fires are controlled.
Unmanaged - stands that are overgrazed or subjected to repeated burning.

e. For unmanaged woodland with litter cover of less than 75%, C values should be derived by taking 0.7 of the appropriate values in Table 1. The factor of 0.7 adjusts for the much higher soil organic matter on permanent woodland.

Table III. Erosion Control Practice Factor, P

Land Slope %	P Values			
	Contouring	Contour Stripcropping	Contour Irrigated Furrows	Terracing*
2.0 to 7	0.50	0.25	0.25	0.10
8.0 - 12	0.60	0.30	0.30	0.12
13.0 - 18	0.80	0.40	0.40	0.16
19.0 - 24	0.90	0.45	0.45	0.18

*For prediction of contribution to off-field sediment load.

values are not used directly in the equation. Instead, each of these factors is entered into Figure 5, and a combined LS factor is obtained.[8] This combined factor is used in Universal Soil Loss Equation.

Sediment Transport

Sediment that has been detached and delivered to a stream channel by the erosion process is transported as suspended particles, as bedload rolling or sliding along the stream bed, and as saltation load that is interchangeable between suspension and bedload. The manner of transport depends on the particle size, shape, and specific gravity (these are also important considerations in sediment deposition and will be discussed further later) and on the velocity and turbulence of the flow. Small, light-weight particles are transported by suspension, while large, heavy particles are transported as bedload.

In most streams the *suspended sediment* is more damaging than the bedload. Suspended sediment blocks the penetration of light into the water reducing the growth of microscopic organisms on which insects and fish feed and damages the gills of fish as well, so that sport fishing may be curtailed. Water in reservoirs which is muddy from suspended sediment is not desirable for other recreational purposes either, and it must be treated before it is suitable for industrial use or human consumption.

Suspended sediment particles are always in the process of falling due to the effect of gravity, but they are held in suspension by the turbulence of the stream flow. For some sizes of material the turbulence will be enough that it is always in suspension; this is the suspended load. Some other material may be just heavy enough that it alternately falls to the bed and then bounces or is lifted by the turbulent flow back into the main stream of flow; these bouncing particles constitute the *saltation load*.

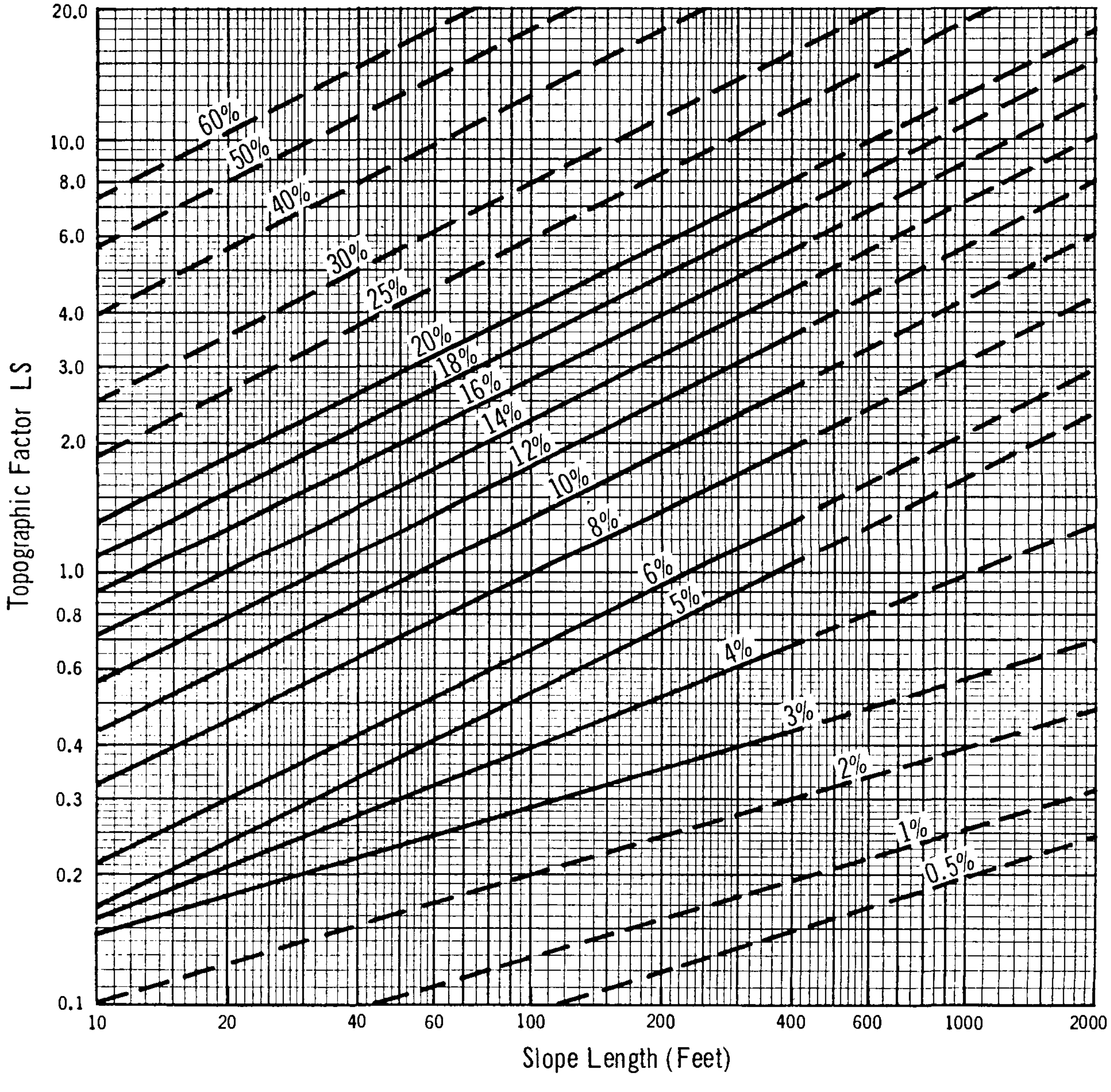


Figure 5. Chart for determining the value of the topographic factor, LS. (The dashed lines indicate values beyond the range for which data are available). After Soil Conservation Service.

Bedload is transported by rolling, sliding, and occasionally jumping along the streambed. This movement is due almost entirely to the drag force exerted on the streambed by the moving water. As the flow, and thus the drag force, varies, the shape of the bed changes. At very low velocities the bedload does not move at all. Then as the flow velocity increases, the threshold of motion is reached, and with any further increase, motion of the bed begins. If the bed is of fine material, such as sand, then with further increase in velocity the bed develops ripples in a sawtooth fashion as shown in Figure 6a. At higher velocities larger and more regularly spaced formations appear on the bed, Figure 6b. These are known as dunes, and when they first begin to appear they carry the ripples superimposed, as in Figure 6b. At still higher velocities, the ripples disappear, and only the dune pattern remains, Figure 6c. Dunes are larger and more rounded than ripples. Neither dunes nor ripples extend across the full width of the stream; both formations tend to occur in the form of short-crested waves appearing as staggered arrays when seen from above, ripples have a more regular, parallel formation than dunes. Both dunes and ripples migrate slowly downstream through the lifting of material from the upstream face and its subsequent deposition on the downstream face. The next bed formation develops when the dunes are erased by the increasing velocity of flow, leaving a flat bed as in Figure 6d. Further increase in the velocity leads to the formation of standing waves on the bed, Figure 6e, which occur in association with, and in phase with the surface water waves shown in the figure. As flow increases the surface waves become so steep that they break, as in Figure 6f; at the same time there is a gradual movement upstream of the whole bedform wave system. These waves are then called antidunes.

(a) Ripples

(d) Flat bed

(b) Dunes with superposed ripples

(e) Standing waves

(c) Dunes

(f) Antidunes

Figure 6 Forms of Bed Roughness in Alluvial Channels.

In addition to the forms noted above, bars of sediment may be found in the streambed. These are dune-like forms, but their length may be equal to or larger than the width of the channel, and their heights are about the same as the depth of water flowing over them. They occur at irregular intervals along the stream with their location depending on the hydraulic and geometric characteristics of the stream.

Sediment Deposition

Deposition is the inverse operation of erosion. Eroded material may be deposited immediately below the source, or may be transported great distances before being deposited in channels, on floodplains, or in lakes, estuaries, and oceans. This sediment may cause severe damages, or conversely, may be beneficial depending on the amount, character, and place of deposition.

The deposition of sediment in drainage ditches, irrigation canals, and in navigation channels creates serious problems in loss of services and dredging costs. The filling of drainage ditches leads to an increased water table elevation causing crop damage. Sediment in irrigation ditches reduces the rate and volume of water supplied, and this can lead to serious crop damage if the supply is less than crop requirements. The sediment deposited in navigation channels must be removed periodically to maintain a minimum navigable depth. Dredging navigation channels is a major portion of the maintenance work by the Corps of Engineers and amounts to millions of dollars annually. Considered together the deposition of material in these three types of channels can cause considerable economic losses over a major portion of the country.

Deposits that occur in floodplains may bury crops. Infertile deposits may reduce long-term crop productivity. Deposits in housing within the floodplain may be a primary contributor to post-flood damages. However, the deposition of fertile material onto agricultural lands is, of course, a beneficial effect of sediment deposition. This points out that damage is often dependent on one's outlook. If the ancient Egyptians had used the floodplain of the Nile for extensive urban growth, instead of for farming, they probably would have considered the annual deposition of sediment to have been damaging also.

Deposition of sediment also may adversely affect lakes and reservoirs. When sediment-laden water flows into a large body of water, its velocity and transporting capacity are reduced and the sediment load begins to settle. In natural lakes which have no outlets, all of the sediment is deposited. In lakes and reservoirs which have outlets, the percentage of sediment deposited depends on the detention time of the reservoir, which in turn depends on the volume of the reservoir and the rate of inflow. Both the location of the deposited material and the loss of storage volume are important considerations regarding reservoir sedimentation. The location is important because shoals may form near recreational or residential areas and cause considerable loss in revenue or property value. The loss of storage is of importance because the filling of the reservoir with sediment destroys the intended purposes of water supply, power, irrigation, and in case of extreme amounts of deposition, flood control.

In addition to where sediment deposition may occur and the potential damage that may result, the reader may be interested in the basic principles involved in the process of deposition. As mentioned before, most sediment particles that are in transport would settle out of the flow due to their own weight were it not for the turbulence of the flow. For this reason, large portions of sediment are deposited in the floodplain and in reservoirs where the flow is relatively tranquil. The bedload sediment does not have to settle since its motion is already along the channel bed. When the flow velocity slows to a point where the drag is no longer sufficient to propel the bedload, its movement halts.

In analyzing the settling of suspended material, the simplest case is a smooth, non-rotating sphere falling at a constant velocity through an infinite fluid free of disturbances. Unfortunately, most sediment particles are not spherical, so their fall velocities cannot be calculated directly from the data used for spheres. Also, fluid conditions are seldom ideal. However, by using various correction coefficients, a calculation can be made for many conditions.

The equation for the fall velocity of a smooth, non-rotating sphere. in an infinite, still body of water at 68 degrees Fahrenheit can be determined from Stoke's law to be

$$V_s = 1.704d^2 \ (W_s-1) \times 10,$$

where V_s is the settling or fall velocity in feet per second, d is the diameter of the particle in feet, and W_s is the specific gravity of the particle.[9]

Sediment grains are never exactly spherical. In fact, they vary widely in shape from rod-shaped, to nearly spherical, to disk-shaped. For this reason it is necessary to relate shape to the rate of fall of a sphere. This is done by means of two coefficients: the shape factor, SF, which is defined as $a/(bc)^{\frac{1}{2}}$ and length ratio, b/c; where a, b, and c are lengths of the mutually perpendicular axes with the direction of fall being parallel to the direction of length a, see Figure 7. Entering these coefficients into Figure 7, a relative resistance factor K can be determined. Shapes which have a low value of K drop faster than

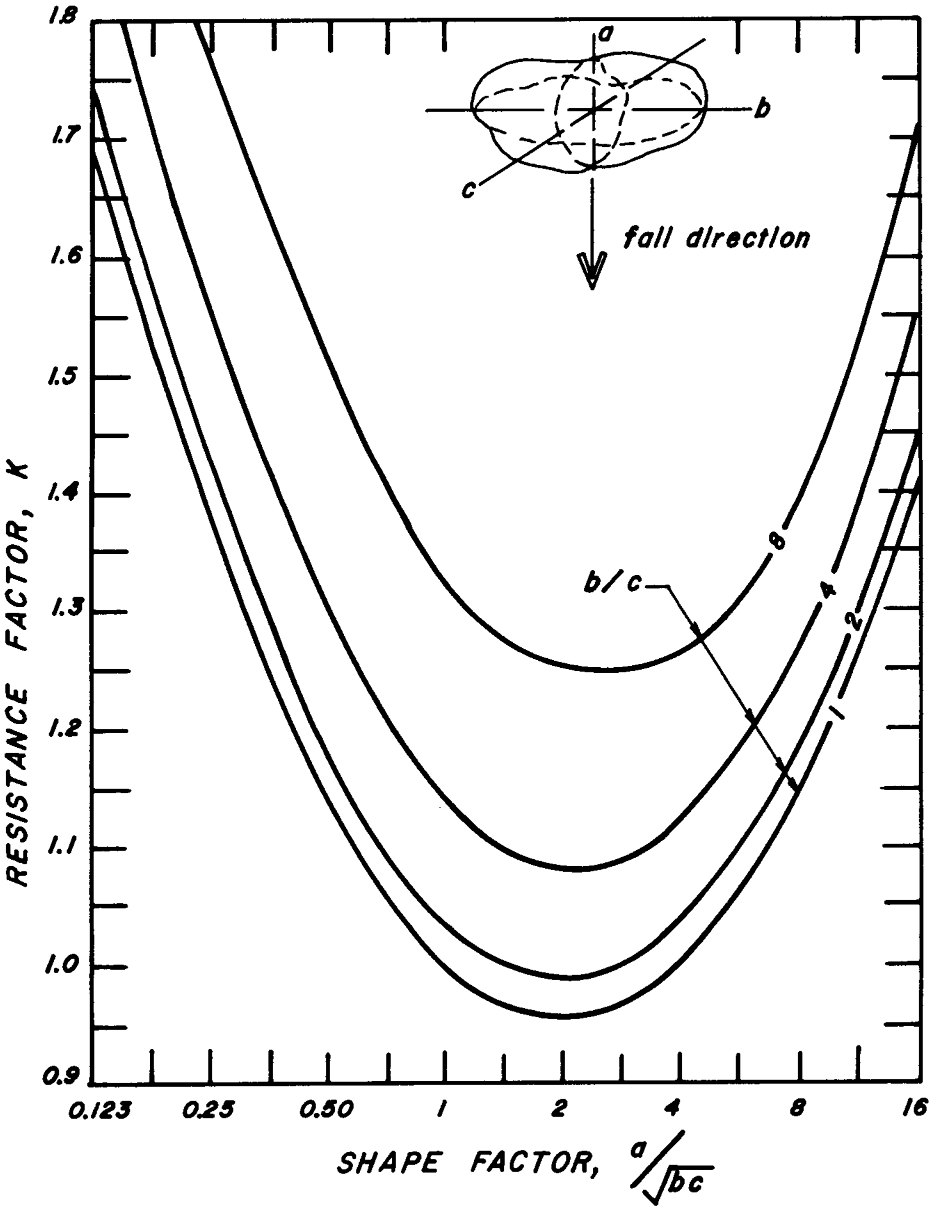


Figure 7. Relative restance to fall values for various shapes. (After McNown et. al.[10])

those with high ones. (The application of the adjustment factors is beyond the scope of this report; anyone wishing to pursue the discussion of these factors further should consult a good fluid mechanics book).

Stoke's equation is used to determine the fall velocity of a single particle in an infinite fluid. When numerous particles are dispersed throughout the fluid, the fall velocity will differ from that of a single particle due to the mutual interference of the particles. If only a few closely spaced particles fall as a group, they will fall faster than a single particle. However, if particles are spaced throughout the fluid, the interference between adjacent particles will reduce the fall velocities of all particles.

In addition to the above factors, increasing particle roughness and rotation, the presence of a fluid boundary, and increasing fluid turbulence, all reduce the rate of fall of a particle in suspension. These considerations can be related to a reduction factor for fall velocity, but again, this is beyond the scope of this report.

Conclusion - Sedimentation

The erosion of large amounts of soil resulting from human activities--construction, agriculture, mining--is a very serious national problem. It is not that these activities have been intended to degrade nature; instead, the problems have arisen as a consequence of some useful or necessary task. As Vanoni[11] says:

> If a row-cropping is a necessary agricultural practice, some degree of increase in upland erosion must be expected. If roads and trails are to be built in the alluvial valleys in the Southwestern desert and if cattle are to graze in these areas, some degree of gullying must be expected. If water is to be diverted and consumptively used from major stream systems, aggradation may be expected. If flows of water are introduced into normally dry waterways, erosion can be expected. Flooding and erosion are a normal expectancy on floodplains. Ill-considered occupancy inevitably results in loss. If natural channels are deepened, shoaling is sure to happen. A predictable reaction to a previous action may hardly be called "damage"

> although the reaction is, in its overall nature, injurious; rather, these reactions should be considered in the nature of costs for benefits brought about by the original action.

The problem of erosion can be lessened to a large extent by taking measures to reduce the rate of erosion at the site, by trapping material that is eroded on the site, or by trapping eroded material as near below the site as possible. It is important to note, however, that the sedimentation-related problems resulting from man's activities cannot be totally alleviated unless such activities cease altogether, and this is far from being a practicable alternative.

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CHAPTER III

FLOOD-DAMAGE REDUCTION

Introduction

Most of the early settlements in Kentucky were on the banks of a major stream, and usually they were within the stream's floodplain. These locations were desirable because the land was suitable for farming; the stream provided water, food, transportation, waste-water disposal; and, because the floodplains were flat, it was easy to build cities, railroads and highways as the population grew. On the other hand, building in these locations meant that periodic flooding was a certainty, as Vogel[1] describes it:

> . . . a river is a stubborn creature, ever bound to assert its rights. Through the ages it has ground away the rocks and swept away the soils to create a floodplain, and this from time to time it claims as its own. Death and taxes are proverbially regarded as the two inevitable companions of earthly existence. They have an equal, however, in the waters of a great stream surging over its banks, crossing the level land, destroying with tremendous force all that is erected in its path. Smaller creeks and branches demonstrate the same violent possessiveness-the right to claim their floodplains and to destroy what man has put before the onrushing water.

A simplified restatement of this idea is that nature creates floods, but man creates flood damages.

Flood damages are due either to inundation during high flood stages or to the effects of high-velocity currents produced by the flood flows, or both.

One of the worst effects of inundation is the sediment deposit left by the flood. In urban residential and manufacturing areas this deposit is particularly damaging to property and is very difficult and costly to remove. Also, inundation ruins carpets, some furniture, and plaster walls; short-circuits electric outlets and equipment; and may destroy large portions of produce and commercial stock.

The effects of the flood current include the sweeping away of bridges, houses and other buildings, the tearing up of streets and roads, and the eroding of farmlands.

The damages which occur due to flooding can be classified as direct damages, indirect damages, secondary damages, intangible damages, and uncertainty damages. *Direct damages* are those to private and public structures and facilities. The amount of direct damage depends on the type of property, its value, and the cost of restoring it to its original condition. *Indirect damages* include the value of lost business and services, plus the cost of alleviating hardship (supplying drinking water, hospital services, etc.) in the stricken area. Although these are difficult to quantify, the Corps of Engineers uses the following guidelines for indirect damages:

1. residential damage	15% of property value
2. commercial	35%
3. industrial	45%
4. utilities	10%
5. public facilities	35%
6. agriculture	10%
7. highways	25%
8. railroads	25%.

Secondary damages occur when production and/or services in an area are hindered by flooding in another area. Secondary damages, however, are normally offset by secondary benefits and are not usually considered in a summary of damages. *Intangible damages* include damages to environmental quality, social well-being, and aesthetic values. These factors cannot be quantified as an economic loss. Finally the *uncertainty damages* are "an amount in excess of the expected value of the damages that floodplain occupants are willing to pay to avoid a flood loss."[2]

Historically, national policy toward flood losses has been either to protect flood-prone areas by flood-control structures or to bear the losses incurred. Although these alternatives remain, methods of flood damage reduction today are considerably more complex, see Figure 1. The individual elements in this damage-reduction scheme will be discussed in the following sections on corrective measures and preventive measures. These sections will be followed by a section on comprehensive planning for flood-damage reduction.

Corrective Measures

As the name implies, corrective measures are those which are taken in an attempt to reduce the damage to property that is already situated in a flood-prone area. These measures may be classified as flood control and other measures. Flood-control structures have been the most commonly employed method of protecting property liable to flooding. The objective of these structures is to reduce the extent of overflow in the floodplain so as to ensure a relatively harmless flow of flood waters past an area.

Dams which are intended for flood control are called *flood-retarding structures*. The function of a flood-retarding structure is to store all or a portion of the flood flow in order to reduce the flood peak at the point downstream to be protected. In the ideal case, the structure would be situated immediately upstream of the protected area and operated to cut off the flood peak. This is done by discharging all of the flood inflow up to the point where this discharge equals the maximum non-damaging

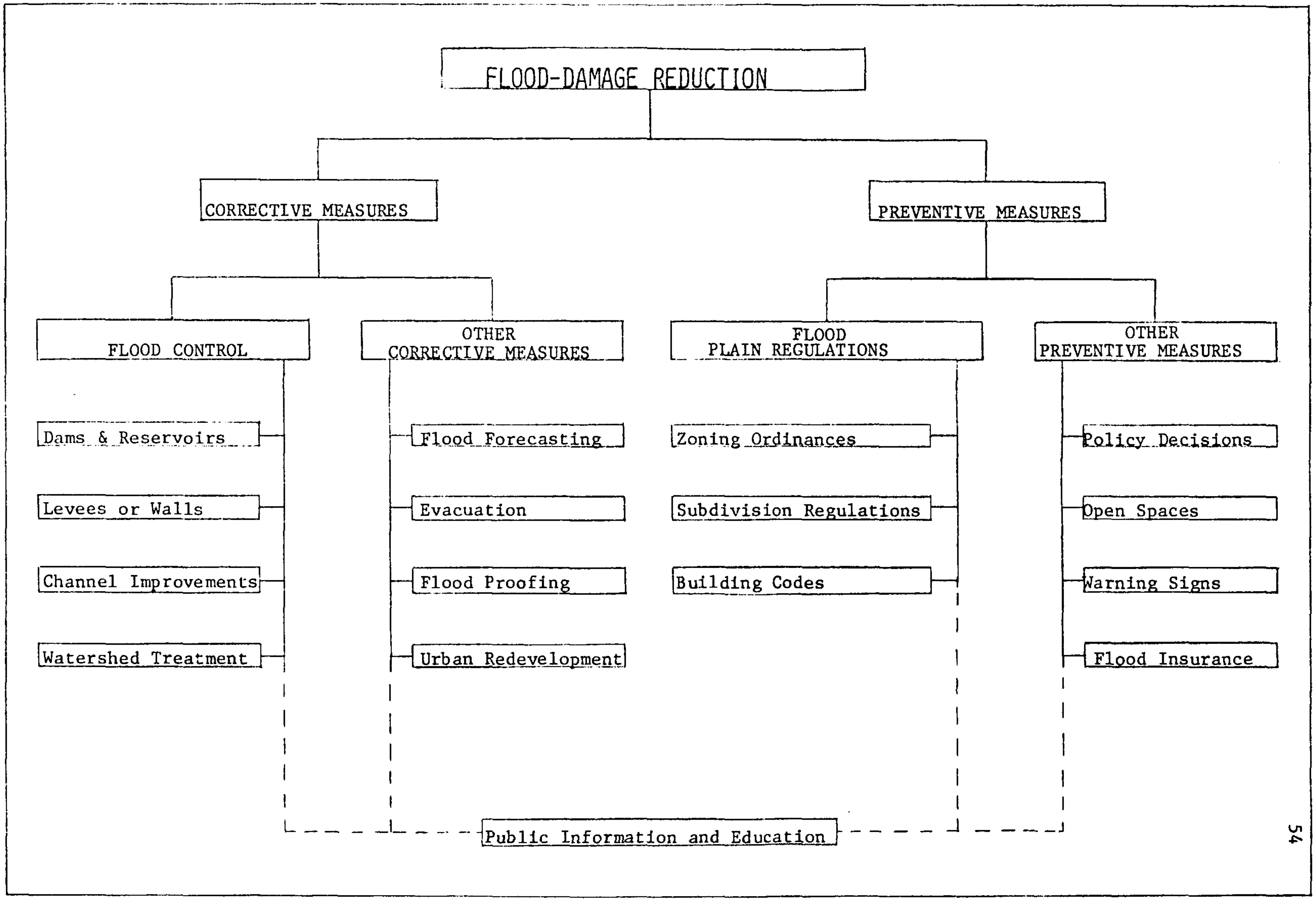

Figure 1. Methods of flood-damage reduction

flow capacity of the stream at the protected area. All flow in excess of this is stored in the reservoir, then released as soon as possible in preparation for the next flood.

There are some difficulties in this idealized flood-retarding structure. First, it is not always possible to locate the structure just above the area to be protected, perhaps because the floodplain is so wide that a dam would not be economical or because such a location would inundate much valuable land and developments. Moving the structure farther upstream may solve these problems, but it will also reduce the effectiveness of the structure since it will no longer be able to control the area between it and the protected area. A second problem is that it may not be economically feasible to build a structure so large that it can store all of the excess flood water. It may be that an increase in the cost of the additional storage past a given point will be greater than the losses that would occur if the associated flooding were allowed. A final problem with the ideal flood-retarding structure is that it has its maximum potential when it is empty. After a flood has occurred, a portion of the available flood storage is not available for use until it can be released. It is always possible that a second storm may occur before this release is accomplished. Consequently, a portion of the structure's storage capacity often is held in reserve as protection against a second flood. Considering these problems, it is obvious that a flood-retarding structure is seldom fully effective in flood prevention.

Some dams may be designed to provide water supply or recreation benefits or both, as well as flood control. These facilities are called *multipurpose structures*. They are operated similarly to flood-retarding structures except they can never be totally emptied due to their other designated uses. So in order to provide an equal amount of flood protection, in addition to water supply and recreation, a multi-purpose structure must be larger than a flood-retarding structure.

Levees and floodwalls protect flood-prone areas by acting as lateral dams paralleling the stream to confine the floodwater to a floodway area. They are built in the floodplain near to the stream so as to provide maximum protection while encroaching as little as possible on the natural floodway. A levee is an earth dike, while a floodwall is usually concrete or masonry in construction. In general, both levees and floodwalls must satisfy all of the same design criteria as a dam.

Of the two, levees are more frequently used for flood reduction because they can be built at relatively low cost from the materials available at the site. The slopes of the levee must be protected against erosion by sodding, by planting with shrubs or trees, or by placing riprap.

Because of the flat side slopes generally used in levee construction, a levee of any considerable height will occupy a large area. Although real estate prices for levees may be reasonable in rural areas, in cities these costs may be prohibitive. In such a case, a floodwall may be the preferable alternative, see Figure 2. Floodwalls are designed to withstand both the lateral pressure and the uplift forces caused by the floodwater at maximum design stage. If the floodwall has earth fill behind it, it must be designed also as a retaining wall.

Channel improvements can produce significant reduction in flood stages at a point on a stream by improving the channel's hydraulic capacity. Straightening to remove undesirable bends, dredging and widening to increase channel area, removing brush and trees, lining with concrete,

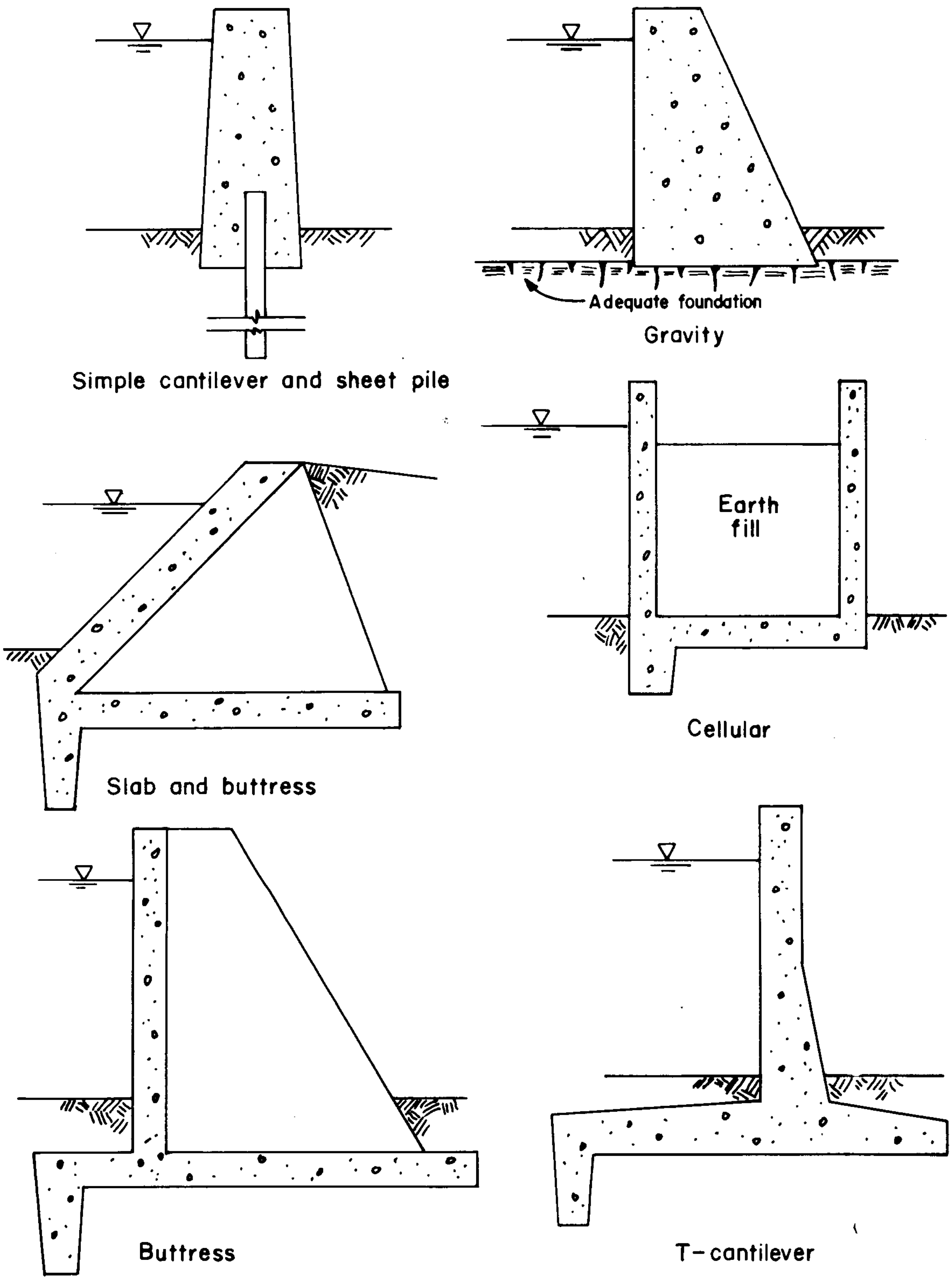

Figure 2. Some typical floodwall sections.

and other improvements can all be effective at lowering the flood levels at the point where they are made. However, these measures provide local protection only and may increase flood magnitudes at downstream points. The effect of a flood-control measure on areas other than that protected should always be considered. Channel improvement projects have received intense opposition in recent years because of the extreme environmental disturbance associated with their construction.

Watershed treatments, generally applied only to small areas, attempt to lower the flood heights of a stream by making the soil more absorptive and by providing vegetation to retard the overland flow. Treatment measures include crop rotation, construction of terraces, contour strip cropping, and selective planting or reforestation.

Corrective measures, other than flood-control structure, include flood forecasting, evacuation, flood proofing, and urban development.

Reliable, accurate, and prompt *forecasting* of floods and flood heights is necessary to save lives and reduce property loss in those flood-prone areas that do not have flood-control structures. Because of the technical expertise involved in these forecasts, they are generally made by federal agencies, such as the U. S. Weather Bureau, the Corps of Engineers, the Tennessee Valley Authority, and the Bureau of Reclamation. There are many areas for which forecasts are not available, and in many areas where they are available, there is not efficient means of alerting endangered persons, helping with evacuation, or helping those temporarily homeless or distressed. For these reasons, flood forecasting in many areas is relatively ineffective for flood-damage reduction.

In those areas where the populace is forewarned, *temporary evacuation* of people and property can be an important factor in reducing losses and averting disaster. After it is certain that flooding is eminent, buildings can be evacuated, materials can be raised above the expected flood level within a building or moved to higher ground, sandbags can be placed, and mobile homes and other transportable property can be moved to safe locations.

Permanent evacuation of some areas may be more economically feasible than any other flood-damage-reduction alternative. In this case, property subject to inundation is purchased, improvements removed, and residents evacuated. The land is then used for agriculture, parks, and other purposes not subject to flood damage and that will not interfere with flood flows.

Flood proofing is a combination of structural changes and adjustments to properties subject to flooding in order to reduce or eliminate flood losses, see Figure 3. These measures are more simply and economically applied to new structures, but may also be applied to existing ones. Flood proofing is a feasible alternative only where flooding of low stage, low velocity, and short duration is expected; where traditional flood-control measures are not feasible; where individuals in an area desire protection but are opposed to flood-control structures; and where a property owner wants a higher degree of flood protection than flood-control structures provide.

Urban redevelopment can be used in those areas that are not suitable for other forms of flood regulation. Federal funds are available to provide considerable assistance to municipalities in need. A redevelopment program should include construction of any appropriate flood-control

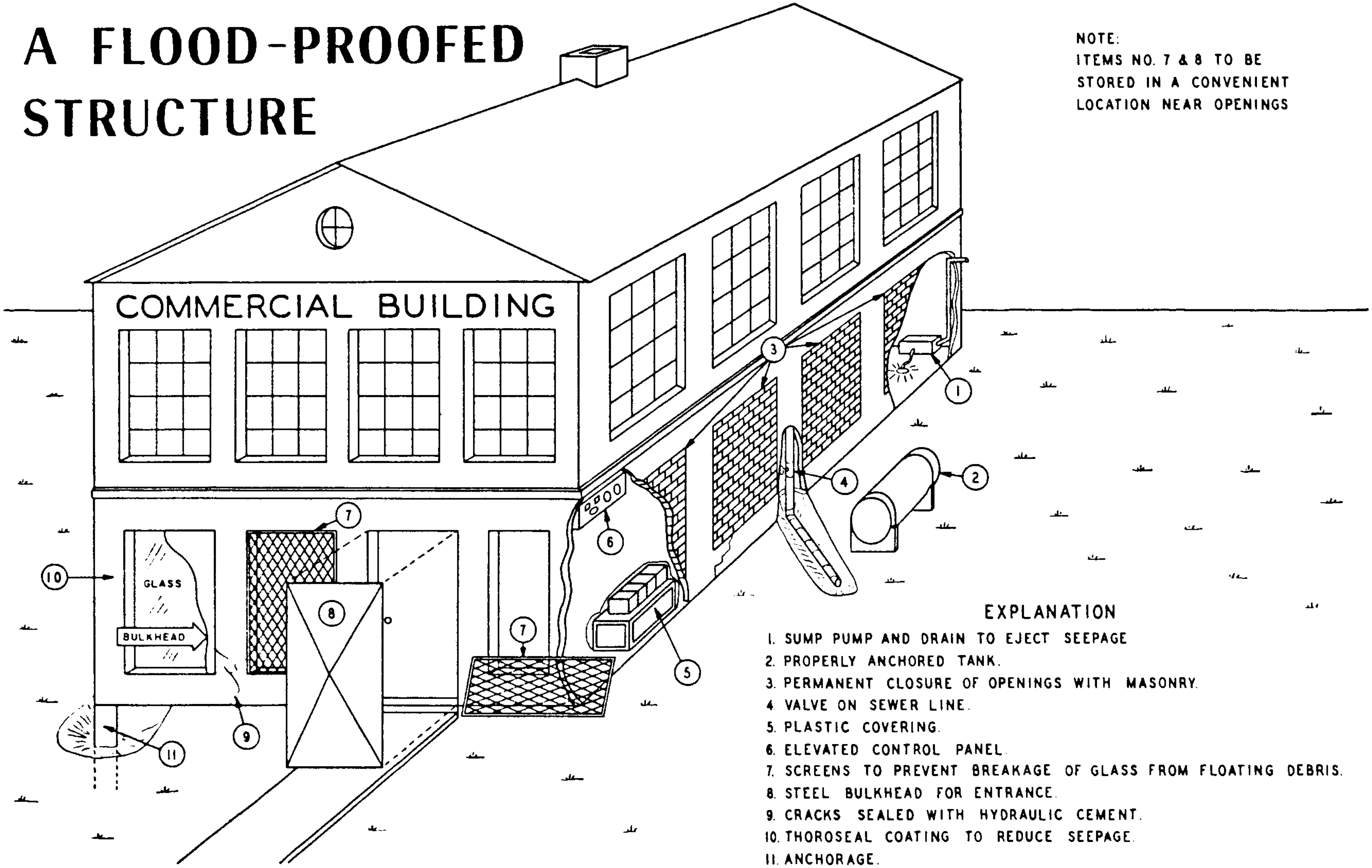

Figure 3. An illustration of typical flood-proofing measures. (After Corps of Engineers.)

works and setting aside some flood-prone areas as open land, parks, parking lots, and other uses that will not be damaged by flooding. Any structures or roadways which must be situated in the floodplain should be elevated above the expected level of flooding.

Preventive Measures

Approximately ten billion dollars have been spent on federal and other flood-control measures since 1935. Yet, in this same period of time, average annual flood losses have risen continuously. Since it has been shown repeatedly that existing flood-control structures are effective, what are the reasons for the perpetual increase in average annual flood loss? Some of the reasons are inflation, improved accounting techniques, the occurence of larger and more infrequent floods (due to increased runoff and channel constriction), and especially the increase in the value of property on lands liable to flooding.

By far the most influential of these factors is floodplain development. White[3] reported in 1960 that in a survey of seventeen urban floodplains, selected because of their diversity, all areas studied had an increase in the number of structures in the floodplain over the twenty-one year study period, even those whose population decreased. Of these new developments, commercial and industrial facilities outnumbered residential. The same growth pattern was evidenced regardless of whether a major flood had not occurred in fifty years or one had occurred in the last few years. Although the many factors involved precluded any definitive explanation of this growth, two factors appeared to provide a powerful stimulus to floodplain development. These were new highway construction and construction of flood-control structures.

New highway construction in urban areas tends to follow the level lands and relatively sparsely populated areas of the floodplains. This construction removes a substantial portion of the low quality residences and thereby induces commercial and industrial development in the flood-hazard area due to improved transportation access and to the availability of land. The construction of a flood-control facility lures development into the floodplain by giving developers an increased, and often ill-founded, sense of security regarding flooding in the protected area. This development may move beyond the limits of protection or may be damaged by the occurrence of a flood exceeding that for which the control structure was designed.

The fact that flood damages continue to rise faster than flood-control structures can be established for protection indicates that corrective measures alone cannot solve the nation's flood damage problems. Efforts must be made to prevent the increase in the flood-damageable property in the floodplains.

Preventive measures, again see Figure 1, can be classified as either floodplain regulations, such as zoning ordinances, subdivision regulations, building codes and health regulations, or as other measures, such as development policies, open spaces, warning signs, and flood insurance.

Floodplain regulations are attempts by the community to reduce flood damages by the adoption and use of legal tools to control the extent and type of future development that will be permitted in the floodplain.

One of the primary tools in floodplain regulation is the *zoning ordinance*. Zoning is the legal tool whereby a community can implement and enforce its planning program by controlling and directing the use and development of property within its jurisdiction. Division of the community into zones of varying, designated uses should be the result of a comprehensive planning program for the entire area. Designated floodways may then be zoned for the passing of floods and other limited uses as an integral part of the comprehensive plan. Ordinances should also provide regulation over the floodplain areas outside the floodway, such as setting an elevation below which certain types of development cannot be constructed. Figure 4 shows how a floodplain can be properly regulated.

Subdivision regulations are used by local governments to specify the manner in which land may be divided. Typical specifications might be width of streets, requirements for curbs and gutters, size of lots, elevation of land or flood levels, size of floodway, and other items regarding the welfare of the community. These regulations can provide an efficient means of controlling development in presently undeveloped floodplain areas. In order to obtain maximum flood-damage reduction, zoning regulations should show the extent of the floodplain, the floodway limits, and encroachment lines on the subdivision maps; prohibit filling of the channel and floodway, since this filling would restrict channel flow; require that subdivision streets be above the selected flood level; and require that the building site for each lot be above the selected flood height.

The final method of floodplain regulation is the *building code*. The building code is a set of regulations adopted by the local government which set standards for the construction of buildings and other facilities in order to protect public health, welfare, and safety. A well-conceived building code can help reduce the damages to buildings

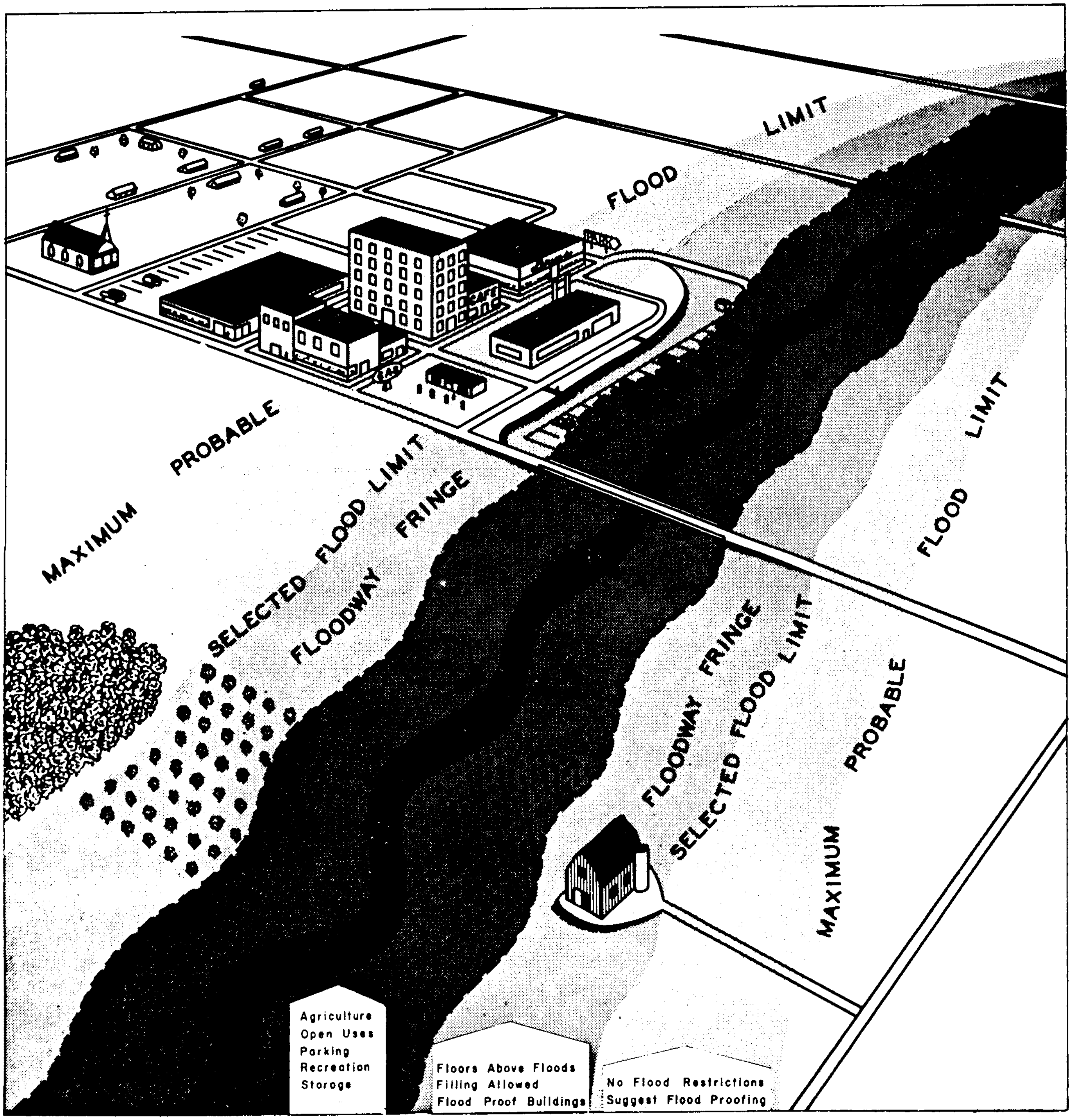

Figure 4. Floodplain regulations to encourage wise use and avoid flood damage. (After TVA)

within the floodplain by specifying sufficient anchorage to prevent flotation of buildings from their foundations, by establishing minimum basement and first-floor elevations, by requiring structural strength to withstand additional forces due to flood depth and velocity, by restricting the use of material unsuitable for exposure to water, and by prohibiting the storage of equipment or products which might be hazardous to life when submerged, such as electrical equipment or toxic chemicals, within a flood-prone area.

In addition to floodplain regulations, the actions and *policy decisions* made daily by local governments that prevent construction of streets and utilities in undesirable areas will help deter development in floodplains. By locating streets improvements, schools, and other public facilities other than in the floodplain, a local government can set a positive example for the rest of the community to keep damageable property on higher ground.

Local governments can also help reduce flood damages by purchasing space in the floodplain to set aside for recreational and other *open-space* uses or by encouraging private interests to set aside such lands. These open areas near a stream have a natural attraction to the public and may be the best use of areas not suitable for other types of development. Federal grants are often available to assist communities in acquiring such open spaces when linked with a program of comprehensive planning.

Another method of discouraging development in floodplains is the erection of *flood warning signs* in the floodplain or the prominent posting of previous and expected high water levels. These signs would not designate any legally enforceable building limits, but merely inform the potential developer that a flood hazard exists.

The last of the preventive measures is *flood insurance.* Flood insurance does not, in itself, prevent or reduce flood damages. Instead, it converts the highly irregular loss pattern into a series of uniform annual premimum payments, thus preventing catastrophic losses to severely flooded areas. By setting all premiums proportional to the degree of risk flood insurance can become a means of encouraging wise use of the floodplain through economic pressure. For this to occur, however, it is essential that the actuarial rates are accurately assigned. If the premium is too low, excessive development in the floodplain will be encouraged. If the premimum is too high, worthwhile development of the floodplain will be discouraged.

Comprehensive Planning

In the past only one or two flood-damage reduction measures were considered for flood-prone areas, and these were usually flood-control structures. Many solutions that were better suited were not undertaken, either because they were not considered early enough in the planning process or they were not considered at all.

Recently, three criticisms have arisen concerning these traditional, structure-oriented solutions:

1. Average annual damages continue to rise in spite of large expenditures for, and success of, flood-control structures.
2. People move into flood-hazard areas believing (and, unfortunately, all too correctly) that the federal government will build structures to protect them.
3. Natural floodplains have an important ecological function and should be preserved.

Thus it has become obvious that control measures alone cannot stop the rise in flood losses. Therefore, floodplain zoning and land-use planning were developed as feasible alternatives.

However, zoning, land-use regulations, and flood insurance alone still are not the ultimate answer. A combination of several flood-damage abatement measures may be required to solve a flooding problem.

The best solution to a flooding problem is dictated by the floodplain's characteristics. Where potential agricultural and urban damages are small, the best solution is to suffer the damages that occur. Structural measures are the only means of protecting croplands, but their economic justification requires either exceptionally good cropland or frequent flooding or both. A few widely scattered buildings can best be protected by flood proofing. At some density of development, the use of structural measures will become less costly than flood proofing. Impending scattered urban development is best suited to land-use regulation. Again, as pressure to develop increases, structural measures become more economically feasible than land-use regulation.

In general, nonstructural measures are best applied to protecting areas where urban development is widely scattered, where additional planning flexibility is desired, where channel improvement greatly increases flooding downstream, where flood-control structures are too expensive, where funds cannot be obtained to finance structural measures, or where, in conjunction with structural measures, they provide the most protection at least cost.

Of course, few flood-prone areas fit neatly into one of three categories, and so some combination of the possible solutions may be required to provide the best protection most economically.

The planning process for a comprehensive flood-reduction plan should include the following steps:

1. Recognize the problem.
2. Define the problem.
3. Enumerate alternatives.
4. Evaluate limitations and alternatives.
5. Narrow the alternatives.
6. Reevaluate limitations.
7. Search for modifications.
8. Decide on a solution.
9. Take action.

The planning staff for such a plan should include engineers, economists, lawyers, sociologists, community leaders, and others, so that the final plan is the result of a coordinated effort considering all aspects of both the problem and its solution. In this way, the resulting solution should offer an efficient solution that does not create new problems to the community as it relieves the flooding problem and that is acceptable to the public both from aesthetic, recreational, historical and other aspects.

Conclusion - Flood-Damage Reduction

Most communities that are located on a stream either have had or will have a flood problem. It may be only a drainage problem for cities on streams with small watersheds, or it may be a major flood problem. The problem may be small if development has not encroached on the floodplain, or it may be considerable if development is extensive. In any case, the earlier the problem is recognized, the easier it is to prevent it from becoming great.

The solution to an individual flooding problem may be by use of corrective measures (keep the water from man) or preventive measures (keep man from the water) or both. The solution to the national problem of ever-increasing average annual flood loss is by comprehensive planning involving corrective and preventive measures for those flood-prone areas where development has already occurred and preventive measures for those areas that have not been developed.

Finally, perhaps the most important flood reduction measure is, as listed at the bottom of Figure 1, public education and information. Each citizen should realize that he bears the burden of flood damages in higher prices due to destroyed goods and lost services; and, through his taxes, the cost of relief services and payment to flood-stricken areas. In the end, the citizenry must realize that the one billion dollars of annual flood losses and the hundreds of millions spent on flood control are significant drains on the national economy. With this realization, the nation should be motivated to overcome increasing flood damages through a unified effort of private actions and governmental planning and regulation.

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The Floods of April

PART II

INTRODUCTION TO PART II

Record and near-record floods hit 15 southeastern Kentucky counties and nearby parts of Tennessee, Virginia and West Virginia, April 4-7, 1977, following a major storm. Damages to property were estimated at well over $100,000,000 in Kentucky and the lives of four Kentuckians were lost.

Kentucky counties affected sufficiently to be declared disaster counties are shown on the map, Figure 1.

Bell
Breathitt
Floyd
Harlan
Johnson
Knott
Knox
Lawrence
Leslie
Letcher
Magoffin
Martin
Perry
Pike
Whitley

No large Kentucky cities lay in the path of the storm. However, there were dozens of small cities and towns and densely populated rural areas that were severely damaged. Among the worst hit Kentucky communities were those listed below by river basins:

Big Sandy	Licking	Kentucky	Cumberland
Martin	Salyersville	Hazard	Cumberland
Paintsville		Neon-Fleming	Harlan
Pikeville			Middlesboro
Prestonsburg			Pineville
South Williamson			Williamsburg

Parts of this report emphasize five of the most severely damaged communities; Pikeville, Prestonsburg, Harlan, Pineville and Williamsburg and their drainage areas. This report examines the rainfall, the nature of the storm, factors that tended either to increase or to decrease the flooding effects of the storm, the extent of the flood and

Figure 1. Map showing the 15-county disaster area due the April 1977 flood.

damage it caused, and those structures and programs which tended to reduce flooding and flood damages.

Background information on other floods in the area, economic development in the area, floodplain conditions and soil disturbances will also be examined.

CHAPTER IV

RAINFALL AND THE APRIL 1977 FLOOD

This discussion of the impact of the rainfall for the 1977 flood includes the following topics:

1. The total amount of the rainfall.
2. The rainfall frequency.
3. The distribution of the rainfall over a watershed.
4. The intensity of the rainfall.
5. The direction and rate of movement of the storm.
6. Relative moisture content of the soil.

Total Rainfall

The total rainfall causing the April 1977 flood will be discussed in terms of the amount of rainfall and a comparison with the rainfall of other large floods. Table I shows the rainfall at selected stations in the Kentucky disaster counties for the 1977 and three other large floods experienced in this century.[1] The stations were selected on the basis of having records available for a sufficient length of time to include several large floods, especially in the worst hit counties of Bell, Floyd, Harlan, Knox, Martin, Pike, and Whitley. It will be seen that the rainfall causing the 1977 flood ranged from less than three inches at Paintsville, Salyersville, and Jackson to more than six inches at Harlan and Middlesboro and in the Upper Big Sandy Valley.

TABLE I

RAINFALL ACCOMPANYING SELECTED FLOODS IN INCHES[3]

STATION	1946 Jan. 7-8	1957 Jan. 28-30	1972 Feb. 24-26	1977 April 3-4
Elkhorn City		Missing	2.38	3.93
Pikeville	3.16	3.08+	2.59	4.18
Paintsville	2.40	2.30	4.37	2.99
Salyersville		2.38	3.78	2.78
Benham	3.64			
Cumberland		Missing	2.61	5.41
Baxter		4.85	2.58	7.27
Harlan		4.55		
Middlesboro	5.80	4.21	2.10	6.85
Pineville		5.10	2.53	5.23
Barbourville		5.99	2.52	4.31
Williamsburg			2.32	4.64
Whitesburg		3.77*		3.94
Hazard	4.4	4.27	1.71	3.75
Jackson	3.1	2.96	4.77	2.75

* Calculated.

From the hyetographs[2] (Figures 1 and 2) it will be seen that the highest rainfalls were recorded in the upper reaches of the Cumberland and Big Sandy and along the Pine and Black Mountains. The 6.85 inches of rainfall at Middlesboro and 7.27 inches at Harlan were among the highest reported in Kentucky. Readings of 6.96 inches at Putney, 7.31 inches at Closplint, and 8.79 inches at Martins Fork Dam were recorded.

Unofficial measurements were reported by the National Weather Service as 5.2 inches at Hindman, 5.5 at Pippa Passes, 5.39 near Fishtrap Dam, 5.0 at Martin, 4.0 at Ash Camp and 5.57 at Burdine.

The Big Sandy River drains a large portion of southern West Virginia and northwestern Virginia. Table II shows recordings from rain gages and buckets at relevant points in West Virginia. The high readings at Gary (5.31) and Welch (6.00) affected the degree of flooding on the Tug Fork of the Big Sandy. Extremely high reports included 15.5 inches atop a mountain separating the Tug Fork from the Levisa Fork of the Big Sandy. This rainfall would have contributed to the flooding of communities on the Tug Fork, such as South Williamson. However, it was of no consequence to the middle and lower portions of Levisa Fork because all the water in the drainage area above Fishtrap Dam was impounded and released after the floodwaters had subsided.[4] Similarly, rainfall which fell in the upper Russell Fork basin and drained into the Flanagan Reservoir in Virginia was retained.

These rainfalls were obviously large, but how do they compare to other floods? What is their calculated recurrence interval?

Three of the largest and most extensive among the memorably large floods of this century in eastern Kentucky are those of January 1946,

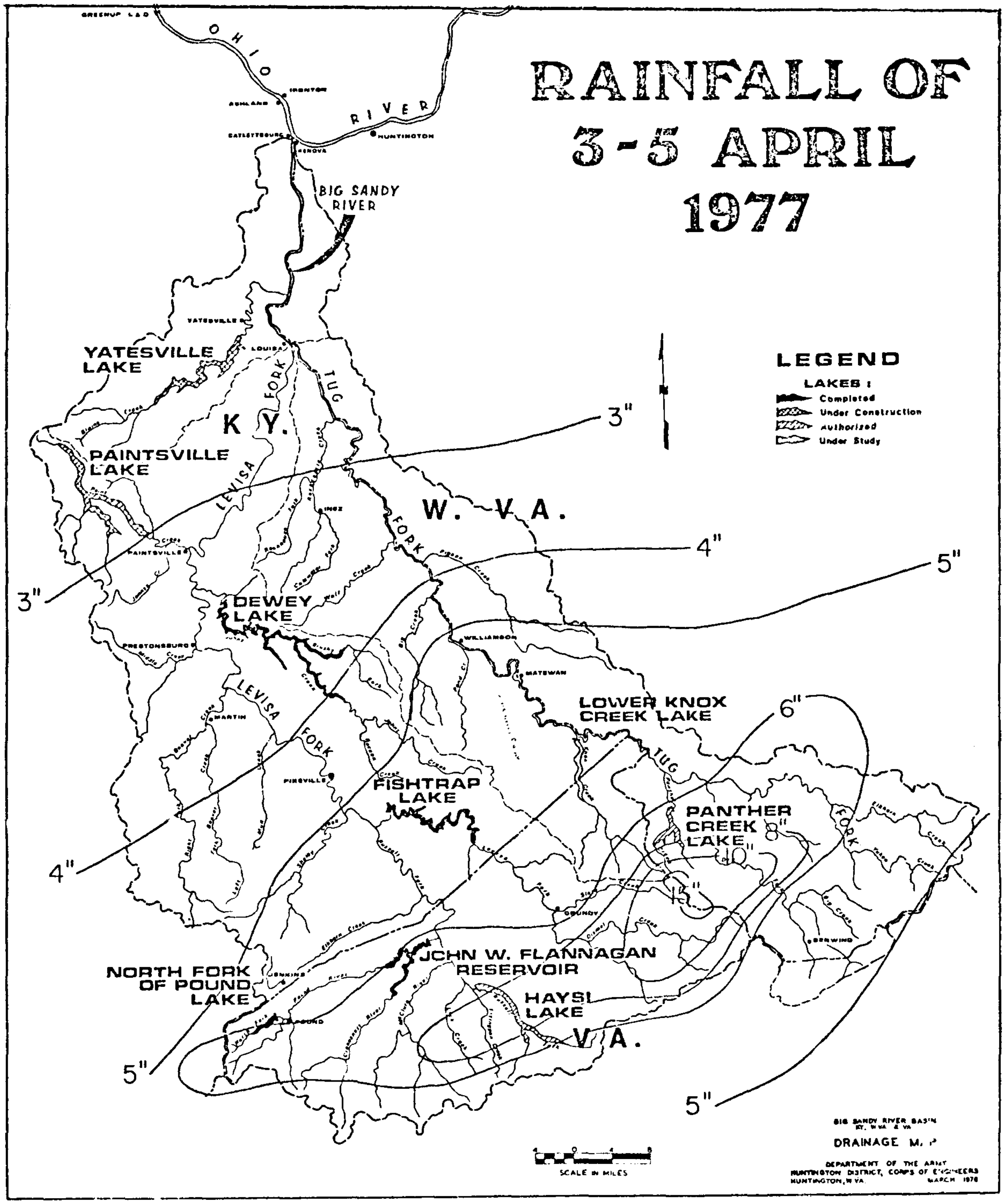


Figure 1. Hyetograph of April, 1977 flood. (Corps of Engineers)

FIGURE 2

HYETOGRAPH OF APRIL 3-4, 1977 STORM

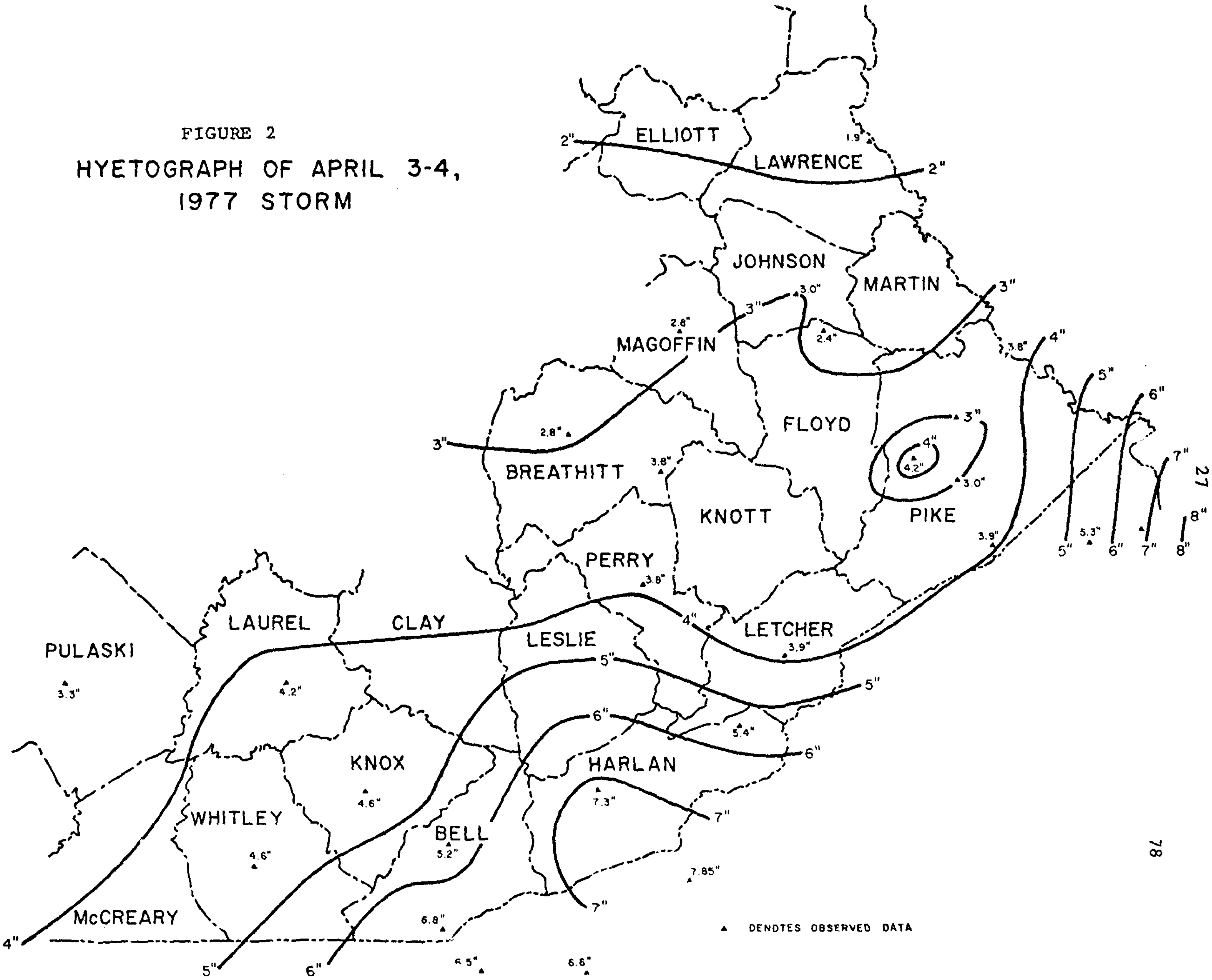


TABLE II

RAINFALL IN THE TUG FORK RIVER VALLEY, APRIL, 1977

STATION	PERIOD OF RAINFALL	24-HOURS ENDING APRIL 5th	TOTAL RAINFALL
Regular gages			
Gary	April 3-5	2.98	5.31
Welch	April 3-5	3.50	6.00
War	April 3-5	3.28	4.73
Williamson	April 4-5	2.64	3.85
Dingess	April 3-5	1.75	3.00
Kermit	April 3-5	1.28	2.45
Bucket Survey			
Rawl, Mingo Co.	5:30p 4/3 to 6:00P 4/4		4.50
Jolo, McDowell Co. El.	1320, 8P. 4/3 to early 4/5		6.00+
1.2 mi. from Jolo El.	1920, early 4/4 to early 4/5		5.50+
Bradshaw, 1.4 mi. SW of	Jolo Elev. 1280, April 3-7		5.35
Panther, McDowell Co.,	April 3-5		5.25
Panther St. Park,	early 4/3 to late 4/6		3.50+
Buchanan Co., Va., El.	2840 ft. 3.9 mi. SE of Jolo, 8p. 3/3 to early 4/5		8.00
Bandy, Va., Tazewell Co..	early 4/3 to late 4/6		5.25
Buchanan Co., 3.8 mi. SW Jolo, Elev. 2557, 9 a.m., 4/4 to early 4/5			6.50+
McDowell Co. 3.1 mi. SW Jolo, El. 2610, 8 p. 4/3 to early 4/5			10.00
2.5 mi. WNW of Jolo, El. 2080, 8 p. 4/3 to early 4/5			10.00
2.8 mi. SW of Jole, El. 2300, 8 p. 4/3 to early 4/5			15.50
1 mi. No. of Bradshaw,	April 1 to early 4/5		7.00+
Coretta, W. V., McDowell Co. El. 1500, 7 p. 4/3 to early 4/5			13.00
1.3 mi. ESE Coalwood, El. 1550, 6 p. 4/3 to 4/6			7.00 est
1.3 mi. ESE Coalwood, El. 1550, 8 p. 4/3 to 2 a.m., 4/5			6.80 o.f.
Jewel Ridge, McDowell Co., El. 2600, 8 p. 4/3 to late 4/5			6.80 o.f.

The plus marks indicate that the buckets overflowed.

January 1957, and February 1972. Tables I and III show that the rainfall causing the 1977 flood exceeded the highest among these three by the margins shown below:

Pikeville	0.98 inch
Whitesburg	0.17 inch
Cumberland-Benham	2.80 inches
Harlan-Baxter	2.42 inches
Pineville	0.13 inch
Middlesboro	1.05 inches.

The 1977 flood rainfall was less than the highest of the other three by 1.68 inches at Barbourville, 0.52 inch at Hazard and 2.02 inches at Jackson. The total direct rainfall for other large storms is shown for selected stations below and in Table I.

	Rainfall Inches
Middlesboro-Nov. 27-28, 1973, two days	8.39
Barbourville-Nov. 27-28, 1973, two days	4.65
Baxter-Nov. 27-28, 1973, two days	6.17

How often could rainfall equal to or greater than that of April 1977 be expected to occur? Although records of rainfall have been kept for less than 100 years at these stations, the National Weather Service has calculated that the 100-year recurrence interval rainfall for storms of 48 hours would be as follows for the counties listed below:[5]

Bell County	7.3 inches
Breathitt County	6.9 inches
Floyd County	6.7 inches
Harlan County	7.2 inches
Johnson County	6.7 inches
Knott County	6.9 inches
Knox County	7.3 inches
Lawrence County	6.5 inches
Leslie County	7.1 inches
Letcher County	6.9 inches
Magoffin County	6.8 inches
Martin County	6.6 inches
Perry County	7.0 inches
Pike County	6.7 inches
Whitley County	7.4 inches

TABLE III

CONTRIBUTING RAINFALL WITH FLOOD CRESTS AND PEAK DISCHARGES, SELECTED STORMS

STATION	1946			1957			1972			1977		
	Rainfall Inches	Flood Crest	Flood Discharge*	Rainfall Inches	Flood Crest	Flood Discharge	Rainfall Inches	Flood Crest	Flood Discharge	Rainfall Inches	Flood Crest	Flood Discharge
BARBOURVILLE				5.99	42.28	43,000	2.52	29.28	20,100	4.31	45.91	56,100
CUMBERLAND	3.64	9.65	7,500	4.41	11.50	11,800	2.61	10.52	3,240	5.41	15.88	10,700
ELKHORN CITY				?	24.21	51,200	2.38		7,320	3.93	24.80	58,000
HARLAN - BAXTER		22.81	37,900	4.55	19.89	31,000	2.58	11.36	12,200	7.27	30.26	64,500
HAZARD	4.40	26.55	36,000	4.27	37.54	47,800	1.71	21.55	23,000	3.75	32.25	39,500
JACKSON	3.10	38.8	41,800	2.96	40.41	53,500	4.77	31.56	31,000	2.75	35.80	39,000
MIDDLESBORO	5.20	20.92	6,160	4.21	15.31	3,980	2.10	8.66	1,890	6.85	23.35	11,700
PAINTSVILLE	2.40	41.06	58,300	2.30	45.92	69,700	4.37	37.26	38,500	2.99	42.18	43,000
PIKEVILLE	3.16	42.9	50,300	3.08	52.72	85,500	2.59	30.13	22,400	4.18	51.5	81,600
PINEVILLE		49.31	57,900	5.10	47.35	54,900	2.53	32.03	19,700	5.23	54.86	80,500
SALYERSVILLE		20.60	5,600	2.38	20.79	5,880	3.78	20.82	5,930	2.78	20.9	4,980
WHITESBURG				3.77	14.70	7,730				3.94	11.01	4,610
WILLIAMSBURG	4.73			2.95	33.78	49,700	2.32	21.33	22,000	4.64	35.03	46,600
*Discharge - cfs												

The rainfall which produced the 1977 flood surpassed the 48-hour, 100 year recurrence storm only at Harlan and Middlesboro in Kentucky. It surpassed 10-year expectancies at Cumberland and Pineville.

It should be noted, as shown in Figure 3, that the 24-hour period of maximum rainfall at Middlesboro in April 1977 amounted to 6.00 inches. This compares with a 100-year maximum expectancy for a 24-hour period of 6.3 inches, see Table IV.

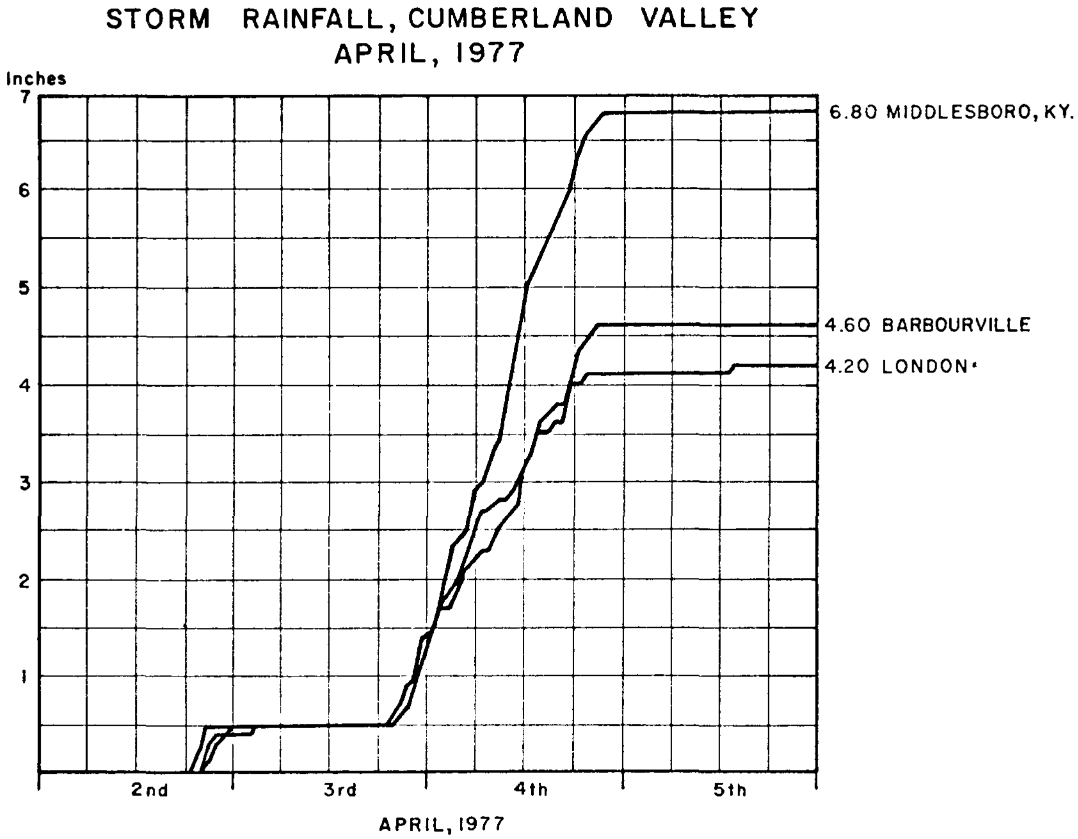
Distribution

The hyetographs (Figures 1 and 2) show that the heaviest rainfall of the April 1977 storm fell along a southwest to northeast axis from north central Tennessee, near Whitley County, Kentucky, northeast along the Kentucky border through northwest Virginia and southern West Virginia with bulges northwesterly into Harlan, Leslie and eastern Pike counties, Kentucky. The total rainfall decreased by approximately half as it reached a line running from Pulaski County northeast through Breathitt, Magoffin, Johnson and Martin Counties.

The storm was heaviest in two locations; one slightly southeast of Pike County and the other just south of Harlan County. Bell and Harlan counties received the heaviest rainfall in Kentucky. However, the rainfall was much heavier in the Big Sandy headwaters in Virginia and West Virginia which drain through Kentucky.

Intensity

The rate of rainfall is an important aspect with regard to the flood-producing potential of a storm. Since the infiltration rate for most



Twenty-four hour maximum rate of rainfall:

Middlesboro - 6.0"
Barbourville - 4.1"
London - 3.5"

Figure 3. Instantaneous records of April, 1977 rainfall at Middlesboro, Barbourville, and London.

TABLE IV

RAINFALL FREQUENCY EXPECTATIONS

COMPILED BY DOWR FROM DATA SUPPLIED BY U. S. WEATHER SERVICE

24-HOUR RAINFALL IN INCHES

COUNTY	FREQUENCY, YEARS						
	1	2	5	10	25	50	100
BELL	2.6	3.1	3.9	4.5	5.2	5.8	6.3
BREATHITT	2.6	3.0	3.7	4.3	4.9	5.4	5.9
FLOYD	2.5	2.9	3.7	4.2	4.8	5.3	5.7
HARLAN	2.6	3.0	3.8	4.4	5.1	5.7	6.1
JOHNSON	2.5	2.8	3.6	4.1	4.7	5.2	5.7
KNOTT	2.5	2.9	3.7	4.3	4.9	5.5	5.9
KNOX	2.6	3.1	3.9	4.5	5.2	5.8	6.3
LAWRENCE	2.5	2.8	3.6	4.0	4.7	5.1	5.6
LESLIE	2.6	3.0	3.8	4.4	5.0	5.6	6.1
LETCHER	2.5	2.9	3.7	4.3	4.9	5.6	5.9
MAGOFFIN	2.5	2.9	3.7	4.2	4.8	5.3	5.8
MARTIN	2.5	2.8	3.6	4.1	4.7	5.2	5.6
PERRY	2.5	3.0	3.8	4.3	5.0	5.5	6.0
PIKE	2.7	2.9	3.6	4.2	4.8	5.4	5.7
WHITLEY	2.7	3.2	4.0	4.5	5.3	5.9	6.4

soils is relatively small, usually only a fraction of an inch per hour, rainfall of medium to high rates will easily exceed the soil's infiltration capacity, and all of the excess will become runoff.

The rates of rainfall at London, Barbourville and Middlesboro for the 1977 flood can be seen in Figure 3. Greater steepness of the curve means a higher rate of rainfall. The rates were about the same at all three sites from 8:00 p.m., April 3, until 2:00 a.m., April 4. From that time until 7:00 p.m., April 4, the rate of rainfall at Middlesboro averaged much higher than at the other two places. In the four-hour period from 9:00 a.m., until 1:00 p.m., April 4, 1.65 inches of rain fell at Middlesboro. Although this rainfall alone would not be significant, the steady and relatively high rate for the preceding 16 hours and the succeeding nine hours resulted in a 50-year, two-day expectancy rainfall of 6.0 inches.

Rainfall amounts for periods less than 24 hours were not available for other locations within the storm limits. Rainfall for 24-hour periods ending at 7:00 a.m., April 3, 4, and 5 are shown below for some selected stations:

TABLE V

(Rainfall, 24 hrs., ending 7:00 a.m.)

STATION	COUNTY	April 3	April 4	April 5
Elkhorn City	Pike	0.60	1.60	2.33
Paintsville	Johnson	0.40	0.60	2.39
Burdine	Letcher	0.87	1.90	2.50
Whitesburg	Letcher	0.44	1.74	2.20
Jackson	Breathitt	0.68	1.00	1.75
Cumberland	Harlan	0.78	2.02	3.39
Baxter	Harlan	0.49	2.96	3.82
Pineville	Bell	0.46	2.79	2.44
Gary, W. Va.		0.75	1.75	3.50
Williamson, W. Va.		0.00	1.21	2.64+

Figure 3 shows that the storm was more concentrated in time than would be apparent from considering Table 5. Figure 3 also shows that in the London to Middlesboro area the rain reported in the data above for April 3 occurred the evening of April 2 ending at 3:00 a.m, April 3. At 7:00 p.m., April 3, a high intensity rainfall began at London and lasted until 8:00 p.m., April 4. The U. S. Weather Service at Charleston reported that a similar pattern was true for the upper Big Sandy.

Movement of the Storm

It has already been noted that the storm moved in a northeasterly direction. Since all the major Kentucky streams affected flow westerly, some northwest and some southwest, this meant that the storm movement was generally upstream for the major streams. From Figure 3 it can be noted that the cessation of the rainfall occurred on April 4 at about 8:00 p.m. at London, 9:00 p.m. at Barbourville and 10:00 p.m. at Middlesboro. This is a progress eastward of about 10 miles per hour.

This movement is substantiated somewhat by the fact that a larger percentage of the rainfall fell during the 24 hours ending at 7:00 a.m., April 5 at Gary and Williamson than was true in the upper Kentucky and upper Cumberland river basins.

The upstream movement of the storm, least evident in the Big Sandy, tended to lower its flooding effects because it gave the water that fell downstream some time to move out ahead of the runoff of rain that fell upstream. There were exceptions to the streamflow directions, such as Yellow Creek at Middlesboro, Upper Martins Fork in Harlan County, Elkhorn Creek in Pike County and upper Russell Fork in Virginia. In these cases, the influence of downstream storm movement tended to maximize flood heights.

The Effects of Soil Moisture

Soils in their natural state may absorb substantial rainfall. The capacity of a given soil to absorb rainfall is determined, in part, by the extent to which it is already saturated, which in turn is affected by previous rainfall and by air temperature. No measurements of the soil moisture were available for the time of the April 1977 flood. However, some observations may help evaluate the conditions.

The area had just passed through a record long period of snow coverage and melt. Precipitation was deficient by about one inch for the month of March and nearly five inches for the year. The soil had only recently thawed from a freeze of record depths, up to 3 feet or more.

Temperatures in the area averaged about 3.5 degrees above normal for March.[6] This tended to increase evaporation, but the average temperature of about 49 degrees was too low to deplete soil moisture significantly by evaporation.

Table VI shows that there had been a total of from 0.3 to 0.7 inch of rainfall at most stations March 30 and 31. Elkhorn City, Cumberland, Baxter and Salyersville reported 0.45 to 0.78 inch of rain April 2. Table VI provides the antecedent rainfall for this and similar floods.

It is probable, therefore, that much of the moisture-holding capacity of the soils was filled as of April 3. However, the available capacity probably exceeded that of the storms producing the February 1972 flood or the January 1957 flood (Table VI) because of lower antecedent soil moisture and higher temperatures in 1977.

TABLE VI
RAINFALL PRECEDING & DURING 1957, 1972 & 1977 E. KY. FLOODS

YEAR 1957 MONTH Jan. - Feb.

DAY OF MONTH

STATION	19	20	21	22	23	24	25	26	27	28	29	30	31	F 1	E 2	B. 3
BS ALLEN			.15		1.17				.27	.63	2.17	1.05			1.06	
BLAINE			.30	.32	.94		.03			.78	1.01		.18	.82		
DEWEY DAM	T		.12		1.16	T	.03	.04	.15	.59	1.21	.80	.12	.40	.51	
ELKHORN CITY	Record Missing															
FREEBURN	T		.13	.04	.87	.04		.02	.20	.67	1.29	.04	.16	.63	.49	
INEZ			.10	.10	1.12				.27	.90	1.30		.35			
LOUISA	T		.08		1.15		T	T	T	.43	.83	.41	.09	.30	.60	T
PAINTSVILLE	T		.12		1.13	T			.15	.60	1.10	.60	.36	.36	.50	T
PIKEVILLE		T	.16	.17	.79		T	.04	.45	1.04	2.04	-	-			T
CU. BARBOURVILLE			.30	.40	.74		.02		.50	1.05	3.60	1.34	.55	.98		.10
BAXTER			.35		.55		.05	.02	.30	.85	2.77	.93	.30	.80	.55	T
BENHAM			.13		.74			T		1.10	2.30	1.01	.35	.65	.68	.02
CUMBERLAND																
CU. FALLS		.50			.50					2.50	5.76		.30	.96		.02
LONDON		.23	.04	2.12	.02		.04		.80	1.51	2.48	.03	.38	.82		.06
MIDDLESBORO	T		.47	.01	1.01		.07	.02	.29	1.30	2.08	.83	.65	.85	.62	.05
PINEVILLE	T		.21	T	.60	T	.03	.02	.42	.77	2.97	1.36	.51	.69	.69	T
WILLIAMSBURG			.25	.40	.50		.04		.66	2.85	.05	.05	1.10		1.67	.02
KY. BUCKHORN																
BURDINE			.15	.15	.80					1.00	2.47	.30	.25	.60		
HAZARD			.22	T	1.32				.30	.92	2.10	1.25	.25	.01	.84	.05
HINDMAN		.08	.12	1.02	.41		.08		1.02	.73	1.65	.60	.26	.68	.57	.07
HYDEN			.47		1.55						4.80		T	1.14		.13
JACKSON		.11	,07	.30	1.40	T	T	.05	.21	1.20	1.76		.20	.87		.09
JEREMIAH			.16		1.18				.44	.74	5.20			.88		
LI. SALYERSVILLE			.16		1.19				.12	.68	1.70		.30	.90		.02

TABLE VI (cont'd.)

YEAR 1972 MONTH February

DAY OF MONTH

STATION	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
BS Allen	1.13	.08	T	-	.42	.34	.10	-	-	T	-	1.80	1.09	1.81	
Blaine	1.43	.09	-	-	.25	.34	-	.10	-	.10	-	.96	.58	1.89	
Elkhorn City	.90	.14		.01	.43	.02	.22	.02		.15		1.35	1.08	.95	.17
Fishtrap Res.	.95	.20		.01	.24	.11	.25	.10		.07		1.33	1.22	.97	.20
Freeburn	.68	.36		.06	.06	.23	.36	.12				1.52	1.13	1.66	.11
Paintsville	1.45				.40	.12	.14					2.00	.75	1.62	.10
Pikeville	T		T		.26		.30			.06	.24	.67	.22	1.70	
Tomahawk	1.10	.10			.86	T	.13	.19				1.33	.76	1.59	
CU. Barbourville	1.16	.06	.03	T	.35	.15	.35	.02	-	.30	-	.80	1.29	.43	.03
Baxter	1.12	.09	-	T	.28	.10	.43	.06	-	.30	-	.62	1.23	.73	.17
Cumberland	.05	.07	-	T	.25	.18	.10	T	T	.29	.21	1.15	.76	.70	
Cumb. Falls	.44				.21	.25	.11			.43	.47	1.13	.45		
London	.15		T	T	.29	.45	.09	T		.19	.26	1.63	.01	.34	
Middlesboro	.96	.03			.41	.11	.32	T		.46		.65	.74	.71	.01
Pineville	1.10	.08		.03	.44	.19	.07	.28		.51		1.00	.71	.82	.03
Williamsburg	1.04	.08			.17	.10	.14	.03		.17		.70	1.00	.62	
Ky. Buckhorn	1.06	.11	T	T	.50	.23	.19	T		.11	-	1.31	.94	.97	T
Burdine	1.15	.05	-	-	.40		.40	.25		.35		1.10	.92	1.00	.15
Hazard	1.08	.11			.39	.10	.31		.35			1.05	1.29	.96	.04
Hindman	.22				.10		.21					1.85	.43	1.38	
Hyden	1.12	.08		.03	.04	.09	.22	.02		.19		1.00	1.31	.79	.02
Jackson	1.17	.12			.52	.12	.16	.04		.10		2.14	.90	1.73	
Jeremiah	.86		.06		.29	.20	.10			.18	.18	1.42	.42	1.00	
Li. Salyersville	1.41	.05			.46	.05	.12	.10		.06		1.53	.71	1.54	.04

TABLE VI (cont'd.)

YEAR 1977 **MONTH** March, April

DAY OF MONTH

STATION	25	26	27	28	29	30	31	1	2	3	4	72 Hours
BS Elkhorn City					T	.23	.11		.60	1.60	2.33	4.53
Fishtrap											3.00	
Pikeville						No Report				1.92	2.26	4.18
Paintsville				T						.60	2.39	2.99
Grundy, Va.						.13	.12			1.80	3.48	5.28
Dewey										.85	1.54	2.39
CU. Cumberland						.26	.22		.78	2.02	3.39	5.41
Baxter					T	.33	.31		.49	2.96	3.82	7.27
Harlan												
Martin's Fork					No Report							
Pineville						.30	.27			2.79	2.44	5.23
Middlesboro						.07	.35			2.60	4.25	6.85 7.85 Bucket
Barbourville						.10	T			2.31	2.00	4.31
Williamsburg						.08	.31			2.62	2.02	4.64
KY. Burdine												5.57 Bucket
Hazard							.70			1.80	1.95	3.75
Hindman												
Hyden							.06	.15		2.05		
Buckhorn					No Report					1.35	1.95	3.30
Jackson					No Report					1.00	1.75	2.75
Whitesburg					No Report					1.74	2.20	3.94
Li. Salyersville									.45	.79	1.54	2.78

Summary - Rainfall and the April 1977 Flood

The storm on the third and fourth of April 1977 drenched eastern Kentucky with rainfall amounts ranging from two inches (2") in Elliott and Martin Counties to more than seven inches (7") in Harlan County over a period of about twenty-nine (29) hours. Rainfall in some areas bordering Kentucky, including some that contributed to floods within the state, was even higher than this.

According to U. S. Weather Service information, the rainfall contributing to the April 1977 flood exceeded that for all previous large floods at Baxter, Pikeville, and Pineville. It was less than record amounts by 1.68 inches (1957) at Barbourville, 1.54 inches (1973) at Middlesboro, and 0.52 inches (1957) at Hazard.

The recurrence intervals of the rainfall in most of the disaster area were small. Only at Harlan and Middlesboro did they reach 100-year recurrence levels. However, it is not the amount of rainfall at the location of the flood that is important, it is the rainfall in the watershed above the location that determines the degree of flooding. For the April 1977 flood, rainfall was the highest in the upper reaches of the affected watersheds.

Storm movement and antecedent soil moisture may have affected run-off from the rainfall but there is no way to determine any such effects.

REFERENCES

1. Rainfall data for the 1977 flood was obtained from offices of the U. S. Weather Service in Louisville and Charleston.

2. One of the hyetographs, Figure 1, was prepared by the Corps of Engineers, Huntington District. The other, Figure 2, was prepared by the Division of Water Resources.

REFERENCES (cont'd)

3. Rainfall data for storms other than that of April 1977 were obtained from climatological data reports for the relevant months.

4. Information on the operation and performance of dams was supplied by the Ohio River Division of the U. S. Army Corps of Engineers, Cincinnati, Ohio.

5. Rainfall frequency tables prepared by the Division of Water Resources from data provided by the U. S. Weather Service.

6. Climatological Data, Kentucky, March 1977, Volume 72, Number 3, Environmental Data Service, National Oceanic and Atmospheric Administration, National Climatic Center, Asheville, N.C.

CHAPTER V

EXTENT AND DAMAGES

The 1977 flood in Eastern Kentucky was by all accounts a large one. The question of <u>how large</u> poses in turn further questions: What were the crest stages of the flood? What were the flows in the streams? How does this flood compare with other large floods?

The crest stages at selected points are shown in Table I for the 1977 and three other large floods (January 1946, January 1957, and February 1972). The degree of severity was not uniform throughout the 15-county area due to variations in the rainfall amount and runoff factors, as well as the operation of flood-control structures.

Streamflow records are incomplete in most of the worst flood areas because the stream gages were overtopped by the floodwaters in some cases, and in others the electricity that operated the gage recorders was off. At these locations, the maximum elevation was measured by hand, and the approximate peak flows then calculated. A comparison of information shows that the height of the 1977 flood exceeded the highest of the other three floods listed above at Elkhorn City, Salyersville, Harlan, Pineville, Middlesboro, Barbourville, and Williamsburg. The amount by which previous records were exceeded at Harlan and Pineville was substantial.[1]

The volume of water passing a point on a stream in a specified unit of time is the stream discharge, or flow rate. The peak discharges of the relevant streams at major towns are shown in cubic feet per second (cfs) in Table II for the 1977 and the other three major floods. The

TABLE I

CONTRIBUTING RAINFALL WITH FLOOD CRESTS AND PEAK DISCHARGES, SELECTED STORMS

	1946			1957			1972			1977		
	Rainfall	Flood		Rainfall	Flood		Rainfall	Flood		Rainfall	Flood	
STATION	Inches	Crest	Discharge*	Inches	Crest	Discharge	Inches	Crest	Discharge	Inches	Crest	Discharge
BARBOURVILLE				5.99	42.28	43,000	2.52	29.28	20,100	4.31	45.91	56,100
CUMBERLAND	3.64	9.65	7,500	4.41	11.50	11,800	2.61	10.52	3,240	5.41	15.88	10,700
ELKHORN CITY				?	24.21	51,200	2.38		7,320	3.93	24.80	58,000
HARLAN - BAXTER		22.81	37,900	4.55	19.89	31,000	2.58	11.36	12,200	7.27	30.26	64,500
HAZARD	4.40	26.55	36,000	4.27	37.54	47,800	1.71	21.55	23,000	3.75	32.25	39,500
JACKSON	3.10	38.8	41,800	2.96	40.41	53,500	4.77	31.56	31,000	2.75	35.80	39,000
MIDDLESBORO	5.20	20.92	6,160	4.21	15.31	3,980	2.10	8.66	1,890	6.85	23.35	11,700
PAINTSVILLE	2.40	41.06	58,300	2.30	45.92	69,700	4.37	37.26	38,500	2.99	42.18	43,000
PIKEVILLE	3.16	42.9	50,300	3.08	52.72	85,500	2.59	30.13	22,400	4.18	51.5	81,600
PINEVILLE		49.31	57,900	5.10	47.35	54,900	2.53	32.03	19,700	5.23	54.86	80,500
SALYERSVILLE		20.60	5,600	2.38	20.79	5,880	3.78	20.82	5,930	2.78	20.9	4,980
WHITESBURG				3.77	14.70	7,730				3.94	11.01	4,610
WILLIAMSBURG	4.73			2.95	33.78	49,700	2.32	21.33	22,000	4.64	35.03	46,600
*Discharge - cfs												

TABLE II.

	Flood Years	Gage Height (ft.)	Discharge cfs	Recurrance Interval
Elkhorn City	1957	24.21	51,200	
(Russell Fork)	1977 4/4	24.80	54,200	
Pikeville	1957	52.72	85,500	
(Levisa Fork)	1977 4/5	51.46	81,600	200
Prestonsburg	1862	49.4		
(Levisa Fork)	1957	48.78	69,700	
	1977 4/5	45.71	45,500	100
Paintsville	1862	46.6		
(Levisa Fork)	1957	45.92	69,700	
	1977 4/6	42.19	43,600	80+
Salyersville	1939	25.4	14,300	
(Licking River)	1977 4/5	20.90	4,980	
Whitesburg	1957	14.7	7,730	
(N. Fk. Ky. R.)	1977 4/4	11.01	4,610	11
Hazard	1957	37.54	47,800	
(N. Fk. Ky. R.)	1977 4/4	32.25	39,500	30
Cumberland	1957	16.50	11,800	
(Poor Fork)	1977 4/4	15.88	10,700	23
Harlan (near)	1969	24.90	43,200	
(Cumberland River)	1977 4/5	30.26	64,500	100+
Middlesboro	1973	20.24	9,980	
(Yellow Creek)	1977 4/4	23.35	11,700	85
Pineville	1946	49.31	57,900	
(Cumberland River)	1969	49.77	56,200	
	1977 4/5	54.86	80,500	125-150
Barbourville	1946	42.8		
	1973	42.65	49,500	
	1977	45.91	56,100	100+
Williamsburg	1957	33.78	49,700	
	1975	34.54	45,600	
	1977 4/7	35.03	40,600	50-75

1977 flood was a 100-year flood at Prestonsburg, Harlan and Pineville and a 200-year flood at Pikeville. The flood at Pikeville, although less than the 1957 flood, reached its peak with the protection of dams that were not in service in 1957. Therefore, its recurrence interval under present conditions is much larger than under 1957 conditions.

The relationship of the 1977 flood to the 1946, 1957, and 1972 floods is shown in graphic form in Figure 1 for four cities. It should again be noted that the height of floods is not a direct relationship to rainfall in a drainage area.

The rise and peaks of the 1977 flood on Tug Fork are shown in Figure 2. The figure indicates the very rapid rise of the flooded stream. Table III shows the rises at Harlan, Pikeville, and Williamsburg.

The heights of the 1977 flood in relation to flood stage and bankful stage are shown for selected towns in Table IV, along with the drainage area above the towns.

The Corps of Engineers has prepared estimates of damages in various communities from past intensive evaluations of flood damages and assessments of developments in the floodplains. Certain smaller communities are not included, nor are rural areas.

Corps estimates include the following for Kentucky:[2]

Big Sandy:		
Tug Fork	$10,300,000	(The authors estimate that Kentucky suffered 20 percent of the $51,600,000 COE estimate for Tug Fork)
Levisa Fork	$63,600,000	
Licking:		
Salyersville	No estimate	

DRAINAGE AREA RAINFALL & STREAM DISCHARGES for SELECTED STORMS

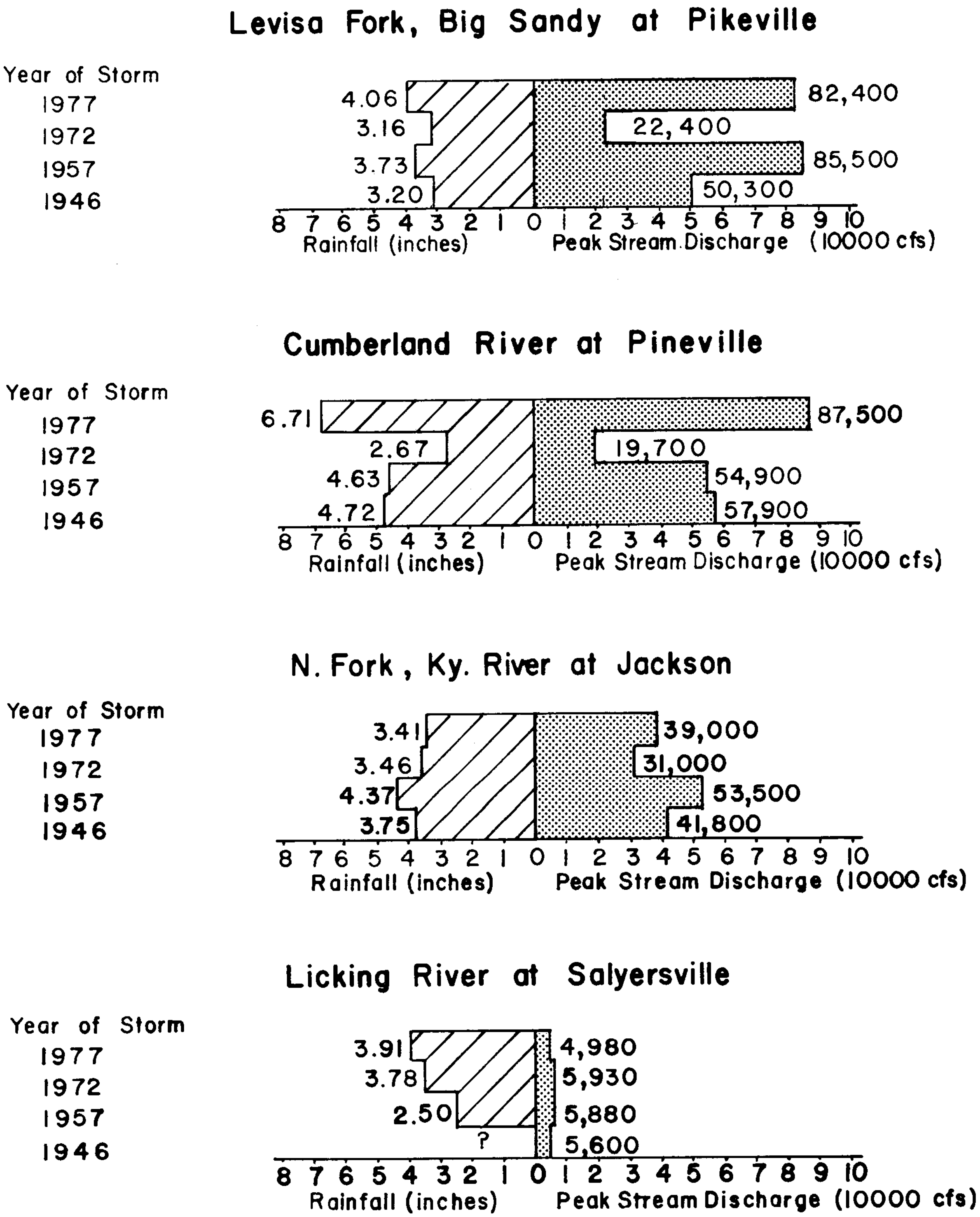


Figure 1. Comparison of floods for four cities in eastern Kentucky.

FIGURE 2

FLOOD ELEVATIONS ON TUG FORK, APRIL 1977

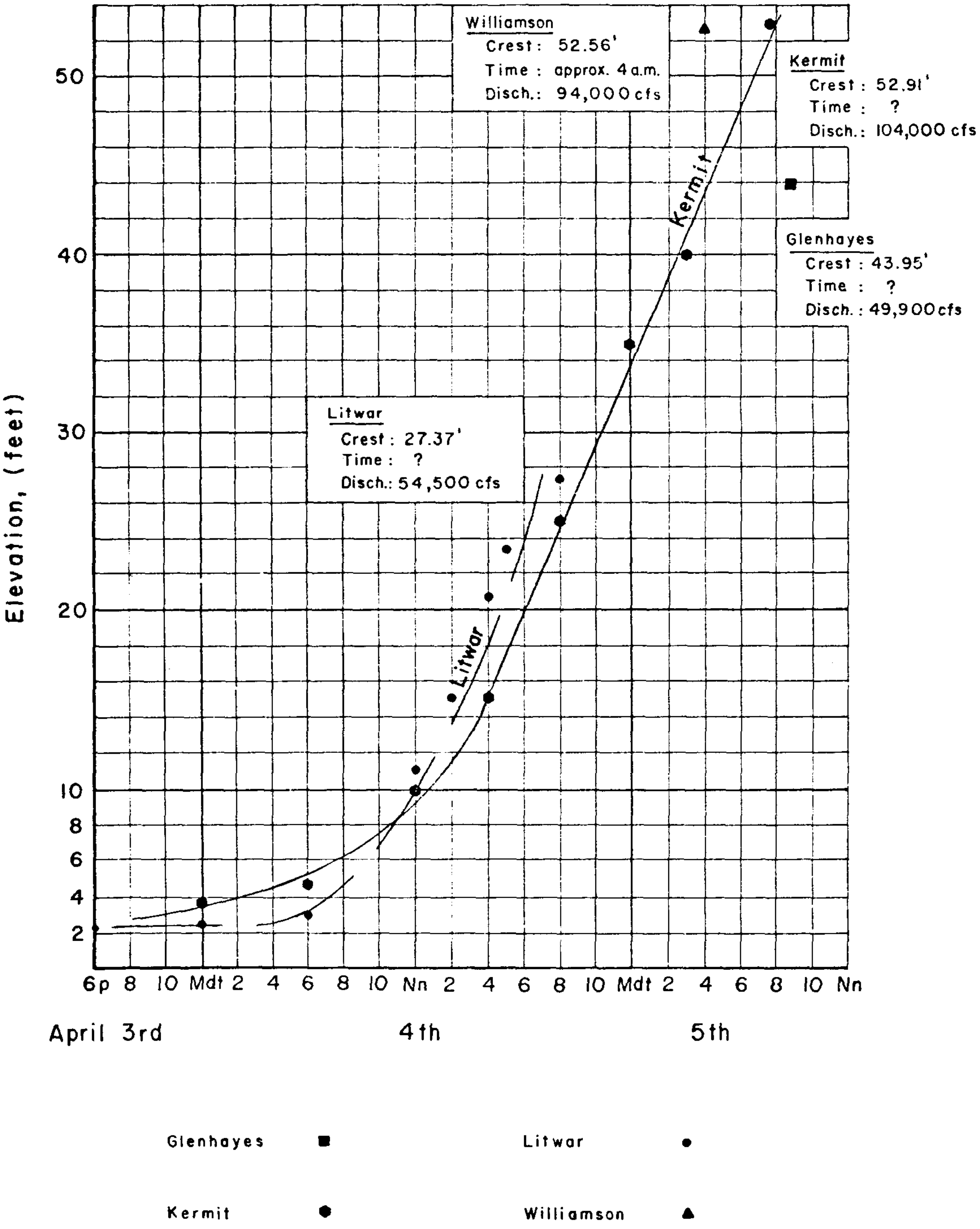


TABLE IIIa

April, 1977, Flood Gage and Discharge Records, Harlan

Date and Hour	Gage	Discharge, cfs
April 4, 2:00 A.M.	3.37	1,640
4:00	5.79	4,240
6:00	10.74	11,100
8:00	14.52	17,700
10:00	19.00	26,600
Noon	22.10	33,300
2:00 P.M.	24.53	39,100
4:00	26.31	43,800
6:00	28.03	48,700
8:00 Inst. Flooded		50,800
April 5, 1:30 A.M. (Crested)	30.26	64,500

TABLE IIIb

April, 1977 Flood Gage and Discharge Records, Pikeville

Date and Hour	Gage	Discharge, cfs
April 3, 12:00 Midn.	5.63	1,680
April 4, 2:00 A.M.	6.09	1,920
4:00	7.18	2,610
6:00	9.18	4,040
8:00	12.40	6,750
10:00	16.33	10,000
Noon	20.08	13,700
2:00 P.M.	24.30	19,000
4:00	29.38	27,600
6:00	34.22	37,100(36.0 ft. = flood stage
8:00	39.28	48,500
10:00	43.97	60,400
12:00 Midn.	47.45	69,900
April 5, 2:00 A.M.	49.93	77,000
4:00	51.14	80,700
6:00	51.46	81,600
7:30 CREST	51.70	81,600
8:00	50.99	80,200
Noon	49.02	74,300
6:00 P.M.	44.01	60,400

TABLE IIIc.

April, 1977 Flood Gage and Discharge Records, Williamsburg

Date and Hour		Gage	Discharge, cfs
April 3,	2:00 A.M.	6.26	2,400
	12:00 Midn.	7.98	3,950
April 4,	2:00 A.M.	8.75	4,690
	4:00	10.24	6,260
	6:00	12.67	9,090
	8:00	14.68	11,600
	10:00	16.26	13,800
	Noon	17.83	16,000
	2:00 P.M.	19.68	18,800 (21.0 ft.=flood stage)
	4:00	21.32	21,400
	6:00	22.92	24,000
	8:00	24.47	26,600
	10:00	25.69	28,800
	12:00 Midn.	26.63	30,400
April 5,	2:00 A.M.	27.31	31,600
	4:00	27.93	32,700
	6:00	28.51	33,800
	8:00	29.07	34,800
	10:00	29.61	35,800
	Noon	30.06	36,600
	2:00 P.M.	30.49	37,500
	6:00	31.13	38,700
	12:00 Midn.	31.68	39,800
April 6,	6:00 A.M.	31.97	40,400
April 7,	10:00 A.M. CREST	35.03	46,600

TABLE IV

SELECTED FLOOD DATA, CERTAIN E. KY. POINTS

STATION	DRAINAGE AREA	FLOOD STAGE	U.S.G.S. BACKFULL	1977 FLOOD CREST
ELKHORN CITY	554 SM	12.5		24.84
PIKEVILLE	1,237	36.0	40.0	51.70
PAINTSVILLE	2,143	35.0	40.0	42.18
LOUISA	3,892	45.0		49.80
CUMBERLAND	82.3		7.0	15.88
HARLAN	374	16.0		30.44
PINEVILLE	809	998MSL.(FW 1019.6")	40.0	49.39(1021.8)
BARBOURVILLE	960	27.0	33.0	45.91
WILLIAMSBURG	1,607	21.0		35.03
WHITESBURG		10.0		11.0
HAZARD	466	20.0	20.0	32.00
TALLEGA	537	23.0		22.3
JACKSON	1,101	29.0		35.80
LITWAR, W. VA.	502			27.4
KERMIT, W. VA.	1,240	38.0		49.8
WILLIAMSON, W. VA.		27.0		52.3
SALYERSVILLE	140			20.9

TABLE V

County	Houses Damaged	
	Major	Minor
Bell	480	393
Breathitt	21	31
Floyd	695	463
Harlan	1,014	829
Johnson	37	167
Knott	0	0
Knox	20	92
Lawrence	3	1
Leslie	1	5
Letcher	3	19
Magoffin	1	3
Martin	390	111
Perry	121	261
Pike-Levisa Fk.	1,004	857
Tug Fork	1,579	540
Whitley	10	103
	5,379	3,875

Kentucky:	
Upper reaches	No estimate
Jackson and Hazard	$ 6,600,000
Locks 4 to 14	$ 50,000
Cumberland:	
Cumberland	$ 120,000
Harlan	$ 6,100,000
Pineville	$ 5,900,000
Barbourville	$ 800,000
Williamsburg	$ 800,000
Middlesboro	$ 500,000
TOTAL:	$94,770,000

Estimates made in the process of seeking federal disaster relief exceeded $175 million.

From a car window survey the week after the flood, Department of Housing and Urban Development officials identified houses suffering major and minor damages as shown in Table V.[3]

An idea of the extent of damages can be obtained from some of the available relief statistics. Five thousand two hundred and ninety-six families were assisted with housing by HUD, and over 40 million dollars was provided by public and private agencies to help relieve the financial losses sustained throughout the 15-county area.

REFERENCES:

1. Flood crest and discharge data were provided by the U. S. Geological Survey at Louisville and Charleston and the Corps of Engineers at Louisville, Charleston and Nashville.

2. Minutes of the Reservoir Operations Coordinating Group, Ohio River Division, U. S. Corps, July 27-28, 1977.

3. Data provided via telephone from Disaster Relief Office at London.

CHAPTER VI

LAND-USE FACTORS AFFECTING 1977 FLOOD HEIGHT AND DAMAGES

Introduction

There are basically two elements in the process by which floods occur: water and land. Man has no control over the water, when it rains and when it doesn't. On the other hand, man's activities can change the land immensely, and to a large extent these activities change the manner and extent of flood occurrences.

It is possible with current technology to measure the amount of rainfall over any given watershed from any storm and to measure the runoff in the stream resulting from that rainfall. From many years of such measurements, it can be determined what effects land usuage has on runoff from the watershed. However, the rainfall and stream gages which are required for these measurements are expensive to purchase and maintain, and the calculations required to evaluate the interrelationships between rainfall and runoff are complex. For these reasons, most existing studies on the effects of land uses on runoff have been conducted on small watersheds where few gages are required and calculations can be handled by a few personnel. No thorough investigations have been made that would give any insight as to what effects land uses (such as mining, urban development, and roadway construction) might have had on a flood as extensive as that of April 1977.

Therefore, the following section of this report will give information on those studies which have been made. Realizing that no analytical determination of the specific effects of changes in land usage can be obtained from such generalized information, no attempt is made to quantify these effects either separately or in the aggregate.

Surface Mining

Intrinsically, surface mining in no more damaging to the hydrology of a watershed than any other large-scale excavation, say subdivision construction. The problem arises from the fact that surface mining often occurs in areas where the steep slopes and surrounding forests accentuate the changes that result from the mining process. Stated concisely, the mountainous areas of eastern Kentucky are not well suited to surface mining. Therefore, to ensure that a surface-mining operation does not create devastating environmental degradation, the operator must take great care in the excavation and spoil-handling processes and begin a well-planned reclamation effort as soon as possible. Even then, there is a significant hydrologic effect on a mined watershed during the active mining period. These effects are described in general terms in the following sections.

Changes in spoil handling. During the late 1950's and throughout the 1960's, the public became greatly concerned over pollution and environmental degradation. Strip mining with its readily observable environmental damages was, then, a prime target for environmental reform.

Subsequently, changes have been made in regulations for mining on sloping land that significantly affect runoff and erosion. These are illustrated in Figure 1. The first example shows the bench left bare as in the 1950's. Such a bench would allow almost 100 percent runoff and a heavy rate of erosion. On the other hand, spoil was often left in such position that water ponded on the bench could delay runoff and help maintain stream flow later by seepage. However, water from these

TYPICAL SURFACE MINING CROSS SECTIONS

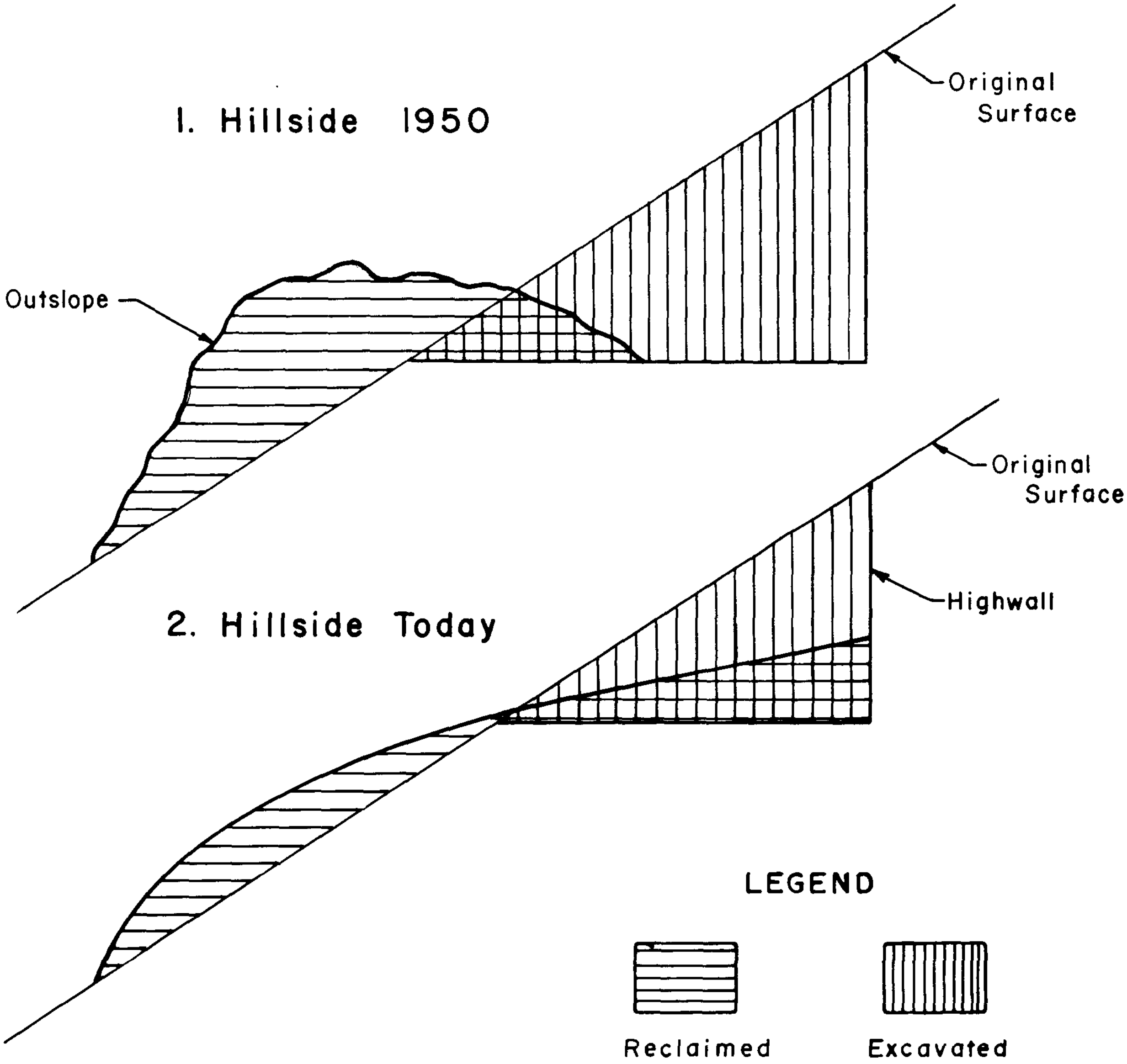


Figure 1. A comparison of previous and current surface-mining processes.

ponds often saturated the spoil in time, thus facilitating slides. The spoil on the outslope was left much steeper at the top of the slope and much deeper, increasing erosion and encouraging slides.

The second example shows current requirements which require spoil to be placed on the bench to a depth of at least four feet above the coal seam being worked. This depth may sometimes be 15 feet or more. A maximum bench slope of ten percent from the highwall is permitted so that no ponding occurs. Operators are allowed to place no more than 40 percent of the first cut (first cut is often the total cut) over the outslope for slopes up to 33 degrees. No fill bench is allowed on slopes greater than 33 degrees. These requirements should reduce runoff, slides and erosion.

On August 3, 1977, President Carter signed into law the "Surface Mining Control and Reclamation Act of 1977," referred to commonly as the "Federal Strip Mine Bill." This Act establishes authority within the U. S. Department of Interior to regulate surface mining and the surface effects of deep mining of coal. Plans are being prepared by the Kentucky Department for Natural Resources and Environmental Protection to implement the Act.

The Act requires segregation and reuse of topsoil assuring quicker and more permanent revegetation, requires that reclamation be kept current with mining, provides for more stringent enforcement, provides funds for reclaiming abandoned land that has been inadequately reclaimed, prohibits spoil over outslopes of 20 degrees, and stipulates other measures which will further reduce the adverse impacts of surface mining on flooding.

Surface areas mined in flooded counties. The total area for which permits were issued for surface mining 1954 through 1976 for the 15 counties amounted to 191,900 acres.[1] Permitted acreages 1954-1976 for selected counties are as follows:

Bell	16,400 acres, or	6.9%	Of total area.
Breathitt	14,000	4.4%	Of total area.
Harlan	13,500	4.5%	Of total area.
Knox	12,100	5.1%	Of total area.
Martin	12,800	8.6%	Of total area.
Perry	20,800	9.6%	Of total area.
Pike	29,300	5.8%	Of total area.

Active permit acreage in the drainage areas of five selected communities are shown below. Land under active permit means that reclamation either has not begun or has not reached a condition acceptable for the Bureau of Surface Mining Reclamation and Enforcement to release the reclamation bonds. The acreages for Pikeville and Prestonsburg do not include land that drains into Fishtrap, Flanagan, or North Fork of Pound reservoirs because these structures retained all runoff from above them. Neither do the figures include surface-mine acreage in the Russell Fork Valley of Virginia below Flanagan dam.

TABLE I.

	DRAINAGE AREA		ACTIVE	ACTIVE	PERMITTED
CITY	SQ. MI.	ACRES	PERMITS	ACREAGE	%
Harlan	374	232,960	136	4,871	2.1
Pineville	809	567,760	269	11,258	2.0
Williamsburg	1,607	1,028,480	644	17,555	1.7
Pikeville	621*	397,240*	249*	5,550*	1.4
Prestonsburg	1,085*	694,400*	282*	6,399*	0.92

*These figures represent the area after deductions for the lakes as explained in the narrative above. Total drainage areas for 1237 and 1701 square miles respectively.

Effects of surface mining on runoff. It is well-known that steep slopes produce rapid runoff. It has been stated previously and illustrated in Figure 1 that under early surface mining practices on hills, benches were left flat but the floor of the benches was partly bare, solid rock, causing nearly 100 percent runoff. Unless caught in ponds on the bench, this runoff joined the rainfall that fell directly upon the spoil banks which were steeper than the natural slopes, thus increasing the runoff.

Current regulations require that the slope on the benches be increased and the spoil on the outslope not be as steep, if there is any. The depth of spoil on the bench may be increased, a larger volume of rainfall can be absorbed, resulting in less runoff than under former methods. However, in storms of high rainfall rate the infiltration capacity is soon exceeded.

In any case, *runoff from an active strip mine is much higher than from the original, undisturbed land.*

Infiltration and percolation. The nature of the spoil causes variations in its capacity for infiltration and for storage of moisture. High infiltration would enable more rainfall to enter the spoil, thus reducing floods and augmenting subsequent stream flow. Collier and others[2] found that the predominantly siltstone and claystone spoil on Cane Branch of Beaver Creek had a very low infiltration and percolation rate. G. B. Coleman[3] in studies of percolation rates of various spoil banks in Pennsylvania obtained the rates shown below for the types of soil described.

TYPE OF SOIL	PERCOLATION (IN./HR.)
1. Sandstone & Yellow Shales (Spoil)	0-17
2. Dark Shale with High Gravel Content (Spoil)	65-397
3. Dekalb Silt Loam (Undisturbed Woodland Soil)	17-60

Soil type one was predominantly sandstone and yellow shale containing 39 percent soil. The low percolation was attributed to void spaces being filled by the soil. Tests on the second type of spoil produced very high percolation rates. This was attributed to a large amount of void space caused by the gravel content. Soil content was 20 percent at both sites. The third soil was from an undisturbed location in nearby woods and was included for comparison.

The infiltration and percolation rates are important, as was pointed out in Chapter I, because the more moisture that can be absorbed by the spoil, the less the adverse effect that surface mining has on flooding.

The type and degree of reclamation affect infiltration and percolation. Grandt and Lang (1958)[4] found that infiltration on comparable level plots of unvegetated spoil in Illinois was 5.2 inches per hour on ungraded spoil compared to 0.9 inch per hour on graded spoil, enabling much more of the rainfall to infiltrate the ungraded spoil. Also, Limstrom (1960)[5] found that infiltration rates were up to seven times greater on bare, ungraded banks than on adjacent bare, graded banks in Ohio.

Vegetation also increases infiltration and percolation rates. On ungraded, silty clay banks in Illinois, Grandt (1952)[6] reported field percolation rates of 9.3 inches per hour on barren areas and 15.6 inches per hour on areas of the same texture that had been covered with vegetation for several years. On graded sections of the same sites the rates were only 0.9 inch per hour on the barren part and 1.5 inches per hour on the part covered with grasses and legumes.

New surface mining tends to increase runoff. *The preponderance of evidence from previous studies indicates that active, unreclaimed, or improperly reclaimed surface-mined areas increase runoff.* Considering all the information on the effects of surface mining on runoff and erosion, *small tributaries with a high percentage of recently disturbed land probably had significantly higher flood levels as a result of the surface mining.* The following case studies give a good indication of the effects of strip mining on the hydrology of Appalachian watersheds.

Case #1. Beaver Creek, McCreary County, Kentucky

Studies were begun on adjacent tributaries of Beaver Creek in 1956, eight months after surface mining began on Cane Branch. Helton Branch was similar in topography, soil, rock formation and soil cover of timberland with a small amount of abandoned farmland. It was used for comparison. Ten percent of the Cane Branch watershed was disturbed by surface mining from 1955 to 1959. Pre-mining records were not obtained. Cane Branch has a watershed of 429 acres, Helton 544 acres.

Over the period 1956 to 1958, Cane Branch varied considerably in stream flow, but total annual runoff was essentially the same as Helton Branch.

Maximum discharge following storms on Cane Branch occurred one hour and ten minutes before peak flows in Helton Branch. Table II shows the dates, rainfall, and peak discharges of selected peaks from Cane Branch was one and a half times as much as from Helton Branch.

The ratio was less (1.27) for the two heavier rainfalls, supporting the statement that topsoil quickly becomes saturated and runoff is virtually 100 percent after that.

The ratio also tended to decrease with time. The average peak discharge following one storm in 1963 and two in 1965 in Cane Branch was 1.31 times that in Helton Branch, while the peak for five slightly heavier storms two in 1960 and three in 1962 in Cane Branch was 1.58 times the peak in Helton Branch.

TABLE II

Rainfall (4 hr. period) and Subsequent Peak

	Maximum Rainfall (Inches)		Peak Discharge, cfs/sq. mi.	
Date	Cane Br.	Helton Br.	Cane Br.	Helton Br.
5-7-60	1.19	1.15	90	40
6-23-60	1.50	1.46	91	36
2-25/28-62	1.38	1.38	275	214
3-30/31-62	.94	.93	63	32
4-10/11-62	.85	.85	75	47
3-11-63	1.36	1.46	190	153
3-24/26-65	1.02	1.03	60	46
3-28/29-65	1.02	1.02	81	54
TOTAL	9.26	9.28	925	622

In the early years of the study, Cane Branch continued to produce a larger daily streamflow for several days after a storm. This is shown in terms of percentage of total discharge in Figure 2. Cane Branch flow exceeded Helton Branch flow 28 percent of the time. Infiltration was larger in the undisturbed Helton Branch and released at a slower rate from its natural condition.

In summary, over the period 1956 to 1966 the mined watershed produced significantly higher average and peak flows then the unmined watershed.

Beaver Creek had very slow, natural reclamation and in a study, 1973-74,[8] seven years after a previous study, McCabe and Associates determined that maximum unit discharges in Cane Branch (the ten percent disturbed watershed 1956-58) for individual storms still exceeded Helton (the unmined watershed used for comparison). Flow duration curves show that for 1973-74 daily average flows of Helton consistently exceeded Cane. The higher peak flows of Cane Branch did not exceed the flows of Helton Branch for one day at this late stage. This was a considerable decrease in difference in seven years, Figure 3.

Case #2. New River, Tennessee

New River, a tributary of the Cumberland River in northeastern Tennessee, has a watershed of 382 square miles. It is a mountainous, forested area similar to much of eastern Kentucky. Surface mining has been conducted in the watershed since the early 1940's. The mining is dispersed fairly uniformly over the watershed.

A graduate student at the University of Tennesse, Hong Shoung Tung,[9] analyzed the rainfall and streamflow records for the basin to determine the impact of surface mining on streamflow. Using this data and a computer model developed by TVA, he could predict the streamflow effect of various combinations of rainfall amounts and surface acres disturbed by mining, assuming other factors remained equal.

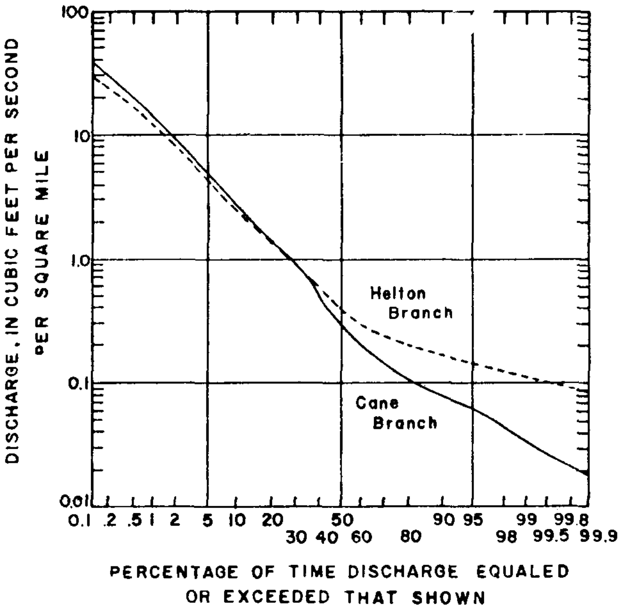


Figure 2. Flow-duration curves, Cane and Helton Branches years 1957-66

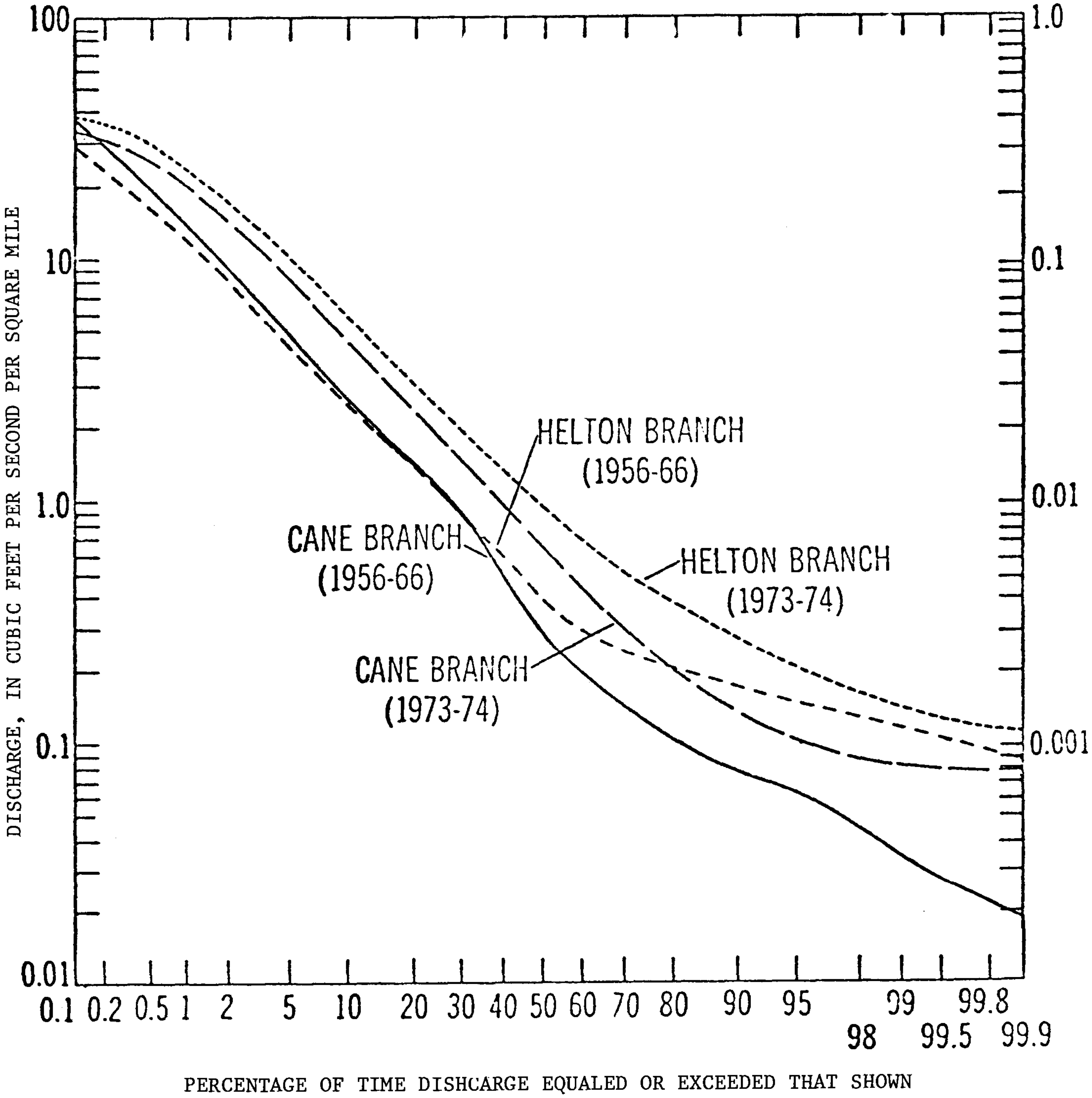


Figure 3. Flow-duration curves, Cane and Helton Branches

The results for rainfalls up to 100 years in frequency expectation with one to five percent soil disturbance by surface mining are shown in Figure 4. It is interesting that the expected differences varied little by amount of rainfall. Stream flow increased somewhat faster with increasing amounts of rainfall in the low ranges after which the increased stages remained fairly constant. It was concluded that a one percent soil disturbance would increase the stream crest from the annual storm by 2.5 feet and from a 100-year storm by 1.9 feet. A given percent disturbance would increase stream crest stage from a one-year storm by 2.9 feet and the 100-year flood by 2.4 feet.

Table III shows the change in streamflow due to varying percentages of land disturbance from surface mining in the New River basin:

TABLE III

PERCENT DISTURBANCE	% STREAM FLOW INCREASE ONE-YEAR STORM	 TEN-YEAR STORM	FLOOD STAGE INCREASES TEN-YEAR STORM	 100-YEAR STORM	% LOW FLOW INCREASE
1.0	27.0	13.0	2.5	1.9	0.0
2.5	17.0	5.0			25.0
5.0	31.0	15.0	2.9	2.4	30.0

Tung pointed out that the results from individual storms may vary with the degree of saturation of the soil when a storm arrived.

Tung's discussion (page 79 of his study) of his findings is presented below:

> In the early stages of contour mining, peak flows increased significantly because the highwall and bench areas created by stripping were capable of intercepting and then routing directly a considerable volume of surface flow through ditches and bench areas to the stream; nevertheless, low flows remained unchanged due to the relatively small scale of bench areas and spoils for storage. As contour mining intensified, the huge dimensions of bench areas and spoils created from multiseam mining were capable of storing considerable volumes of surface water and hence peak flows decreased markedly;

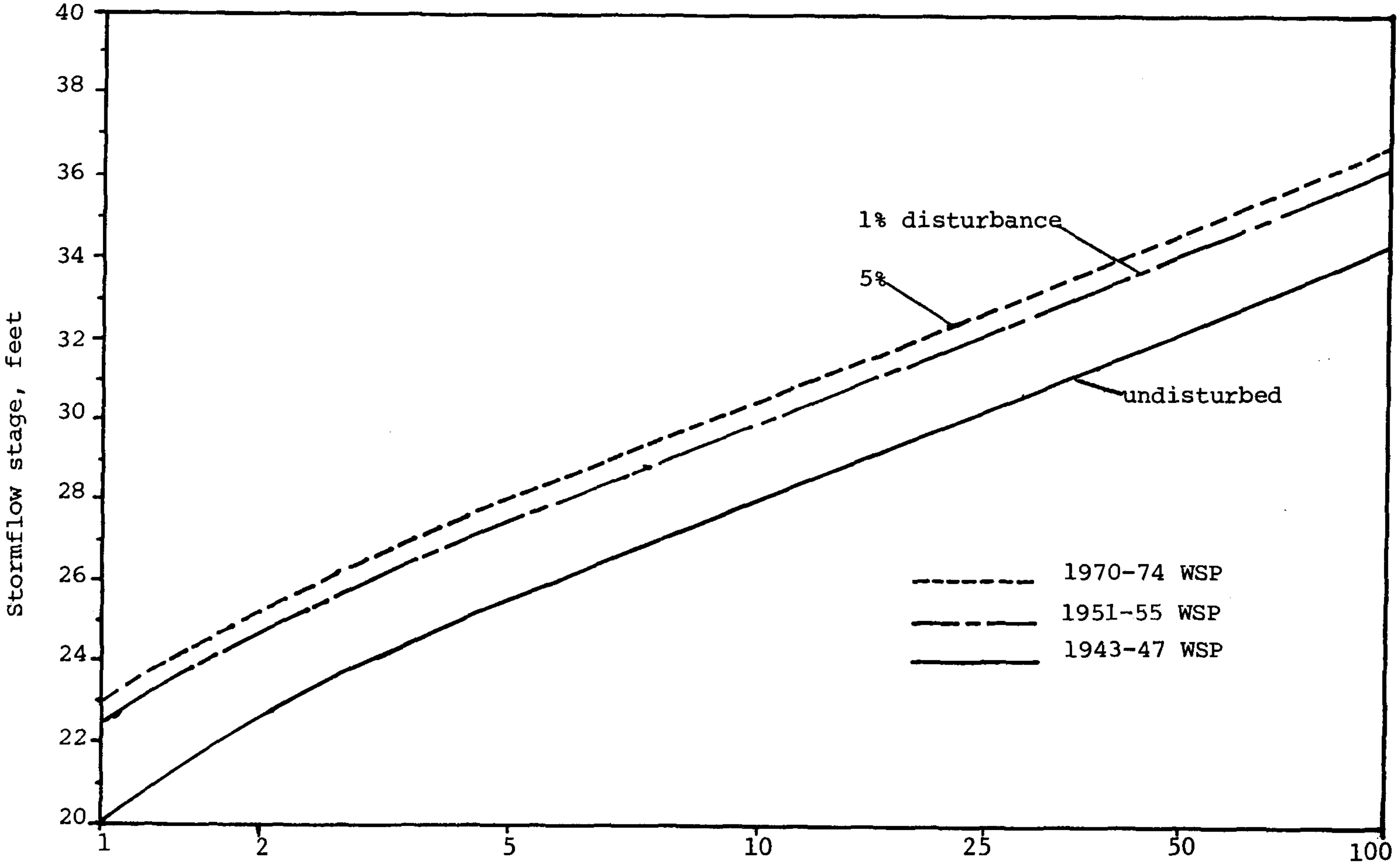


Figure 4. Comparison of the changes in stormflow stages at the flowgage of the New River Watershed, Tennessee, due to strip mining effects. (After Tung.)

> on the other hand, the impounded water in bench areas and spoils were gradually released to the stream as subsurface seepage and then increased low flows. As contour mining further extensified over the watershed, the increases in dimensions of bench areas and spoils further increased storage capacity but, on the other hand, provided more opportunities for directly routing more surface water to the streams. Thus, the increases in peak flows became highly fluctuated at this state depending upon the moisture in bench areas and spoils from previous rainfall. But, low flows increased consistenly.

Case #3. Breathitt County, Kentucky Studies.

Willie Curtis,[10] research hydrologist with the U. S. Forest Service's Northeastern Experiment Station, working with the USGS, studied two small watersheds in Breathitt County, Kentucky. A watershed of 2.4 square miles in Bear Branch and one of 2.2 square miles in Leatherwood Creek were subdivided into three subdrainages each for study of runoff, erosion, and water quality changes. The subdrainage areas were about the same size and were similar in geology, topography and ground cover. Curtis wrote, "Even though the observations represent case history studies of individual watersheds, basic knowledge gained should be applicable to much of the coal-producing mountain land throughout Appalachia."

Three coal seams outcrop at elevations of 1350,1380, and 1420 feet. Ridgetops were at about 1500 feet.

The Leatherwood subbasins were named A, B, and C. The Bear Branch subbasins were Mullins Fork, Miller Branch, and Jenny Branch. All basins were forested. Since pre-mining data were limited, it was assumed that the basins were similar in runoff and erosion before mining.

Jenny Branch remained unmined and was used for comparison.

Lag time, a measure of how much time is required for a stream to respond to rainfall within its watershed, decreased in all mined watersheds. Lag times for leatherwood A andB before mining were 580 and 678 minutes respectively. After 50 percent land disturbance the lag times were 299 and 340 minutes respectively.

Leatherwood A, with 50 percent disturbance, peaked well before C, which had ten percent disturbance.

Runoff peaks (cubic feet per second per square mile) increased greatly. Before mining, Miller Branch had a runoff peak of 10.6 csm compared to 6.9 csm for Jenny, a ratio of 1.5. After 30 percent of Miller was mined, the runoff was 29. 1 csm for Miller versus 11.3 csm for Jenny, a ratio of 2.6.

Mullins Fork had two percent disturbance. Before mining, the flows from Mullins for 49 storms averaged 13.3 csm vs. 10.6 csm for Miller. After the mining (two percent in Mullins and 30 percent in Miller), the runoff from Mullins from 69 storms was only one-third that of Miller, showing a large increase in heavier mined Miller.

Leatherwood A and B had equal runoff before mining. After mining the runoffs were still equal but had increased three times. A mining disturbance of ten percent of the land in Leatherwood C brought a doubling of stream discharge from storms.

The runoff varied with the amount of land disturbance. For example, Leatherwood A with 45 percent disturbance exhibited runoff peaks of 52 csm whereas Leatherwood C, with 16 percent disturbance, averaged 15 csm.

Leatherwood B, with 40 percent disturbance, had a runoff of 44.1 csm for 111 storms versus a runoff of 8.8 csm for unmined Jenny, a five-fold increase.

Curtis attributes the differences to the following changes:

1. The forest canopy and its interception capacity, though small, is removed.
2. Increased surface evaporation partly offsets lost transpiration from the forest.

3. The spoil holds more of its moisture and loses less by evapotranspiration, therefore it has less available capacity for infiltration.
4. Surface sealing is commonplace on mine spoils where the overburden is mainly shale.

Curtis stated further:

> "The flood potential after surface mining in Appalachia becomes more and more important with the increase in percent of land disturbed. Peaks from small areas will flatten out as the flows join streams from other drainages. However, if a number of small drainages in a watershed are mined, flood potential in the watershed may be increased greatly."

Case #4. Jenny Fork and Miller Branch, 1977.

Curtis[11] resumed studies in 1977 on Jenny, Mullins and Miller Branches, five years after the studies reported above. Rainfall in the area totalled 3.7 inches April 2 to 4, 1977.

The 0.72 inch of rain that fell April 2 had little effect upon stream flow. Peak flows came near the end of the storm on April 4. Jenny Fork, the unmined watershed, peaked nearly twice as high as Mullins Fork and more than twice as high as that of Miller Branch. Both Mullins and Miller Branches had a higher yield than Jenny for the next five days. These phenomena were reversals of the results just reported for the period during the two years after the mining took place on Mullins and Miller.

Possible explanations lie in the discussions early in this section:

1. The natural soil on the mined branches was only one to three feet deep, far less than the depth of spoil after mining and after reclamation.
2. The impact of rainfall and the washing of finer material into surface voids seal the surface of the spoil against infiltration early after mining.

3. As vegetation covered the area (Plate 1) and the silt eroded away, infiltration increased substantially, transpiration increased (removing moisture from the soil and thus increasing available holding capacity of the soil), and surface flow was decreased by vegetation.

The vegetative growth on reclaimed areas of Miller and Mullins Branches in April 1977, was well established. According to Curtis, it provided a superior canopy and much more soil surface porosity than natural forests on Jenny Branch. This would indicate that although runoff and erosion increase due to active surface mining, reclamation and weathering of these areas result in better hydrologic conditions than existed prior to mining.

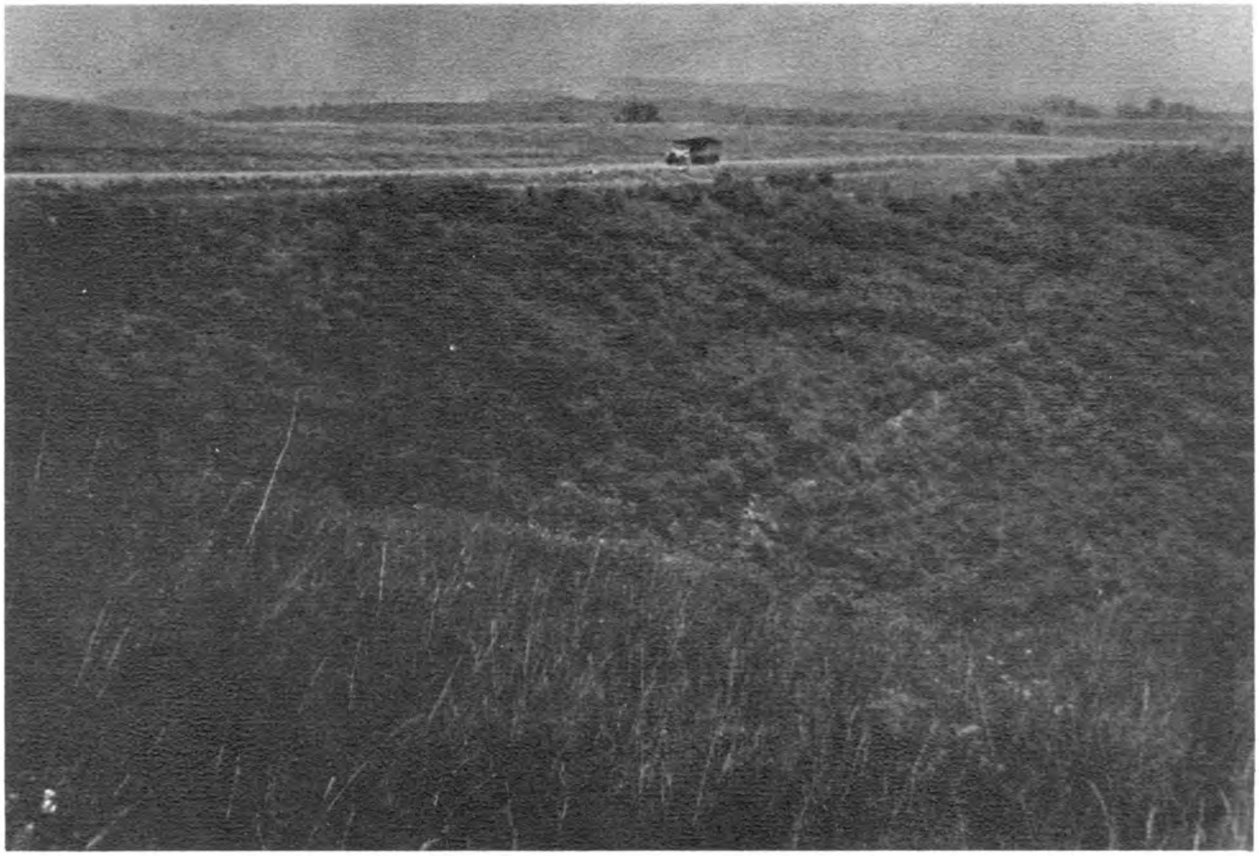
Erosion. Surface mining in Appalachia may result in severe erosion with commonly-used practices. Three erosion sources from mining are the benches and highwalls, the spoil, and the haul roads.

Collier[12] reported annual sheet erosion was as follows for the years indicated in tons per acre:

	1957	1958	1959
Cane Branch	4.89	4.86	7.82
Helton Branch	0.95	0.60	0.61

Curtis[13] reported that sediment in streams of the Breathitt County watersheds which he studied reached peak sediment loads of 150 parts per million before mining. After mining, loads were as shown below:

	Sediment: Parts/million after mining
Leatherwood A	46,400
Leatherwood B	26,900
Leatherwood C	9,600



Courtesy Willie R. Curtis

Plate 1. Reclamation of surface-mined land, Miller Branch, Breathitt County

Mining was in progress in A and B, but had stopped at a level of ten percent disturbance in C. Sediment in C soon returned to premining levels except during severe storms.

Bedload in Leatherwood Creek before mining was virtually zero. After mining began, the first sediment was very fine, unconsolidated material. Later, there was a higher percentage of sand. In December, 1969, two years after mining, deposits consisted of larger pieces of rocks with some sand, but practically no smaller pieces.

Erosion from mine haul roads has been severe. Curtis[14] stated that road erosion is a universal problem because of steepness, poor construction, systems of maintenance and condition of abandonment.

Weigle[16] studied haul roads in Harlan, Bell, and Perry Counties. For roads averaging 65 feet wide, each mile of road exposes an average of 7.9 acres. After abandonment is eight months to two years, the roads had suffered losses of 1.7 to 3.3 acre-feet of soil per mile of road.

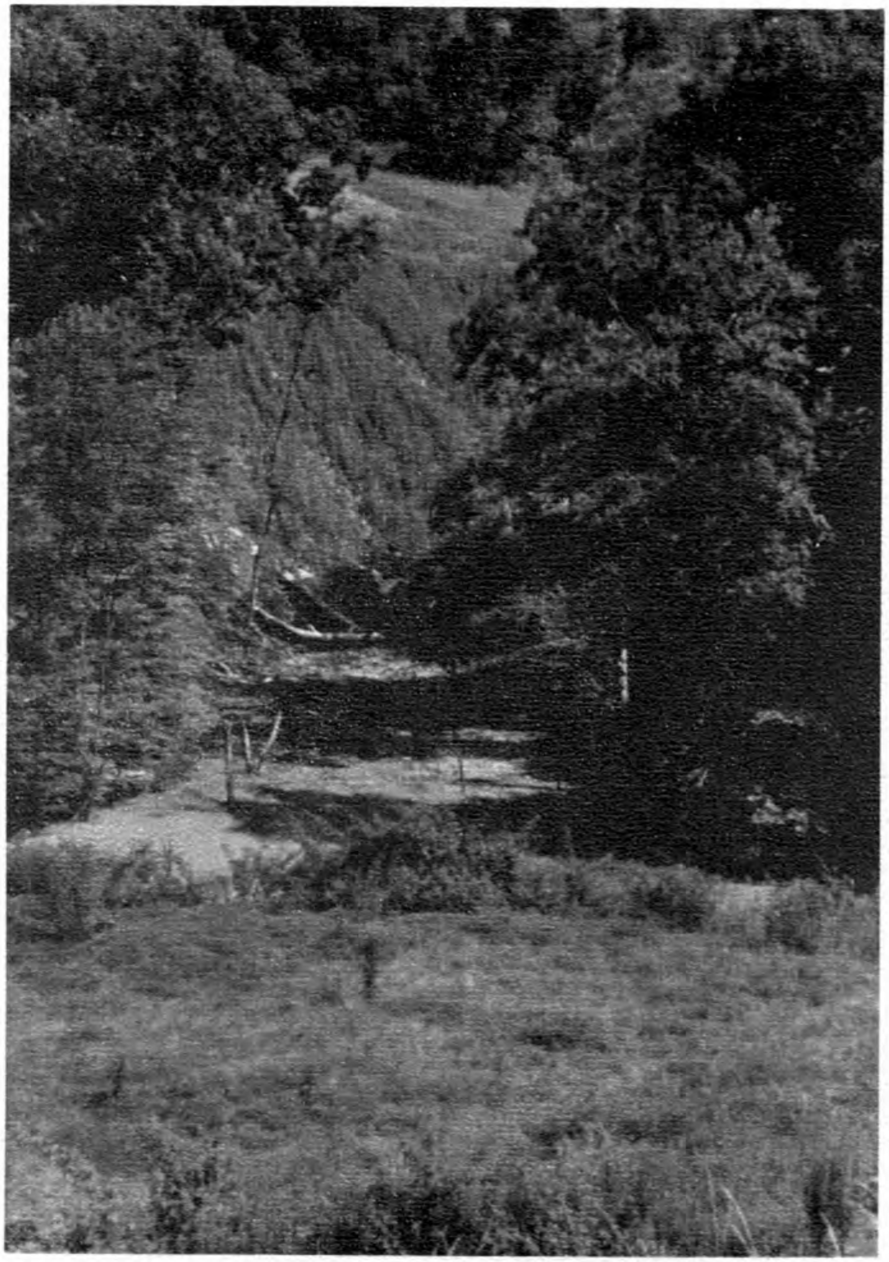
Plates 2 through 6 show erosion and spoil slides on a small hollow. Plate 7 shows small silt beds in a fairly large stream bed with coal and shale particles identified. Much larger rocks and sediment bars are also shown. The type and newness of the rocks indicates that their dislodgement resulted from mining.

From Plates 8 and 9, it is evident that the bars of larger material, such as rock and gravel, both fill and narrow the channels. Some of this is natural. Nevertheless, to the extent that mining adds to such sediment, it tends to increase flooding.

The effect of surface mining on flooding is greatest on smaller tributaries. Plate 10 shows a hollow, the channel of which was filled and and overflowed with rocks from a slide below a mine. Farther downstream, water generally moves more slowly and heavy bedload is dropped.

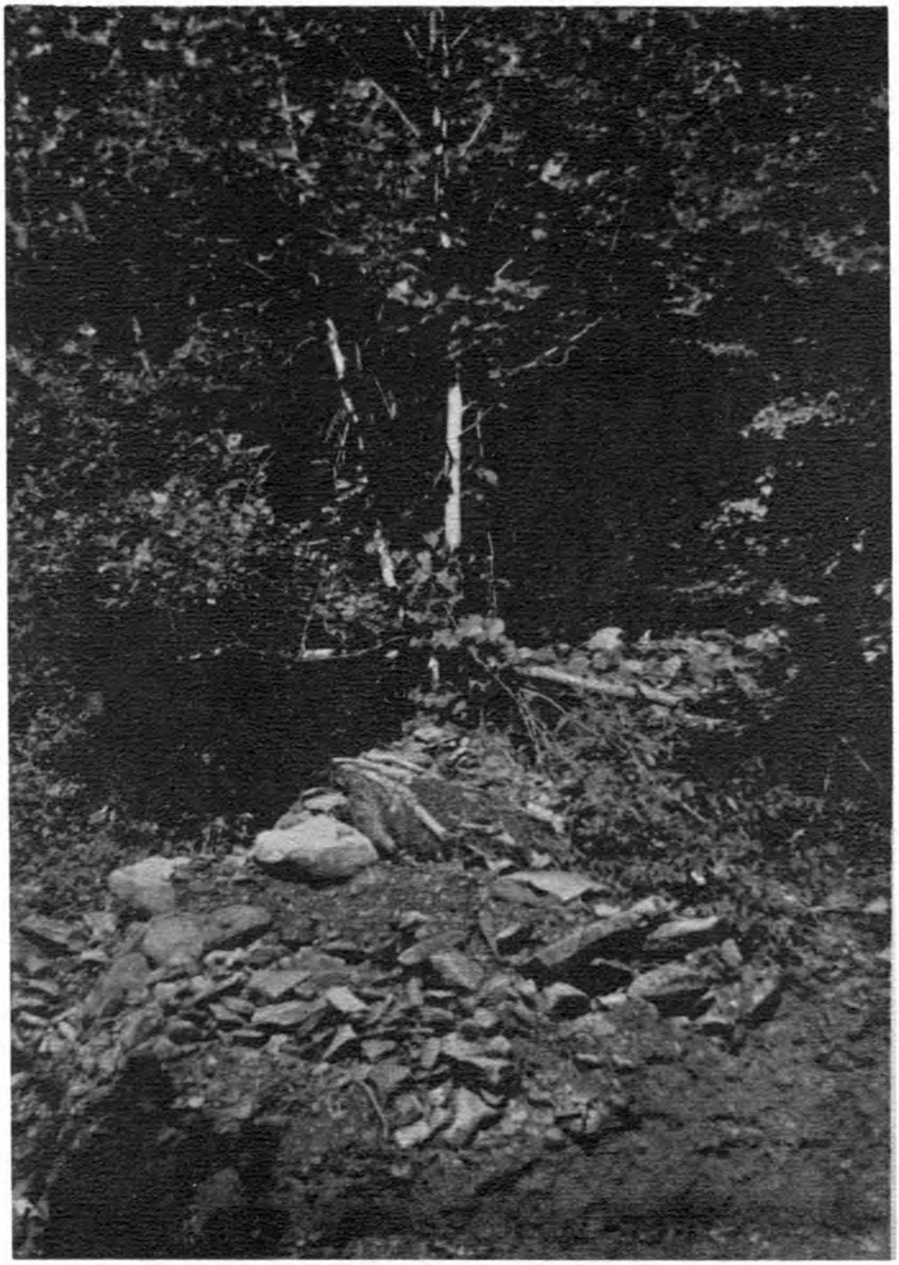
Staff Photo

Plate 2. Slides and sheet erosion of mined area on Linefork, Letcher County.



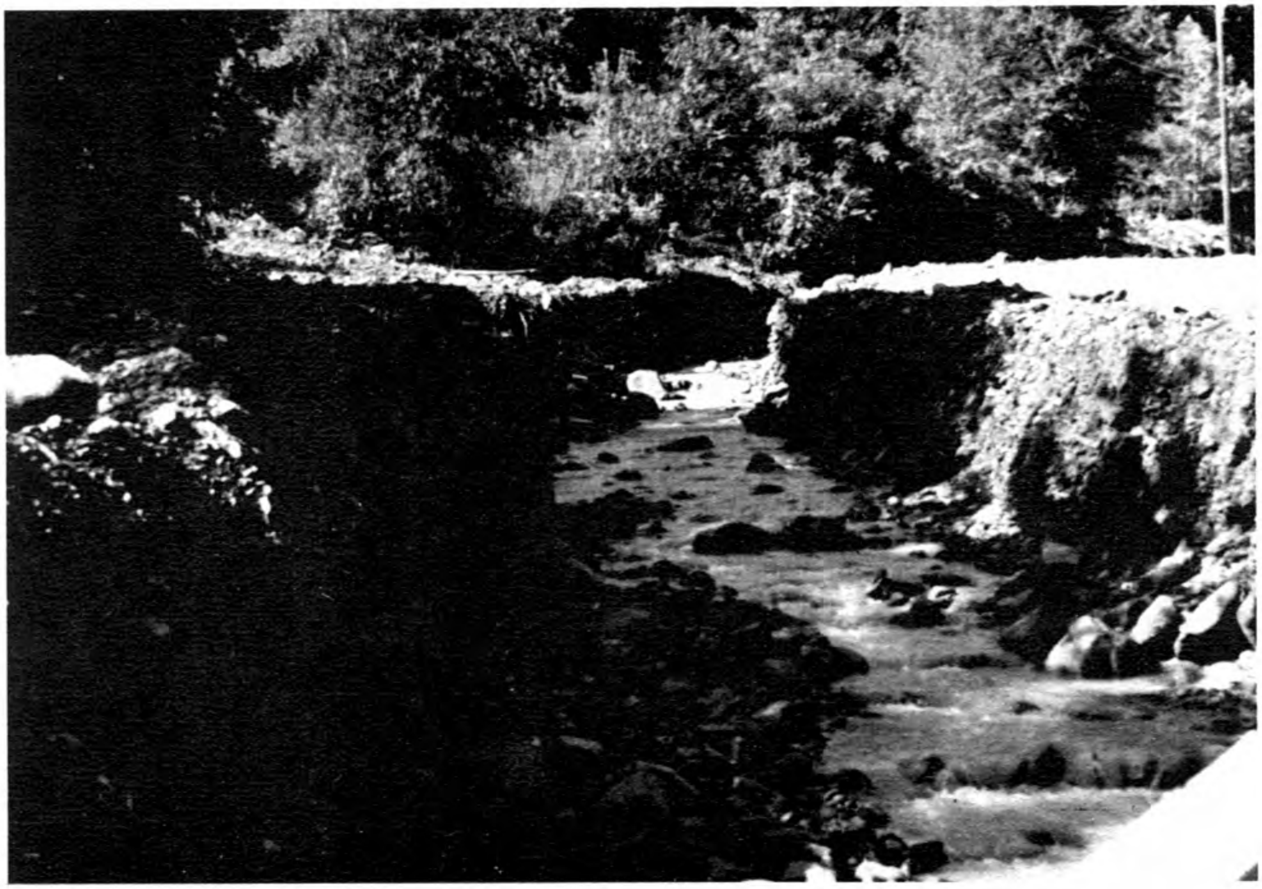
Staff Photo

Plate 3. Slide of mouth of small mined branch of Lost Creek, Perry County.



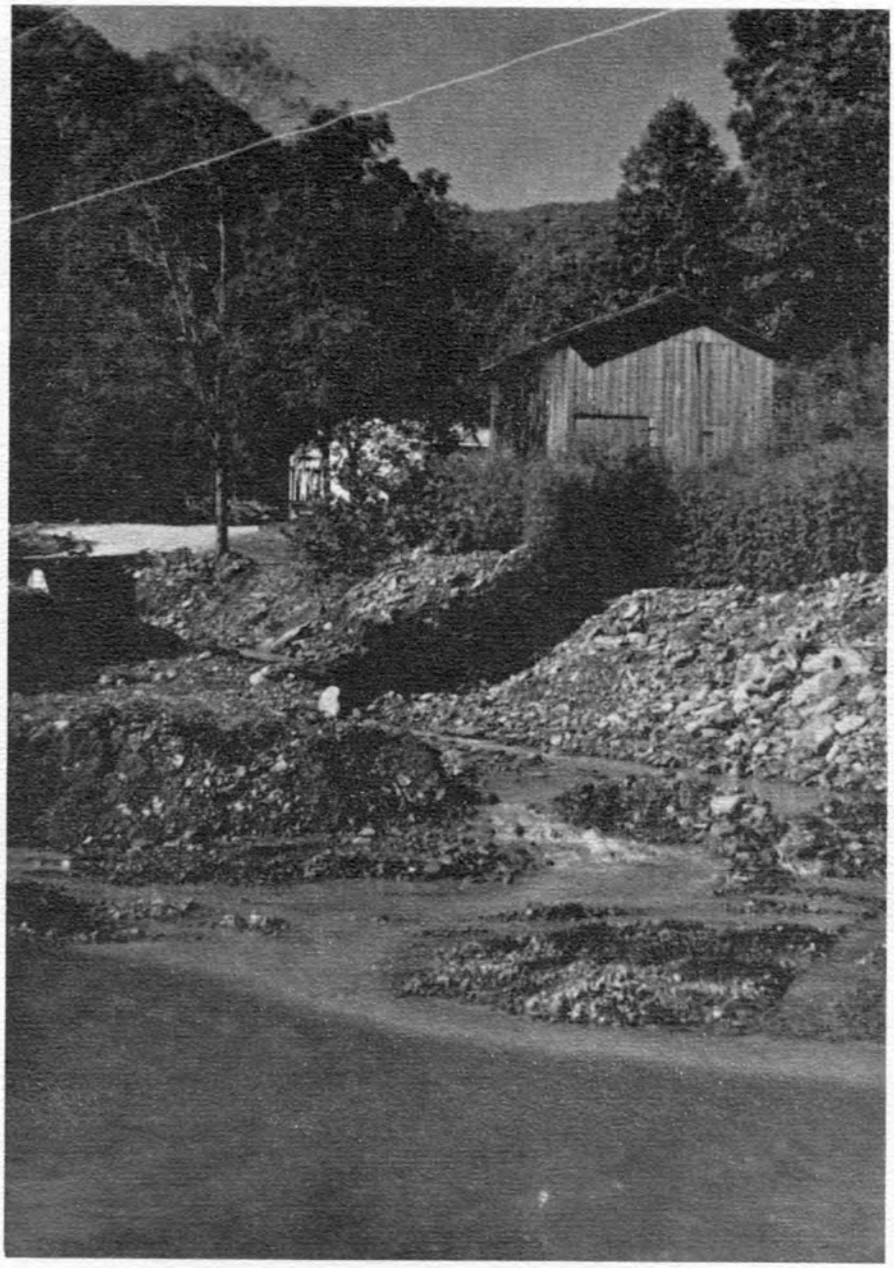
Staff Photo

Plate 4. Slide debris at mouth of small branch off Clover Fork, Harlan County,



Staff Photo

Plate 5. Branch of Clover Fork, below site of Plate 4. Channel had been opened.

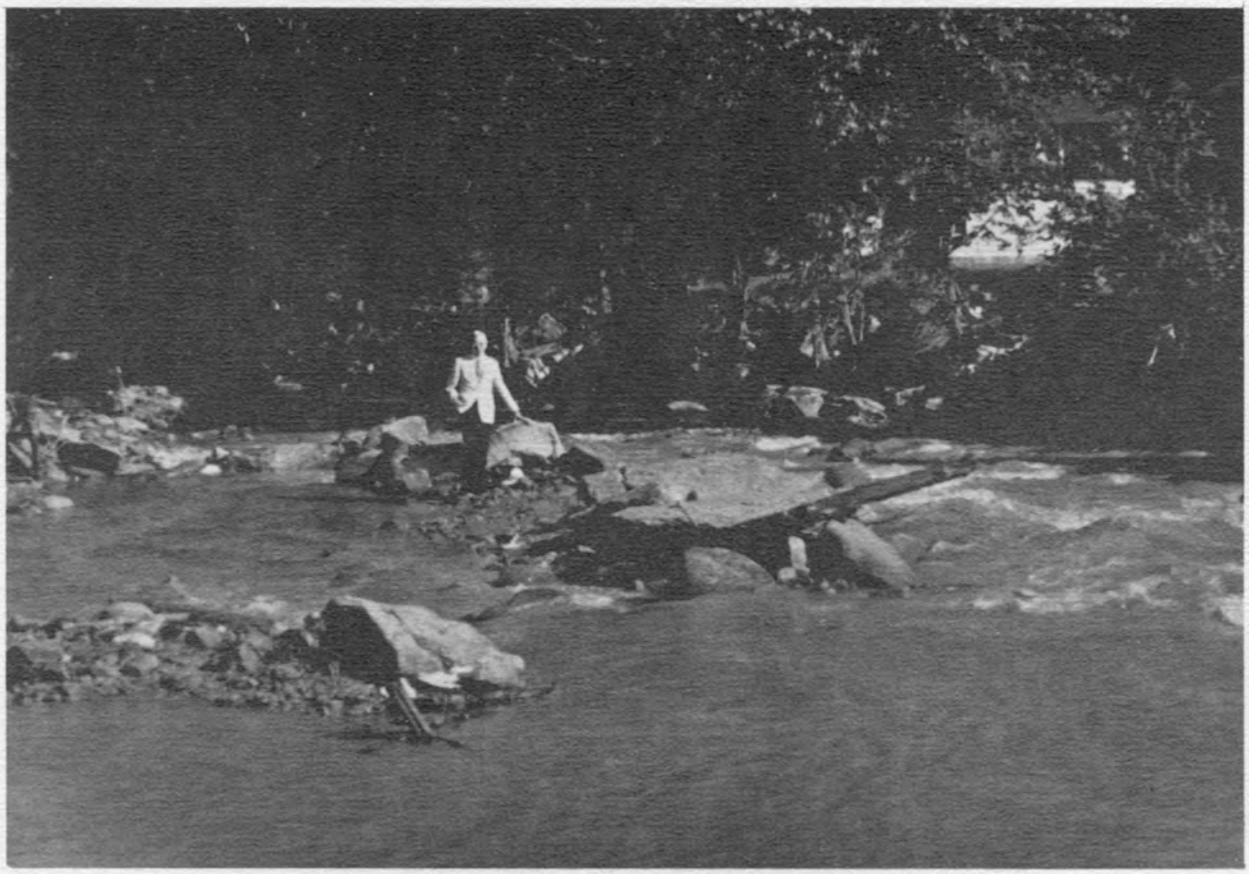


Staff Photo

Plate 6. Rock bedload at mouth of branch into which debris shown in Plate 4 flowed. Clover Fork in foreground.

Staff Photo

Plate 7. Sediment in bed of Clover Fork, Harlan County showing coal and related materials.

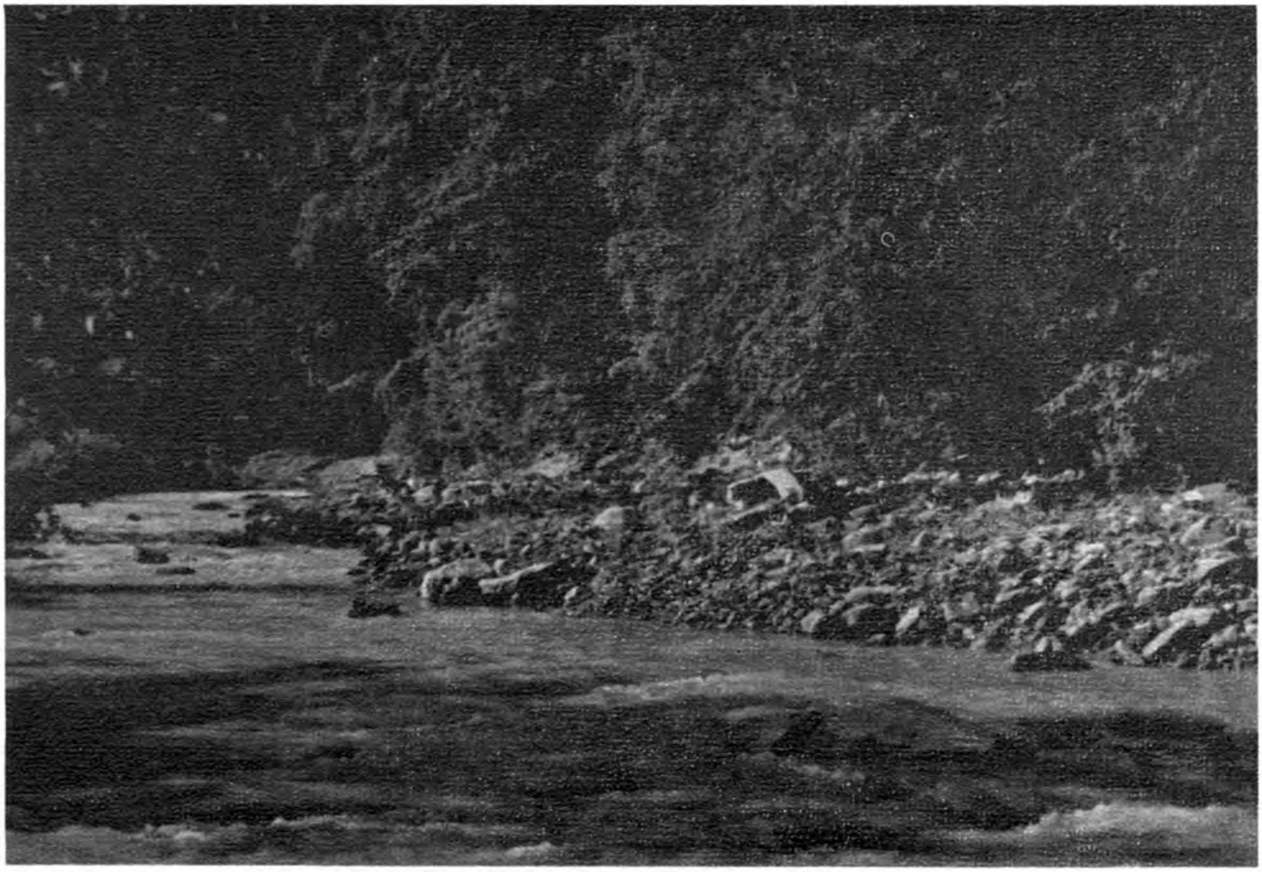


Staff Photo

Plate 8. Large rocks in stream bed of Clover Fork adjacent to site of Plate 6.

Staff Photo

Plate 9. Sediment in bottom of channel of Clover Fork, Harlan County.



Staff Photo

Plate 10. Heavy sediment deposited in one side of channel of Clover Fork narrows the channel.

Fine silt which is left behind by previous floods is picked up as floodwaters rise and their flow velocity increases. As floods recede, sediment is deposited on floodplains and in the channel bottom.

Effective reclamation may lower flood peaks. Analyzing surface mining on gently sloping lands in Indiana, Agnew and Corbett found lower runoff peaks from the mined lands than from unmined soils. Also there was higher streamflow from mined lands during subsequent extended dry periods. The explanation by the authors is as follows:[16]

1. The fresh spoil had 30 percent void space and, therefore, a large moisture-holding capacity.
2. The storage in surface depressions and the final pit ponded most or all of the runoff. This reduced runoff significantly. Water from the ponds which infiltrated into and through the spoil augmented the streamflow during later periods.

Effects of Agriculture

There has been a significant reduction in farmland and cropland in eastern Kentucky since 1940, especially in the worst flooded counties of Bell, Harlan and Pike. This is shown by the data below:[17]

	Land in Farms		Cropland Harvested	
	1944	1974	1940	1974
All 15 counties	2,320,000	458,800	512,074	29,300
Bell, Harlan and Pike	418,294	36,046	67,739	2,844

From this data it is evident that soil disturbance due to agricultural cultivation is insignificant in the 15 disaster counties and is a small portion of what it was in the 1940's. Cropland harvested in 1974 constituted 0.8 percent of all the land in the 15 counties and only 0.2

percent in the worst hit counties of Bell, Harlan and Pike. In these three counties, cropland harvested was only 4.2 percent of what it was in 1940.

Much of the land previously in agricultural uses is now in woodland. Therefore, *agriculture cannot be blamed for the 1977 flood being higher than for any other storm of the last forty years.*

Effects of Forests

Eighty-six percent of the land in the 15-county area is in forests. Included are parts of two national forests and four state forests. In 1974, the forested acreage in the area was 3,303,200 acres which was an increase of some 240,000 acres since 1945.[18]

Hydrologically, *forests are the most desirable land use in Appalachia.* The leaf canopy and ground cover intercepts and cushions rainfall and prevents erosion. The vegetation retards runoff and absorbs and retains moisture. These effects tend to minimize runoff and flooding from a given rainfall.

Considered by itself, *the increase in forested land in the 15-county area would have tended, in the aggregate, to decrease the 1977 flood.* The effects of the April, 1977 flood could have been increased on small watersheds that had been heavily harvested or recently burned.

For more detail on the effects of forestry practices on floods, see the discussion in the Appendix.

Floodplain Developments

Developments have historically been located in the floodplains of those counties flooded in 1977. The hills are steep and building on them is difficult because the soils are unstable. Also, obtaining access to building sites on the hillsides is a difficult and expensive task. Highways and railroads are built in the floodplains where it was less costly and easier to construct and maintain a grade. Also, these locations were more accessible to businesses and homes. It was easier also to bring coal and logs downhill and to provide water and sewer services in the valleys.

Structures in the floodplains have often encroached upon the floodway, raising flood levels and increasing flood damages. By virtue of the value of these structures and their contents, development in the floodplain increased the potential for flood damage.

In the early 1900's while industry and commerce were booming throughout the country, railroads and highways were constructed to provide access into eastern Kentucky. With them came an influx of workers to harvest the area's timber resources and to mine its high quality coal. Many towns grew up to serve these industries and their workers.

After years of heavy harvesting, the high quality timber supply became nearly exhausted. This, coupled with a decreased demand for coal due to the shift of industry, railroads, and residential heating to natural gas and oil, created wide-spread unemployment to eastern Kentucky. About 1940, people began leaving for wartime industrial jobs in the North. The population changes for the area are shown below:

POPULATION CHANGES IN EASTERN KENTUCKY[19]

	1940		1970		1975
15 Counties	526,260		351,324		390,600
Change		-174,946		+39,276	
Percent Change		- 33.3		+ 11.2	
3 Counties (Bell, Harlan and Pike)	190,209		129,209		141,400
Change		- 60,659		+11,850	
Percent Change		- 31.9		+ 9.1	

From these figures, it can be seen that the fifteen counties lost one-third of their population from 1940 to 1970. This trend was reversed in the five-year period 1970 to 1975 when the population of these counties gained 11.2 percent. This reversal was due in part to a national trend against the rural-to-urban migration. Also, after the Arab oil boycott in the early 1970's, the demand for coal skyrocketed, and jobs were again available in eastern Kentucky while much of the rest of the country was in a recession. For this reason, natives stayed home and others moved into the area, explaining perhaps most of the population increase.

While per capita personal income for all Kentuckians increased by 53.1 percent from 1969 to 1974, per capita income increases in eastern Kentucky were as follows:[20]

Bell County	75.1 percent
Harlan	83.1 percent
Pike	98.9 percent
Martin	120.7 percent

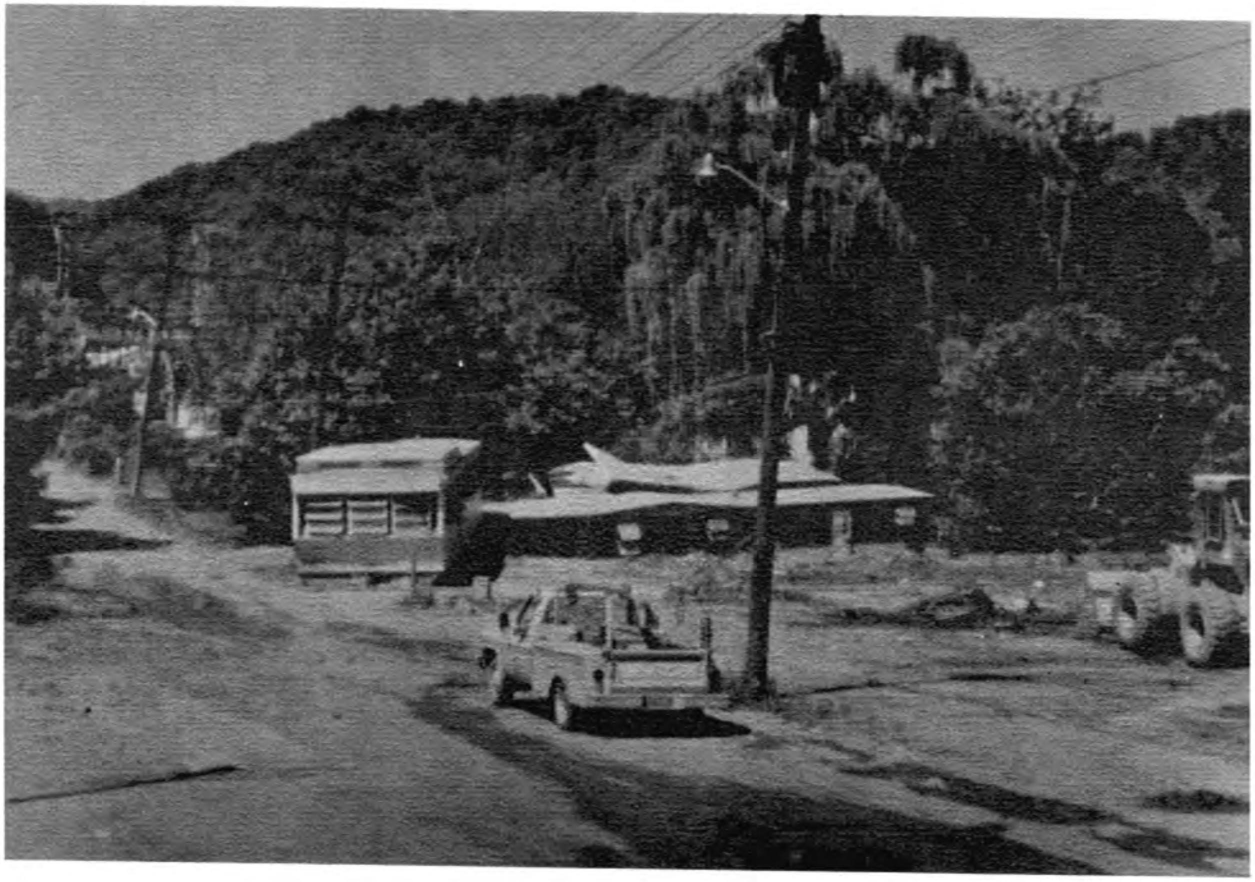
This trend continues and these figures are probably far higher in 1977.

The result has been the occupation of over 11,000 new housing units[21] *in the 15-county area, renovation of commercial and public buildings, and the construction of new shopping areas to serve the growing population. While many of the new homes were erected above flood levels, many homes and most of the public and commercial structures were built in the floodplains.* A large number of the new housing units are mobile homes which are especially prone to flood damage, see Plates 11 through 17.

New construction within the floodplain creates higher potential losses for future floods. Structures and fills located too near a stream obstruct the floodways, increasing flood levels. As the floodway is obstructed,

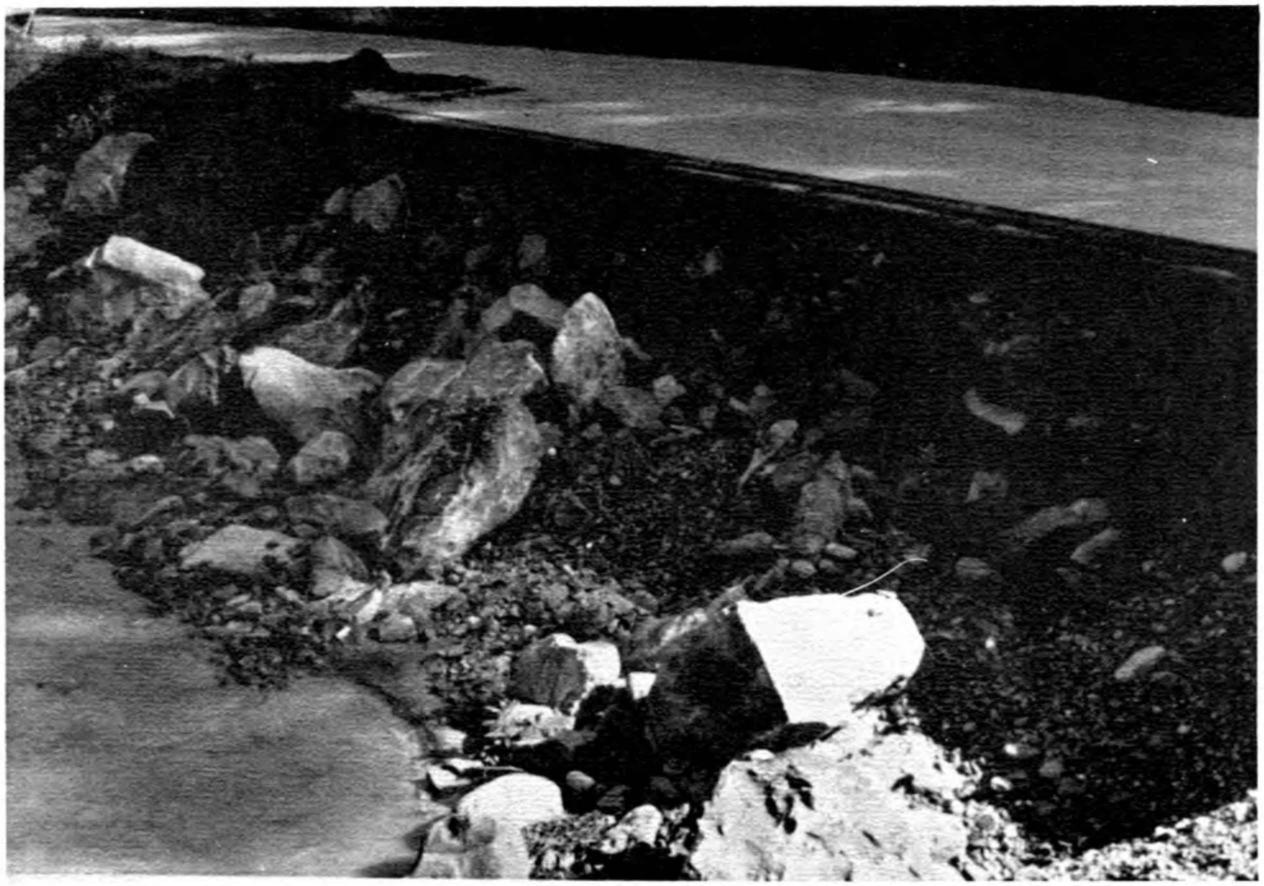
Courtesy Tom Little

Plate 11. Flooded homes in Pineville, Kentucky.



Courtesy Bernie Carter

Plate 12. Mobile homes piled up by Levisa Fork, near Betsy Lane, Floyd County



Staff Photo

Plate 13. Highway bank eroded by Clover Fork, Harlan County.

Courtesy Harlan Daily Enterprise

Plate 14. Commercial damage in Harlan, Kentucky.

Courtesy Harlan Daily Enterprise

Plate 15. Silt damages to commercial property.

Courtesy Tom Little

Plate 16. Industrial plant damaged at Middlesboro, Bell County.

Courtesy Tom Little

Plate 17. New school in Pikeville was one of many public properties damaged.

flood damages to new and existing developments increase.

Factors Tending to Reduce Flood Peaks and/or Damages

For many years man has sought to control floods and reduce their damages. Governments have spent billions of dollars on construction of flood projects and continue to spend millions every year in attempts to reduce flood damage.

Methods of flood control and flood-damage abatement can be classified into two groups:

1. Structural measures,
2. Non-structural activities.

Structural measures. In the last 40 years flood-control reservoirs and multiple-purpose reservoirs have been built throughout the country. In the area of Kentucky affected by the 1977 flood, six Corps of Engineers flood-control dams helped reduce flood damages. The operation and effects of these dams is discussed in the following paragraphs.[22]

The Corps of Engineers operate four flood-control dams on the Big Sandy River. All of these are on the Levisa Fork. *Located upstream from Pikeville and Prestonsburg are Fishtrap, John Flanagan, and North Fork of the Pound River dams. Dewey Dam is located above Paintsville on Johns Creek. These four dams controlled the flood produced within their watersheds, during the April 1977 flood.* The following percentage of flood storage capacities were utilized:

Fishtrap Dam	71.7% of storage
Flanagan Dam	69.2% of storage
North Pound Dam	53.1% of storage
Dewey Dam	40.3% of storage

Fishtrap, Flanagan, and Pound reduced the flood stages as follows:

Pikeville: without the dams the river would have reached 65.5'; the river peaked at 51.5', thus there was a reduction in flood height because of the dams of 14.0 feet.

Prestonsburg: without the dams the river would have reached 57.5'; the river peaked at 45.85', thus there was a reduction in flood height because of the dams of 11.65 feet.

Paintsville: without the dams the river would have reached 53.0'; the river peaked at 42.2', thus there was a reduction in flood height because of the dams, Dewey Dam included here, of 10.8 feet.

Total reduction in damages in the Big Sandy valley attributable to the four dams was estimated at $175,000,000.

There are two flood-control dams located in the Kentucky River drainage, Carr Fork and Buckhorn. Though Carr Fork is relatively small, it reduced the flood crest at Hazard by 2.5 feet and at Jackson one foot, preventing $6,600,000 in damages. Half the flood storage capacity of Carr Fork Dam was filled. Buckhorn Lake located in Perry and Leslie Counties operated to reduce downstream flooding.

The Soil Conservation Service aids local watershed conservancy districts in building flood-control dams on tributaries and headwaters of streams. However, there were no such dams in the 15 flooded counties.

The Commonwealth of Kentucky has no dams that were built for flood control except small structures designed to protect state properties. By chance, the state-owned Cranks Creek dam on a tributary of Martins Fork in Harlan County was empty and the spillway open when the 1977 flood occurred. The reservoir filled to within 18 inches of the emergency spillway, retaining most of the runoff from its 25 square mile watershed. The Corps of Engineers calculated that it protected the Martins Fork valley and reduced the flood crest at Harlan by 1.25 feet, thereby preventing $600,000 in damages.[23]

The local protection project at South Williamson on the Tug Fork of the Big Sandy prevented $375,000 in damages.

The Pineville floodwall and levee was built to protect the city against the 1946 flood. It was overtopped by about two feet.

Much of Barbourville was protected by a levee. Sandbags at the top of the levee and the gates prevented overtopping by the flood which crested several inches higher than the wall. The Corps of Engineers estimated that $6,200,000 in damages were prevented by the project.

Channel improvements, including a bypass canal for Yellow Creek at Middlesboro, facilitated the movement of the water through the city preventing $700,000 in damages.

Nonstructural measures. Structural measures have received the most attention and money and have been effective, considering their limitations. However, it is not feasible, even if it were physically possible, to solve all flooding problems by structural means. Therefore, many Federal agencies and others have shifted emphasis to non-structural activities. Among non-structural measures available are the following:

1. floodplain zoning and management,
2. other land use management,
    a. woodlands
    b. farmland management
3. flood forecasts and warnings,
4. evacuation plans,
5. flood insurance.

Floodplain zoning, which limits construction in the floodplain, is very difficult to implement in the more mountainous counties of Kentucky because alternative building sites are limited and expensive to develop.

Probably most of the floodplain zoning which existed was due to requirements for flood insurance.

Local governments should take a strong initiative in implementing effective floodplain zoning. Now that few federal flood-control projects are being built, the importance of floodplain zoning becomes more critical.

As shown previously, land use has primarily tended to lessen flooding. The increase in forest acreage and the decrease in harvested cropland in the past few decades has tended to decrease runoff and erosion in the 15-county flood area, while surface mining and urban construction have tended to increase them.

An adequate flood forecasting and warning system is often effective in saving lives, but is less effective in decreasing property losses, especially in the upper tributaries because of the short time available to act. Because of the travel time required for the flood crest to move downstream, warnings may be more effective in the lower reaches by allowing transportable property to be moved to higher ground.

Even though flood forecasting stations throughout the mountains are being expanded, insufficient rainfall gaging stations, steep slopes, and high stream gradients make forecasting difficult and reduce the possible warning time. The response to flood forecasts of the April 1977 flood must be credited for saving lives and reducing property damage. Still, local governments are seeking to improve the warning systems.

The value of evacuation plans was clearly shown in Barbourville where a complete evacuation plan had been developed with the assistance of the Nashville District Corps of Engineers. When it became evident that the April 1977 flood would crest higher than the Barbourville levee, the evacuation plan was implemented. Evacuation progressed so smoothly that leaders could soon give full attention to the mobilization of manpower, trucks, bags, and sand to successfully sandbag the levee.

Provided by the Federal Flood Insurance Program and administered by the U. S. Department of Housing and Urban Development, flood insurance reimburses policy holders for most of their financial loss from flooding. In order for flood insurance to be sold in a community or county, the local governing body must (1) apply to be included in the program, (2) establish a building permit system, (3) agree to consider flood risk when issuing building permits, and (4) agree to enact floodplain control measures upon receipt of detailed flood studies from HUD.

After meeting these initial requirements the community or county is placed in the *emergency phase* of the Flood Insurance Program thereby making federally-subsidized insurance available for purchase. After receiving detailed floodplain studies and implementing floodplain management measures, the community or county enters the *regular phase* of the program. All new policies sold after the regular program is in effect are at the actuarial rates. Those who purchase insurance in the emergency phase continue to renew policies at the subsidized emergency rate.

As of April 1, 1977, five of the 15 counties and 23 of the 32 municipalities in the disaster area were under the emergency program. See Table IV.[24] One county and four municipalities were under the regular program. Insurance policies held by 1,361 firms or individuals had a value of $25,546,000.

Any currently non-participating county or municipality can enable its residents in flood-prone areas to purchase affordable flood insurance if they will agree to zone floodplains so that further construction of damageable property therein is prohibited.

TABLE IV[24]

National Flood Insurance Program Status of
Kentucky Disaster Area as of April, 6, 1977

Community Name	Status**	Identification
Bell County	E	December 6, 1974
Middlesboro	R	November 14, 1975
Pineville	E	February 13, 1976
Floyd County	E	December 13, 1974
Prestonsburg	E	October 1, 1976
Wayland	E	March 5, 1976
Wheelwright	E	March 5, 1976
Allen	NP	+ Jan. 23, 1974 & Feb. 27, 1976
Martin	NP	+ May 24, 1974 & Jan. 27, 1976
Harlan County	E	November 29, 1974
Benham	E	May 17, 1974
Cumberland	E	June 25, 1976
Evarts	E	May 17, 1974 & Jan. 27, 1976
Harlan	E	May 21, 1976
Loyall	R	November 7, 1975
Lynch	E	June 4, 1976
Wallins Creek	R	March 2, 1973
Johnson County		
Paintsville	E	March 1, 1974 & Jan. 13, 1976
Knox County	E	May 21, 1976
Barbourville	E	August 30, 1974
Leslie County		
Hyden	E	August 20, 1976
Martin County	NP	+ December 13, 1974
Perry County	R	August 3, 1976
Hazard	R	February 20, 1976
Vicco	NP	+ May 10, 1974 & March 5, 1976
Pike County		
Pikeville	E	February 13, 1976
Coal Run	NP	+ January 10, 1975
Phelps	NP	August 1, 1975
Whitley County	E	December 20, 1974
Corbin	E	February 20, 1976
Williamsburg	E	March 5, 1976
Knott County		
Hindman	E	July 16, 1976
Lawrence County		
Louisa	E	October 29, 1976
Letcher County		
Fleming	E	December 13, 1974
Jenkins	E	July 23, 1976
Neon	E	February 13, 1976
Whitesburg	E	March 5, 1976

TABLE IV (cont'd)

Community Name	Status**	Identification
Magoffin County		
Salyersville	E	January 9, 1976
Breathitt County	NP	+ January 3, 1976
Jackson	E	January 2, 1976

** E = Emergency Program
NP = Not Participating
R = Regular Progress
+ = under Section 202a sanctions

Summary:

Affected Counties:	Emergency	5
	Regular	1
	Under Sanctions	2
	Not Identified	7
		15

Affected Muncipalities:	Emergency	23
	Regular	4
	Under Sanctions	5
		32

Conclusion - Land-Use Factors Affecting 1977 Flood

There are primarily two land uses that aggravated the April 1977 flood. These are surface mining and floodplain developments.

Surface mining has considerable impact on any watershed in which it occurs from the standpoints of runoff and of sedimentation. *Although surface mining probably caused significantly increased flood levels on the small tributaries below individual operations and probably contributed significantly to the sediment deposits left by the flood, there would have been a major flood in eastern Kentucky even if surface mining had not existed.*

Development in the floodplains of eastern Kentucky is largely responsible for the extremely high losses due to the April 1977 flood. Much of the urban and other development which has occurred and continues to occur is in areas that are certain to flood at some time. Every dollar spent on these developments is a gamble on the unlikelihood of a large flood. In April 1977, many investors in eastern Kentucky lost.

Other recent land use changes in the area--a decrease in agricultural land and an increase in forested area--tended to reduce flood potential, as did the Corps of Engineers' operation of flood control structures.

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Population figures for 1975 and projected were taken from a Preliminary Release, Urban Studies Center, University of Louisville, August 12, 1977.

20. Current Population Reports, U. S. Dept. of Commerce, Bureau of the Census, Series P-25, No. 655. May, 1977.

21. The population increase of 39,276 from 1970 to 1975 was divided by the number of persons per household, approximately 3.4, from the 1970 Census of Housing, HC(1)B19 Ky.

22. All miscellaneous information was provided by Corps of Engineers, Cincinnati, Louisville, Huntington and Nashville, including minutes of Reservoir Operations Committees meeting.

23. This information was taken from a letter by E. C. Moore, Chief of the Engineering Division, Nashville District Corps of Engineers to Bernie Carter, Office of the Governor, dated September 15, 1977.

24. This information was obtained from a letter from Glenn C. Woodward, Jr., Director of Region IV, Federal Insurance Administration, dated April 7, 1977.

SUMMARY-PART II

As shown in the preceeding sections of this report, the eastern Kentucky floods of April, 1977 were devastating. In the aftermath, many wonder whether human activities, such as increased strip mining, caused flood levels to be higher. The following is a summary of the information presented in Part II of this report regarding such questions.

Rainfall and Runoff

According to U. S. Weather Service information, the rainfall contributing to the April, 1977, flood exceeded all previous records at Baxter, Pikeville, Pineville, and Whitesburg. It was less than record rainfalls by 1.68 inches (1957) at Barbourville, 1.54 inches (1973) at Middlesboro, and 0.52 inch (1957) at Hazard.

Total rainfall for the third and fourth of April, 1977 in the eastern Kentucky flood area approached the 48-hour, 100-year recurrence interval rainfall only at Harlan (the gage at nearby Baxter recorded 6.78", compared to 100-year expectancy of 7.2"). Recorded rainfalls were also less than the 24-hour, 100-year recurrence interval at all gages. The 24-hour recorded amount at Middlesboro was near the 100-year expectancy, however (6.0" recorded versus 6.3" expected).

Considered by themselves, the rainfalls that were recorded in the flood areas would not explain the high rates of flooding (the recurrence interval of the floods ranged as high as 150 years at Pineville and 200 years at Pikeville). However, the rain gages in the area are few and widely scattered (see the data points on Figure 2, Chapter IV), so there could have been much higher rainfalls in areas away from the gages. In addition, it is not the rainfall at a flood location that determines the degree of flooding there. It is the rainfall in the watershed above the flood location that matters. Very high total rainfall amounts fell in the upper portions of the streams that flooded, ranging as high as 15½ inches, unofficially, in the upper portions of the Big Sandy watershed.

Since the rainfall totals and distributions are nebulous and since streamflow information is sketchy, it is impossible to determine what effects surface mining, floodplain developments, or any other land use had on the floods of April.

For any location within a floodplain, it is almost certain that surface mining, timber harvesting, or the existence of a city in the watershed above will increase flood heights at that location. The amount of this increase is impossible to determine at present.

However, since the affected cities within the 15-county disaster area are located in the floodplains, it is certain that they will continue to be flooded; and, even if no further developments occur, there will someday be an even worse flood than that of April, 1977.

Effects of Developments on Runoff and Streamflow

Streamflows of record or near-record levels occurred in the Big Sandy and Cumberland headwaters. Runoff from the heavy rainfall was increased by disturbances of the soil and by impervious surfaces. Development within floodplains obstructed streams and thereby increased flood levels.

Active strip mining involves about three percent of the total land in the area, two percent of the drainage area in the worst flooded counties. The combination of previously and currently permitted acreage (1954-1976) ranged as high as 8.6 percent of the land in Martin County and 9.6 percent in Perry. These percentages in some small watersheds undoubtedly run much higher.

Most studies made previously indicate that active surface-mined areas result in faster runoff and increased erosion. At least one report indicates that in time surface-mined areas which are regraded and revegetated may yield lower rates of runoff than they did prior to mining. This may require five to ten years after mining.

Agricultural practices involved much less acreage, especially on sloping land, than 30 years ago. The decrease of 483,000 acres in harvested cropland mentioned under "Effects of Agriculture," removed practically all hill land from cultivation and returned much of it to woodland, thus tending to reduce runoff from any given rainfall.

Effects of Erosion and Sedimentation

Erosion from surface mining varies with the care of the spoil and benches, and the rate and practices of reclamation. Research indicates that active strip mining contributes four to six times as much sediment per acre as do agricultural practices.

The increase of 240,000 acres of forests, pointed out in the section on "Effects of Forests," greatly improved the erosion resistance of that acreage.

RECOMMENDATIONS

A. Surface Mining

1. Implement the "Surface Mining Control and Reclamation Act of 1977," Public Law 95-87 requiring operators to use mining techniques which, in aggregate, will tend to lessen the impact of surface mining on flooding. Among the requirements are:

    a. removal, segregation, preservation and replacement of topsoil;

    b. disturbance of the prevailing hydrologic balance at the mine site and in associated off-site areas must be minimized;

    c. reclamation efforts must proceed in an environmentally sound manner as contemporaneously as possible with the mining;

    d. access roads into and across mining sites must be constructed and maintained so as to control or prevent environmental damage;

    e. a diverse, effective and permanent vegetative cover of the same seasonal variety native to the area of land affected must be established on all affected lands;

    f. the operator must assume responsibility for a successful vegetative cover for a period of five full years after the last year of reclamation;

    g. all excess spoil must be disposed of so as to insure stability, proper drainage and to be compatible with the natural surroundings and suitable for intended uses;

    h. no debris, abandoned or disabled equipment, spoil material or waste mineral matter may be placed downslope below the bench or mining cut.

The Act also makes provisions for an abandoned mine reclamation fund to consist of monies from reclamation fee, user charges, and private donations.

Kentucky should implement an interim program to include as many of the provisions of the Federal Act as possible. A permanent program, including primacy for the Act, should be established at the earliest possible date.

2. Initiate experimental and empirical studies of the effects of the surface mining on flooding of medium and large watersheds. This is an area where information is woefully lacking. More information is mandatory if the environmental problems associated with strip mining are to be solved.

3. Study means of stabilizing valley fills and benches under various soil and bed-rock conditions and natural slope.

4. Study the mountain region to identify sites of current or potential surface mining in which mountain tops may be removed and combined with valley fills to provide potential flood-free development sites. Specify the major requirements and limitations of each site, the area that would be provided, and an approximate cost figure for subsidizing the hilltop removal and providing access roads and utilities to the site.

B. Floodplain zoning and management. Flood damages are directly related to the value of damage-susceptible properties in the floodplain. Steps must be taken to ensure that no further flood-damageable development be placed in the floodplains and that any property currently within a floodplain be protected by all available measures. This can be accomplished by floodplain zoning and strongly enforced permitted usage with restricted public services to flood-prone areas. These measures include:

1. Require that future structures in the unprotected floodplain be elevated above the expected flood level. Promote flood proofing of existing structures.
2. Develop a positive plan to substitute agricultural or recreational uses of the floodplain for existing or potential structures of higher potential damage value. This might require a community to make alternative sites available for development. Mountain top removal and valley fills should be investigated as alternatives.
3. Local governments must develop and enforce effective floodplain management measures.
4. Restrict the construction of streets and urban services in flood-prone areas.

C. Other Flood Damage Abatement Measures

1. Encourage the Corps of Engineers and the Soil Conservation Service to reassess all flood-prone areas to determine if structural alternatives are feasible. Assist local communities in analyzing these opportunities and in implementing them.
2. Improve management of forest lands through state and local action to:
   a. Pursue more effective implementation of laws against forest fires.
   b. Require well-planned timber harvesting procedures.
   c. Promote reforestation, timber stand improvement and management.
3. Require local permits for development site construction that will protect against excessive runoff and erosion.

4. Review highway and street construction guidelines to assure:

    a. Adequate stream clearance by new bridges and evaluation of potential remedial measures of existing restrictive bridges.

    b. Possible modification of stream channels to adequately compensate for any road fill in a floodplain.

5. Provide stronger encouragement for communities to qualify for and citizens to purchase flood insurance by including:

    a. Requirements for loans and grants and flood relief.

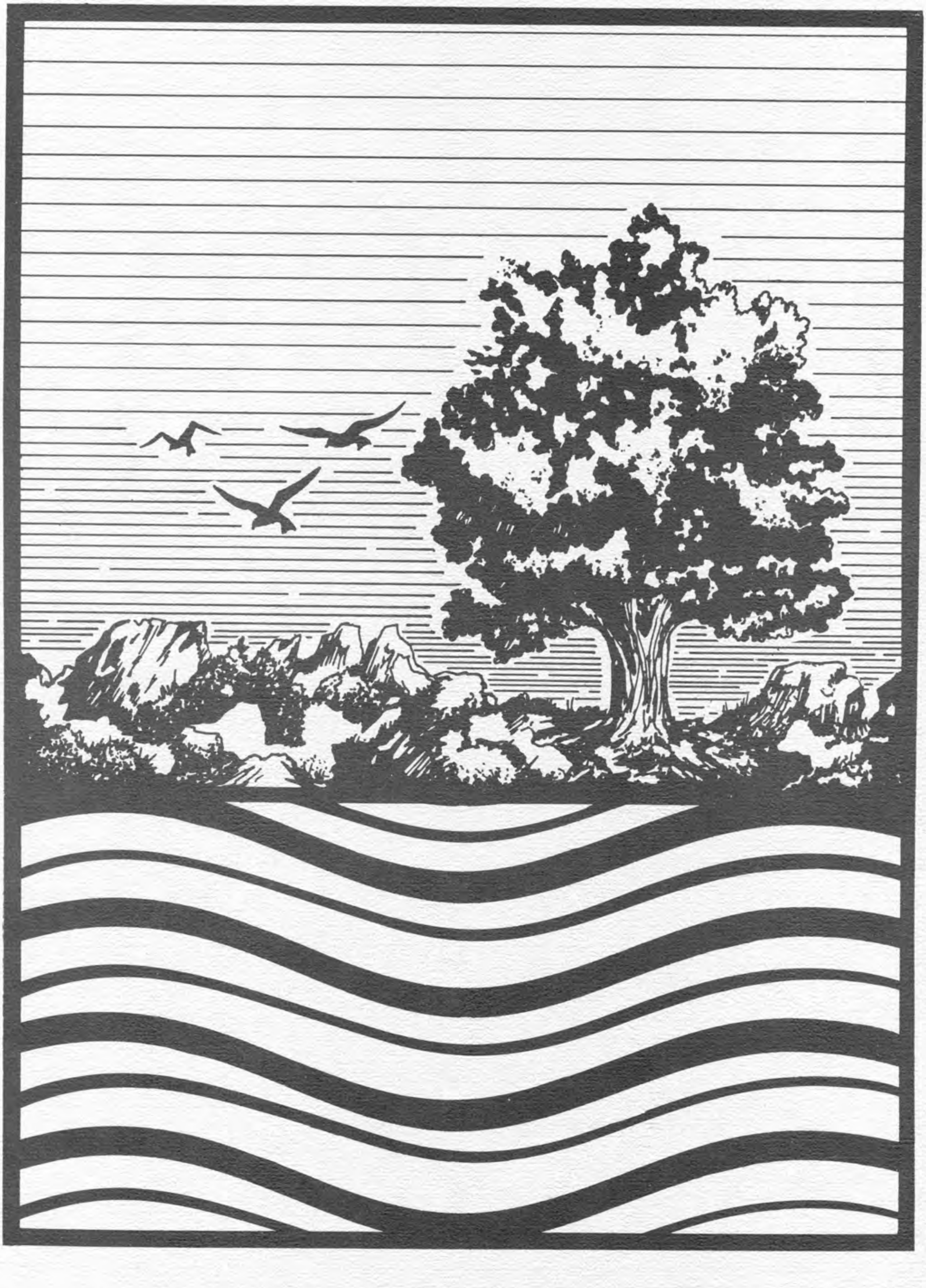
    b. Educational and planning assistance to affected communities.

6. Expand warning and evacuation systems, including:

    a. Additional rain gages, especially on the mountains.

    b. Improved warning systems.

    c. Evacuation plans kept current and with local government understanding and support.



The Floods of April

GLOSSARY

GLOSSARY

ACCELERATED EROSION -- the increased rate of erosion over the normal, or geologic, erosion due to man's activities.

ACRE-FOOT -- a unit of volume equal to one foot of depth over an acre, or 43,560 cubic feet.

ANNUAL FLOOD -- see mean annual flood

ANTECEDENT MOISTURE -- the amount of moisture in the soil preceding a storm.

BEDLOAD -- that portion of sediment transported by rolling or sliding along the bed of a channel.

BUILDING CODE -- a collection of regulations adopted by a local governing body setting forth standards for the construction of buildings and other structures for the purpose of protecting the health, safety and welfare of the public.

CHANNEL -- a natural or artificial watercourse of perceptible extent, with definite banks and bed to confine and conduct continuously or periodically flowing water.

DESIGN FLOOD -- the flood against which a flood protective or control measure is designed to protect an area.

DESIGNATED FLOODWAY -- see floodway

DISCHARGE -- the volume of water per unit time flowing past a given point on a stream, normally expreseed in cubic feet per second (c.f.s.).

DRAINAGE AREA -- see watershed

ENCROACHMENT LINES -- the lateral limits bounding a stream within which no structure or fill may be placed.

ENERGY GRADE LINE -- the mathematically-defined line which indicates the total flow-producing energy available along a stream due to elevation and velocity.

EROSION -- the detachment of soil or rock particles through the kinetic energy of raindrop impact or by the forces generated by flowing water. (Erosion may be classified as accelerated, geological, gully, rill, or sheet erosion. See these headings for further information).

FALLOW LAND -- land that has been plowed and harrowed without seeding for the purpose of destroying weeds or conserving moisture.

FLOOD -- an overflow of water onto lands not normally covered and that are used or usable to man.

FLOOD CONTROL -- the elimination or reduction of flood losses by construction of dams, channel improvements, levees and floodwalls, bypass channels, or other engineering works.

FLOOD CREST -- the maximum stage or elevation reached by the waters of a flood at a given location.

FLOOD DISCHARGE -- see discharge.

FLOOD FREQUENCY -- see recurrence interval.

FLOOD PEAK -- the maximum instantaneous discharge of a flood at a given location, usually occurring at or near the flood crest.

FLOODPLAIN -- the relatively flat area or low lands through which a river, stream, or watercourse flows and which sometimes may be covered by floodwater.

FLOODPLAIN REGULATIONS -- a general term applied to the full range of codes, ordinances, and other regulations relating to the use of land and construction within the channel and floodplain areas. The term encompases zoning ordinances, subdivision regulations, building codes, etc.

FLOOD PROOFING -- a combination of structural methods and adjustments to properties subject to flooding, primarily for the reduction of flood damages.

FLOOD-RETARDING STRUCTURE -- a concrete, masonry, or earthen dam constructed solely for the purpose of protecting a flood-prone area downstream through the storage and controlled release of flood flows.

FLOOD STAGE -- the stage or elevation at which overflow of the natural banks of a stream begins in the reach or area in which the elevation is measured.

FLOODWAY -- the channel of a stream and that portion of the adjoining floodplains designated to provide for reasonable passage of flood flows without significant heading up.

FLOW RATE -- see discharge.

GEOLOGIC EROSION -- the rate of erosion that will occur naturally in an area with no alteration or disturbance by man.

GULLY EROSION -- erosion caused by flowing water concentrated so as to form a channel.

HEAD -- the energy, per unit weight of still or flowing water generally measured in feet.

HEADING UP -- the upstream rise in water surface caused by some obstruction such as a narrow bridge opening or buildings or fill material that limits the area through which water must flow.

HISTORICAL FLOOD -- any known flood for which there is no gage record or other systematic or usable technical record.

HYDRAULIC RADIUS -- the quotient of the cross-sectional area of flow for an open channel divided by the wetted perimeter.

HYDROGRAPH -- a graph or curve representing the stage or discharge, at a particular location on a stream, plotted against time during a flood.

HYDROLOGIC CYCLE -- the perpetual series of events and related processes whereby water evaporates, forms clouds, precipitates, becomes streamflow, flows to the oceans, and evaporates once more.

HYDROLOGY -- the science dealing with properties, distribution, and circulation of water on the surface of the land, in the soil and underlying rocks, and in the atmosphere.

INFILTRATION -- is the movement of water through the soil surface into the soil.

KARST AREA -- an irregular region underlain by limestone or other soluble rock and having sink holes and underground streams and caverns.

LAG TIME -- the time difference from the centroid of rainfall to the associated hydrograph peak.

MEAN ANNUAL FLOOD -- the arithmetic mean of the highest peak discharge experienced during each year of record at a given location. This flood has a recurrence interval of 2.33 years.

MULTIPURPOSE STRUCTURE -- a concrete, masonry, or earthen dam constructed for purpose of recreation, water supply, or navigation as well as the protection of downstream areas from flooding.

NATURAL FLOODWAY -- the channel of a stream or body of water and that portion of the floodplain that is inundated by a flood and therefore used to carry flood flows.

OVERLAND FLOW -- (also called surface runoff) the runoff from a rain fall that travels over the ground surface to a channel.

PEAK FLOW -- see flood peak.

PEAK RUNOFF -- see flood peak.

PERCOLATION -- the movement of water downward through the soil.

POROSITY -- the ratio of the pore volume to the total volume of the soil.

RECURRENCE INTERVAL -- the average number of years between a flood of a given magnitude and an equal or greater flood.

RETURN PERIOD -- see recurrence interval.

RILL EROSION -- erosion of the soil layer forming small channels which are easily removed by normal agricultural methods.

RUNOFF -- that portion of a rainfall which reaches the streams and channels.

RUNOFF PEAK -- the maximum rate of flow that occurs in a channel as the result of a given rainfall.

SALTATION LOAD -- that portion of sediment transported along the bed and in the streamflow in a bouncing motion.

SCARIFICATION -- the breaking up and lossening of the soils surface.

SEDIMENTATION -- the overall process comprised of erosion, sediment transportation, and sediment deposition.

SEDIMENT DEPOSITION -- the opposite process to erosion, wherein material being transported by flowing water is deposited either in the stream channel or on the floodplain.

SEDIMENT TRANSPORTATION -- the movement of eroded materials by flowing water.

SHEET EROSION -- erosion which occurs in such a way that thin, uniform layers of soil are removed.

SILTATION -- see sediment deposition.

SINK HOLE -- a depression formed in karst area either by the dissolving of soluble underlying rock by water percolating through it or by the collapse of the roof of an underground cavern.

SINUOSITY -- the degree of curviness or winding of a stream.

SPECIFIC GRAVITY -- the ratio of the density of a substance to the density of water.

SPOIL -- the earth and rock which is excavated in a strip-mining operation in order to remove the underlying mineral.

STRIP MINING -- a mine that is worked from the earth's surface by the stripping of overburden.

SUBDIVISION REGULATIONS -- regulations and standard established by a local authority, generally the local planning agency, for the subdivision of land in order to secure coordinated land development, including adequate building sites and land for vital community services and facilities such as streets, utilities, schools, and parks.

SURFACE MINING -- any mine that is worked from the earth's surface, especially strip mines and auger mining.

SUSPENDED SEDIMENT -- the sediment that is carried in the flow of a stream by the turbulence of the flow.

TIME OF CONCENTRATION -- the time required for rainfall falling on the most distant part of the watershed to reach a given point on the stream.

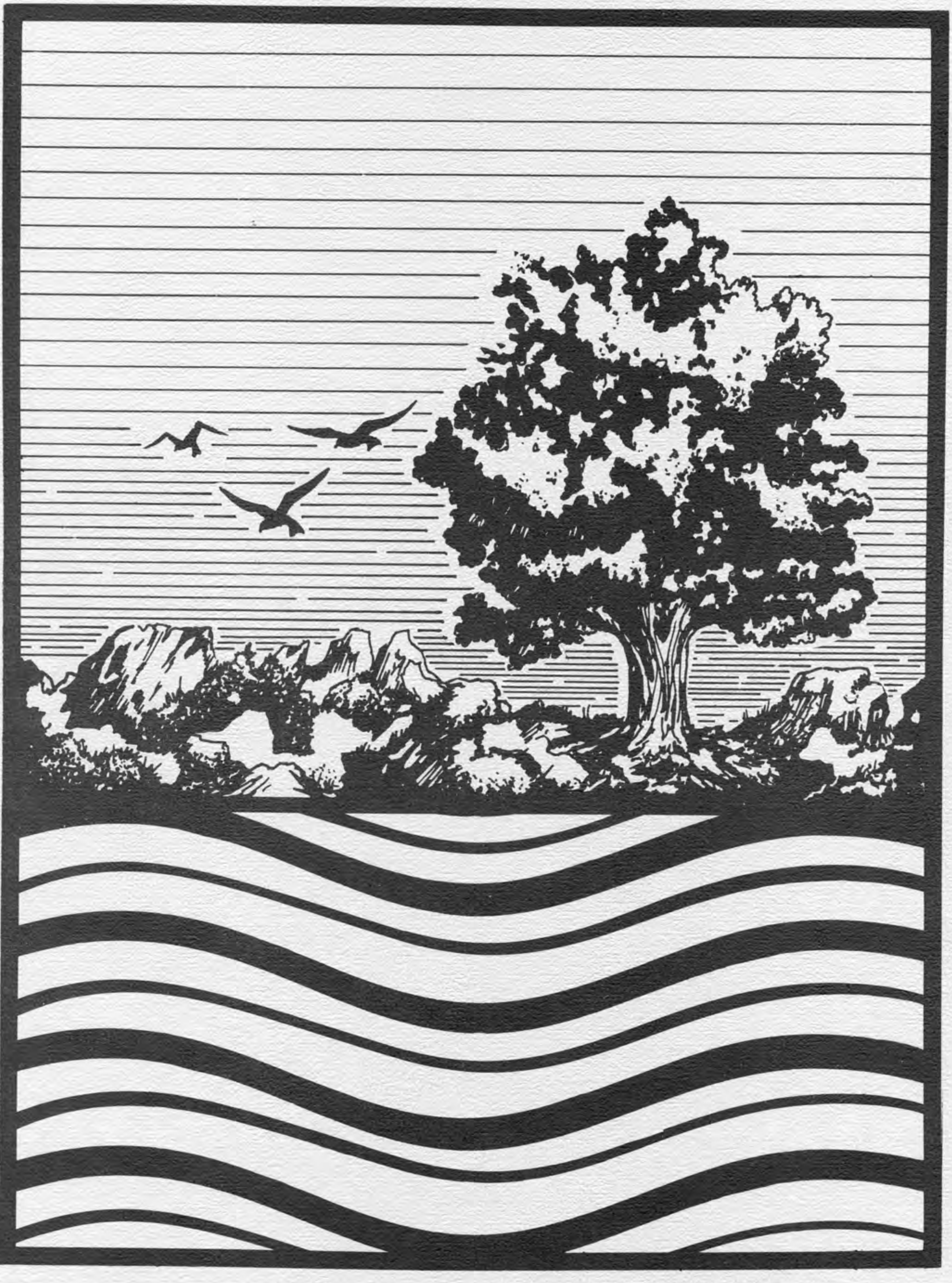
TOPOGRAPHY -- the configuration of the earth's surface including its relief and the location of any natural or man-made features.

WASHLOAD -- the portion of the small sediment particles transported by the stream along the bed, although they are small enough to be suspended.

WATERSHED -- the area above any point on a stream enclosed by a topographic divide such that any precipitation which falls within this area will normally drain by gravity to that point.

WETTED PERIMETER -- that portion of the cross-sectional outline of an open channel that is in contact with the streamflow.

ZONING ORDINANCE -- an ordinance adopted by a local governing body which under police power divides an entire local governmental area into districts and, within each district, regulates the use of land, the height, bulk, and use of buildings and other structures, and the density of population.



The Floods of April

APPENDIX

REPORT ON FORESTRY AND FLOODING IN FIFTEEN DISASTER COUNTIES IN EASTERN KENTUCKY

1977

Fifteen eastern Kentucky counties suffered tremendous losses as a result of a severe flood which occurred in April, 1977. In addition to the unusually heavy rainfall with the resulting runoff, losses are attributed to the heavy accumulation of silt.

In an effort to gain information on factors contributing significantly to these losses, attention has been focused on activities that could possibly contribute to runoff and sedimentation. This particular report focuses attention on forestry activities in the 15-county area.

In brief summary, as a result of the information obtained and judging from the data gathered from the most reliable known sources on forest hydrology, it can be concluded that forestry and logging activities did not contribute significantly to the flooding in eastern Kentucky. This conclusion was reached after giving full consideration to the major activities relating to forest treatment and flood runoff. These major activities are identified as (1) Harvesting; (2) Burning and (3) Other considerations. Details relating to each of these identified activities are as follows.

I. HARVESTING:

Table VIII shows the number of acres of woodland harvested and the calculated miles of logging roads constructed from 1972 to 1975 in 15 counties in eastern Kentucky. Area harvested in 1976 is estimated to be lower due to the downward trend since 1973; however, there is no data available on this at this date.

The significance of this data is reflected by comparing the average yearly land area affected by logging with the total land area. As indicated, these acreages are 24,265 and 3,854,636 respectively. Calculating the effects as a percent of the total shows that a very insignificant six-tenths (.6) of one percent (1%) of total land area is affected per year by logging activities.

In addition, and in direct reference to sedimentation, under natural conditions and with no disturbances, the normal sediment on 3,303,200 woodland acres in the 15-county area that reaches the streams would be 330,320 tons. This is based on factors stated by George Dissmeyer, Hydrologist, U. S. Forest Service. According to Jim Patrick, Hydrologist, U. S. Forest Service, Parsons, West Virginia, "Effects of logging is gone two years following logging activity". For 1976 it is estimated, using maximum factor, that 17,281 tons of sediment reached the streams due to logging effects. In 1975 logging contributed 20,229 tons of sediment to the streams. Therefore, it is evident that logging over the past two years contributed an additional .11% sedimentation over and above natural conditions.

II. BURNING:

Table IX shows the woodland acres burned during the six-month period prior to the 1977, 1972 and 1957 floods. Total woodland acreages in the counties is also presented.

The significance of the woodland acreas burned data lies in comparing the acres burned for the six-month periods prior to each of the major floods occurring in 1957, 1972 and 1977. The total acres burned for these periods are 19,380, 1,066, and 57,246 respectively. The effects of burning cannot be significant judging from the fact that a major flood occurred in 1972 when only 1,066 acres burned, and major floods occurred in both 1957 and 1977 when the acres burned amounting to 19,380 acres and 57,246 acres were significantly greater.

In direct reference to sedimentation for 1976, it is estimated, using maximum factors, that the burned area contributed 11,449 tons of sediment to the streams. This is .004% above the normal rate of erosion.

In addition, the following supporting information reflects further the effects of burning on peak flows. The following statements are taken from "Forests and Floods in the Eastern United States", Research Paper NE-226, page 40 and page 42.

(1) "The effect of burning on flood peaks depends on the proportion of watershed burned and the intensity of the fire. Theoretically, burning may have a greater effect than harvesting; as noted, clearcutting may well have no major effect on flood peaks because of the protective influence of the forest floor; this protection may be destroyed in a watershed completely burned. Despite the potentially damaging effect of fires, however, their hydrological effect in the main is negligible because of current high levels of fire protection."

(2) "Peak Flows. - The effects of burning on peak flows are often assumed to be destructive and self-evident. But if we judge the seriousness of a problem by the research undertaken to meet it, the effects have not been sufficient to generate concern; there are in the East no watershed studies of the effects of fire on flood peaks."

(3) "Plot studies, previously described, point to deleterious effects from repeated burnings, a situation no longer prevalent in any forest region. Annual wildfires are a thing of the past. Prescribed burning in the Atlantic Coastal Plain may come closest to it. Designed to reduce brownspot infection of longleaf pine seedlings, or competition from hardwoods, or fire hazard, it calls for burning every 3 to 10 years (Smith 1962). There has been no evidence, however, that this now commonly accepted practice results in any great increase in peak flows."

(4) "A substantial reduction in area burned has served to diminish the hydrological importance of fire in the East. From 1931 to 1936 an average of 2.3 million acres of forest land burned annually; from 1961 to 1966 the average was 1.0 million acres (USDA Forest Service 1967), or about 0.3 percent of the total forest area. Forest fires, on area alone, cannot be considered a major cause of floods."

III. OTHER CONSIDERATIONS:

Other considerations relate specifically to runoff, storm size, and flood peak. Of great significance are the references to these individually identified subjects as set forth in the following paragraphs taken from Research Paper NE-226, "Forests and Floods in the Eastern United States."

In a sense, a four-line defense in depth restricts increases in flood peaks and flood runoff after clearcutting. First, as the small-watershed studies plainly indicate, overland flow is not generated where the forest floor is not disturbed; seasonal peak flows and storm runoff increase, on the average by only about 10 to 20 percent. In the second line, most overland flow from logging roads, landings, and other disturbed areas can be absorbed by infiltration into adjacent areas, especially where logging operations are properly planned and conducted. Third, the increase in peaks and storm runoffs diminishes--probably dropping to negligible amounts within 5 to 10 years--as regrowth re-establishes interception and storage opportunity. Fourth, rarely is more than 1 to 2 percent of any management unit clearcut in any year under a sustained-yield program of forest management; where forest holdings are in many ownerships of limited area, variation in age and condition of the stands limits the amount clearcut at any one time.

This scattering of clearcuttings could not mount a major flood threat. For example, 10 percent of a major forest watershed in various stages of growth after clearcutting under evenaged management might produce 10 percent more unit-area discharge. Given a rainfall that would produce 6 inches of runoff from the uncut area, the increase in runoff from the areas as a whole would be 1 percent, from 6.00 to 6.06 inches. The likelihood that these increases will become synchronized to augment the flood peak is indeed remote because these increases are derived from various parts of the watershed.

In addition, both James Kennamer, Soil Conservation Service, Lexington, and Willie Curtis, USDA Research Center, Berea, contributed comments reflecting the following information relating to runoff.

A. <u>RUNOFF</u>:

"Under field capacity conditions given rainfall amounting to 7-15 inches in a 24-hour period, significant flooding will result. With soil completely saturated, with all pore spaces filled, any added water must run off."

"Any time field capacity conditions exist, rainfall amounting to 6-11 inches in a 24-hour period will produce severe flooding. Under field capacity conditions, the soil can absorb no additional water, and regardless of any man-caused activity the water must run off and flooding will result."

B. <u>STORM SIZE</u>:

In direct reference to storm size and again referring to Research Paper NE-226, the following information is significant.

"From what has gone before, it should be apparent that the forest has a relatively greater influence on storm flow from small storms; interception accounts for a larger proportion of small rainfalls, and the opportunity for soil-moisture storage will subtract a great proportion from the smaller rainfalls. The forest has less effect, proportionately, on extreme storm events. As Hoyt and Langbein (1955) put it: "We know, however, that nationwide floods seem to roll out of forests as well as off farms'. These floods have been described as follows (Cook 1945):

> 'The great floods that inundate the principal valleys (do so much damage to river cities) are caused by general and protracted storms, covering wide areas and precipitating great depths of water. Although the rates of rainfall are usually low, the volume is enormous. As a result of such storms, the soil becomes thoroughly soaked and infiltration capacities reach minimum values. Moreover, the thinner soils become saturated and finally can retain no more water. Under these conditions, every small stream over thousands of square miles flows at or above bank-full stage for many days. The tremendous volumes of water moving down through the tributaries pass into the valley of the main stream, filling it like a great trough into which water is poured from both sides. Runoff causing floods like these is, of course, affected but little by treatment of the land."

IV. REFERENCES AND MATERIAL:

As indicated earlier the conclusion that forestry and logging activities did not contribute significantly to the flooding in eastern Kentucky was based on data gathered from the most reliable known sources on forest hydrology. The following individuals and source material provided information relating to the statements and data included in this report.

George Dissmeyer, Hydrologist
USDA - Forest Service
Atlanta, Georgia

Dr. George Coltharp
University of Kentucky
Lexington, Kentucky

Jim Patrick, Hydrologist
USDA - Forest Service
Fernow Experimental Forest
Parsons, West Virginia

Mr. Willie Curtis, Hydrologist
USDA - Forest Service
Berea Forest Experiment Station
Berea, Kentucky

James Kennamer, Watershed Planner
USDA - Soil Conservation Service
333 Waller Avenue
Lexington, Kentucky

In addition, repeated references are made to the research paper: Forests and Floods in the Eastern United States. Lull, Howard W., and Reinhart, Kenneth G., USDA Research Paper NE-226, 1972.

For detailed reference and further study the above reference is recommended.

Table VIII:	Forestry and Flooding, 15 Disaster Counties 1977
Table IX:	Acres Woodland Burned

TABLE VIII

FORESTRY AND FLOODING

15 DISASTER COUNTIES - 1977

County	1976 Acres Harvested	1976 Miles Road	1975 Acres Harvested	1975 Miles Road	1974 Acres Harvested	1974 Miles Road	1973 Acres Harvested	1973 Miles Road	1972 Acres Harvested	1972 Miles Road
Bell	NO DATA		940	5.87	1,387	8.67	2,672	16.70	1,294	8.08
Breathitt			850	5.31	1,121	7.00	468	2.92	60	.37
Floyd	AT		760	4.75	191	1.19	0	0.00	1,126	7.03
Harlan			3,625	22.65	3,869	24.18	4,625	28.90	4,487	28.04
Johnson	THIS		520	3.25	563	3.51	588	3.67	242	1.51
Knott			530	3.31	816	5.10	277	1.73	5,028	31.42
Knox	DATE		3,520	22.00	2,097	13.10	4,670	29.18	212	1.32
Lawrence			2,300	14.37	2,954	18.46	2,452	15.32	1,365	8.53
Leslie	TREND		250	1.56	2,734	17.08	2,065	12.90	2,027	12.66
Letcher			1,200	7.50	181	1.13	2,583	16.14	2,656	16.60
Magoffin	OF CUT		760	4.75	856	5.35	1,841	11.50	200	1.25
Martin			920	5.75	1,034	6.46	702	4.38	952	5.95
Perry	IS		830	5.18	1,491	9.31	1,456	9.10	311	1.94
Pike			1,100	6.87	1,161	7.25	2,747	17.16	2,192	13.70
Whitley	DOWN		2,194	13.71	2,862	17.89	2,042	12.76	1,606	10.03
			20,299	126.83	23,317	145.68	29,188	182.36	23,758	148.43
			(104)		(120)		(150)		(122)	

(1 Mile of Road Considered Contains 1.21 Acres)

Total Land Area of 15 Counties 3,854,636 Acres; Average Yearly Land Area Effected by Logging 24,265; .6% of Total Land Area Effected per Year by Logging.

Only about 3 years of log road effect can be considered as silt producing (if that). Not 5 years. Counting the last 3 years at an average of 124 acres per year (372 acres, 3 years) amounts to .01% of the land area in log road possibly contributing silt.

Numerous pieces of research prove that harvesting, including "Total" clear cutting, is not a factor on flooding.

Source: Kentucky Division of Forestry

TABLE IX

ACRES WOODLAND BURNED

County	A. 10/1/76 - 3/31/77	B. 9/1/71 - 2/28/72	C. 8/1/56 - 1/31/57	M Acres Commercial Forest Area
Bell	1,784	26	231	188.4
Breathitt	4,025	15	1,139	277.4
Floyd	3,896	248	2,971	211.2
Harlan	1,579	16	348	268.2
Johnson	3,476	39	354	154.4
Knott	10,451	22	1,455	203.7
Knox	4,162	188	323	184.5
Lawrence	1,947	58	574	217.9
Leslie	981	17	1,532	246.7
Letcher	8,579	77	1,352	194.5
Magoffin	1,891	27	1,029	163.3
Martin	1,838	25	594	129.9
Perry	4,666	35	3,749	192.2
Pike	4,959	204	3,656	441.7
Whitley	3,012	69	73	229.2
TOTAL	57,246	1,066	19,380	3,303.2
				85.69% of Total Area

Source: Kentucky Division of Forestry