Report No. FHWA-RD-74-74

A SAMPLE COMPARISON OF THE GEOMORPHIC CHARACTER OF TWO RIVER BASINS AS RELATED TO SUSCEPTIBILITY TO BRIDGE FAILURE

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October 1974
Final Report

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FEDERAL HIGHWAY ADMINISTRATION
Offices of Research & Development
Washington, D.C. 20590

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16. Abstract From the well-known hypothesis that it is expected that a degree of geologically based similarity would exist in the surface properties of those systems showing a similarity of surface geometry, it is reasonable to assume that drainage basins with the same degree of stability (or instability) possess a certain similarity in geomorphology and channel networks, and vice versa. This study intended to show, in part, the validity of this assumption for two river basins and to point out the importance of a geomorphic investigation of the basin in bridge and also for preventive maintenance of existing bridges. The Tye River Basin was selected as an example of an unstable basin and the North Fork Rivanna River Basin as a stable basin.

The extremely intensive rainfall from Hurricane Camille was a main reason for four failures out of seven bridges in the Tye River Basin; however, the unstable character of the basin itself appeared to be a contributing factor in these catastrophic failures. The analysis clearly reveals the unstable character of the Tye River Basin as related to water and sediment discharges. It is also shown that the geomorphic character of the North Fork Rivanna River Basin is distinguishably different from that of the Tye River Basin.

Because the extent of the study was limited and the analysis is not yet conclusive, it is recommended that more data of this type be collected and analyzed in order to determine the nature of a river basin and its degree of stability from the geomorphic character of the basin as a means of improving bridge design and preventive maintenance of existing bridges.

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UNITED STATES GOVERNMENT

DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

Memorandum

DATE: December 9, 1974

SUBJECT: Transmittal of Research Report No. FHWA-RD-74 - "A Sample Comparison of the Geomorphic Character of Two River Basins as Related to the Susceptibility to Bridge Failure"

In reply refer to: HRS-42

FROM : Project Manager, FCP Project 5H
Environmental Control Group

TO : Individual Researchers

Distributed with this memorandum is the subject report intended primarily for research audiences. This report will be of interest to hydraulic researchers and to State Highway Hydraulics Engineers who are interested in conducting geomorphic investigations for river basins.

This study was initiated as a followup to the FHWA sponsored "River Mechanics Course" which was conducted in 1973 at Colorado State University. The report illustrates the types of analyses that might be helpful in determining the stability of a given river basin. The author included an appendix listing step-by-step procedures he used in making his analyses.

Additional copies are available from the National Technical Information Service (NTIS), Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22151. A small charge is imposed for copies provided by NTIS.

Roy E. Trent

Attachment

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LIST OF FIGURES AND TABLES

PREFACE

This is a follow-up study based on the writer's report on "A Statistical Summary of the Cause and Cost of Bridge Failures" where it was found that more than 30 percent of bridge failures can be attributed to river instability. To curtail this type of bridge failures, engineers must recognize the character of the river over which bridges will be constructed in order to determine what protection they will require. The bridges should then be designed accordingly. Consistent with the well-known hypothesis that it is expected that a degree of geologically based similarity would exist in the surface properties of those systems showing a similarity of surface geometry, it is reasonable to assume that drainage basins with the same degree of stability (or instability) possess a certain similarity in geomorphology and channel networks. To show the validity of this assumption, J. Sterling Jones of the Federal Highway Administration and the writer initiated this study, which was then carried out by the writer.

ACKNOWLEDGMENT

The writer wishes to express his appreciation to J. Sterling Jones of the Federal Highway Administration for his encouragement and support of this study and to Milo Cress of the Federal Highway Administration for his review and valuable comments. The assistance given in compiling the bridge data by Douglas L. Horton and Earl C. Cochran, both of the Virginia Department of Highways, is gratefully acknowledged.

INTRODUCTION

All rivers undergo continuous changes in geometry and flow conditions; some of these changes are vigorous and some are less noticeable. Those rivers with vigorous changes are often classified as unstable, the others are called stable rivers.

Bridges across unstable rivers risk more failures because large floods change the river geometry and the flow takes a new course which often destroys the bridge. Examples of such cases are presented by Karaki and others [7]. In some cases, the upstream sections of the rivers underwent such vigorous changes within less than one year after the bridges were constructed that immediate countermeasures were necessary to protect the bridges. If design engineers had been aware of these river characteristics and the crossings had been selected accordingly, the repair costs would not have been as high. Unfortunately, in the design and site selection of those bridges, the fundamentals of river mechanics were not seriously considered; the possible changes in the course of the river were not an important decision-making factor. These bridge sites were selected based only on the river geometry as it existed at the time of design.

Some engineers have become aware of the need for considering river change in bridge design, yet the present knowledge of river mechanics is still not capable of predicting satisfactorily the future geometry of a river, because rivers undergo local changes in geometry as a result of runoff from precipitation. It is not possible today to accurately predict precipitation for many years into the future in order to assess how a river would change its geometry in that time period. It is therefore suggested in Reference 7 that changes in the course of a river can be estimated to a fair degree of realism by considering the case history of the river and similar examples and to a limited extent by applying the basic principles of geomorphology, hydraulics, hydrology and river mechanics.

The case history for the very river, over which a bridge is to be built, is usually most helpful in predicting how the river will possibly change during the life of the bridge, say 50 years or so. However, the case histories of rivers are seldom sufficiently well documented to be usable for design purposes, nor have most records been maintained long enough to readily allow a realistic prediction of river changes. Therefore, bridge engineers will most likely have to use the examples and case histories of other rivers. The question then arises on which example to choose: obviously the examples of rivers that are similar in climatic, geologic, and geomorphic characteristics.

Long-term climatic fluctuations have caused changes in river geomorphology in finally reaching the present stage. Though it is clear that rivers are dynamic and constantly undergo local changes, will climate drastically change the overall geomorphology of river basins and channel networks within a period of fifty years? It is probable that even a progressive climatic change will not have a detectable influence on the character and behavior of river systems as a whole. This means that rivers that are unstable now will remain unstable and stable rivers will most likely be stable for a number of years.

Schmudde [15] observed in 1963 that about one-third of the flood plain of the Missouri River over the 170-mile reach between Glasgow and St. Charles, Missouri, was reworked by the river between 1879 and 1930. In a study of flood plain vegetation, Everitt [4] concluded that about half of the Little Missouri River flood plain in Western North Dakota was reworked in 69 years. In some rivers, a part of the course seemingly changes in a short time, yet the changes are limited to a certain extent and, taking the river system as a whole, will not be significant in view of long-term observation. Lathrop [10] working on the Rio Ucayali in the Amazon headwaters of Peru estimated that on the average one meander loop will be formed or cut off in 5000 years.

In essence, the present patterns of a river basin and channel network have been formed as the result of integrated climatic, geologic and hydraulic phenomena over many centuries. And thus, to a certain degree, the geomorphology of the river system indirectly reflects the character of precipitation, river regime, and hydrologic inference between them over the whole system. Therefore, a degree of similarity can be expected in subsurface runoff properties in the river systems showing similarity of geomorphology. Eagleson [3] of MIT also stated that it seems reasonable to expect a degree of geologically based similarity in the subsurface properties of those systems showing similarity of surface geometries. If this hypothesis is correct, the geomorphic characteristics of a drainage basin with a stable river would be similar to those of other drainage basins with stable rivers, but would probably be quite different from those with unstable rivers.

OBJECTIVES

It is the purpose of this study to investigate the geomorphic differences between two drainage basins with stable and unstable characteristics by numerical description of the drainage basins and channel networks and to indicate important factors that should be considered in the selection of bridge sites and in predicting the vulnerability of existing bridges to flood damage.

SCOPE

This study (preliminary in nature) shall be limited to two river basins in Virginia, one with serious damages to bridges and the other without noticeable damage during the 1969 Camille floods and the 1972 Agnes floods. From topographic and geologic maps, hydrologic and sediment transport data, and soil profile surveys (when available), a systematic analysis of the geomorphic properties of the two basins will be made and their fundamental differences will be discussed.

The river basins selected for the study are the Tye River Basin above Massies Mill, Virginia, and the North Fork Rivanna River Basin upstream of the Highway 604 crossing. Their locations are shown in Figure 1. The Tye River Basin has seven bridges longer than 20 feet in an area of about 58 square miles. Among these, four were destroyed by Hurricane Camille and rebuilt in 1971; two of these were again severely damaged by Hurricane Agnes. No serious damage was reported in the North Fork Rivanna River Basin where nine bridges are longer than 20 feet in an area of about 54 square miles. These bridge

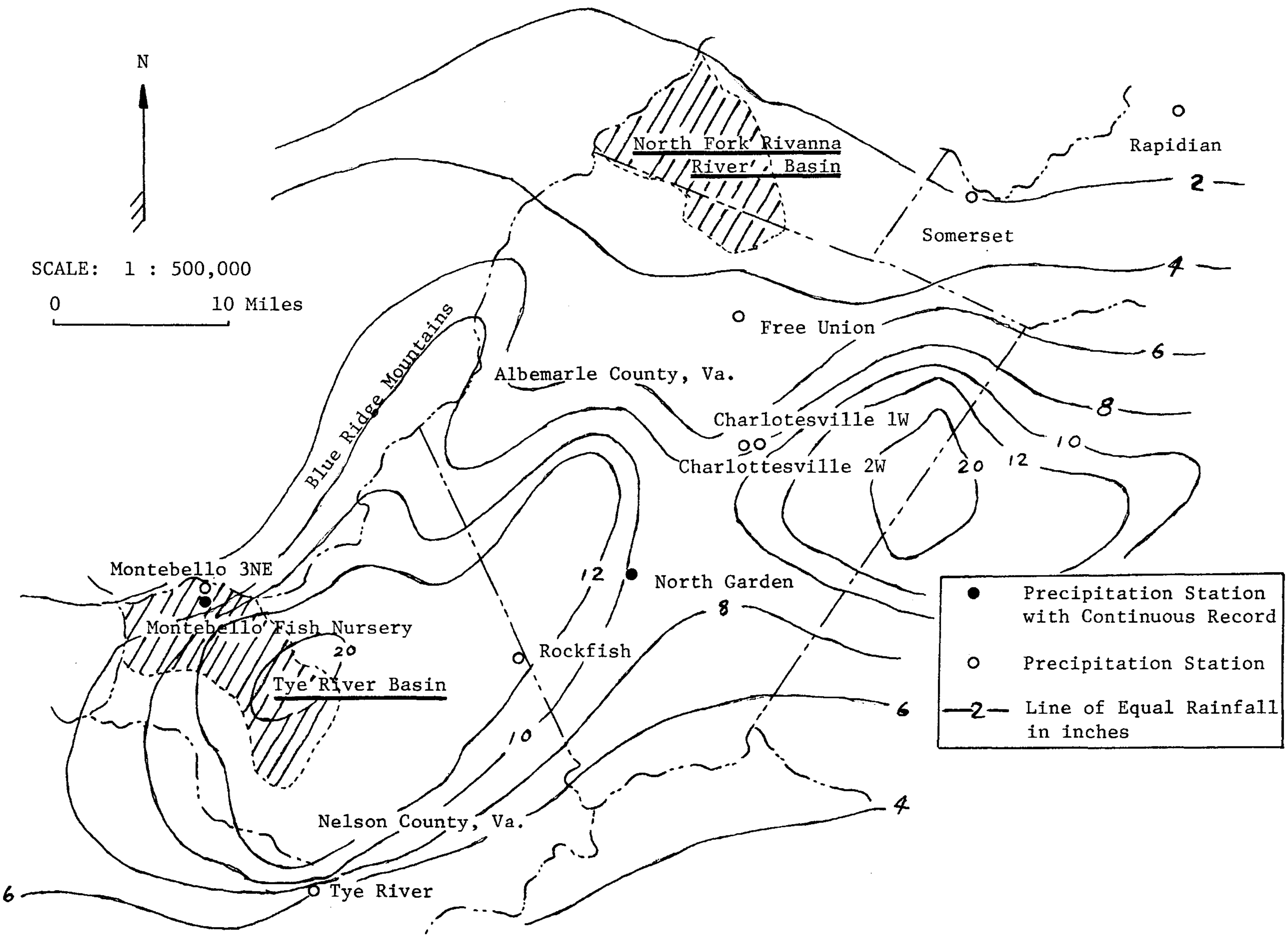

FIGURE 1 ISOHYETAL MAP(Rainfall 19-20 August 1969)

data were obtained from the files of the Virginia Department of Highways and are tabulated in Table 1. These two basins are located about 40 miles apart along the eastern slope of the Blue Ridge Mountains of Virginia.

COMPARISON OF THE TWO RIVER BASINS

A. Geologic Formation and Surface Cover

The geologic formations of these two basins are tabulated in Table 2. These data were obtained from the Geologic Map of Virginia, published in 1963 by the Virginia Division of Mineral Resources. No significant change in geologic formation in terms of hydrologic behavior can be detected: the composites of the formations in the areas are both highly impermeable. Information regarding the subsurface soil of some counties where the survey has been completed may be obtained from County Soil Survey Reports, U.S. Department of Agriculture, Soil Conservation Service. Unfortunately, no soil surveys are available for the counties where the two basins are located, either from the Soil Conservation Service, the Bureau of Reclamation or the U.S. Corps of Engineers.

A reconnaissance by the writer of the two basins and bridge sites revealed that the subsurface soils and land covers were the same for both basins. No boring tests were attempted to find the thickness of the subsurface soil; however, the bridge files of the Virginia Department of Highways indicate that at the bridges destroyed by the floods, the boring tests made for the new bridges show that the subsurface soils are quite thin, in the order of about 10 to 30 feet to reach bed rock. In the

TABLE 1 BRIDGE DATA

(A) Tye River Basin above Massies Mill, Va.
(Drainage Area: 58 sq. mi.)

Bridge No.	River	Hwy.	Location	Length ft	Year Built	Damaged by
1122	Tye	56	1.7 mi. to Rt. 151	137	1966	None
1113	North Fork of Tye	56	9.6 mi. to Rt. 151	105	1962	Camille
1021			Substitute of No. 1113	144	1971	Agnes
6210	Cub Creek	680	0.3 mi. to Rt. 56 0.1 mi. to Rt. 681	22	--	None
6085	North Fork of Tye	687	3.1 mi. to Rt. 56 4.7 mi. to Rt. 686	73	--	Camille
6086			Substitute of No. 6085	104	1970	None
6083	Tye	680	0.1 mi. to Rt. 56 0.3 mi. to Rt. 697	164	1970	Old Bridge by Camille
6082	Tye	680	0.1 mi. to Rt. 56 0.2 mi. to Rt. 681	73	--	Agnes
6091	Tye	699	0.1 mi. to Rt. 807 0.1 mi. to Rt. 56	88	1970	Old Bridge by Camille

(B) North Fork Rivanna River Basin upstream of Hwy. 604 Crossing
(Drainage Area: 54 sq. mi.)

Bridge No.	River	Hwy.	Location	Length ft	Year Built	Damaged by
6259	Lynch	810	0.7 mi. to Rt. 664 1.2 mi. to Rt. 628	45	1960	None
6139	Lynch	810	0.3 mi. to Greene Co. 0.3 mi. to Rt. 663	44	--	None
6137	Lynch	810	at crossing Rt. 628 1.4 mi. to Rt. 601	44	--	None
6009	Lynch	603	0.3 mi. to Rt. 663 0.4 mi. to Greene Co.	83	--	None
6029	Roach	603	0.2 mi. to Rt. 624 0.8 mi. to Rt. 648	61	--	None
6017	Lynch	628	0.2 mi. to Rt. 614 1.0 mi. to Rt. 601	38	--	None
6016	Lynch	628	0.9 mi. to Rt. 810 0.7 mi. to Rt. 614	35	1960	None
6015	Roach	627	at Rt. 614	62	--	None
6071	Roach	627	1.7 mi. to Rt. 615 0.3 mi. to Rt. 632	40	1959	None

TABLE 2

GEOLOGIC FORMATIONS OF THE TYE RIVER BASIN

AND THE NORTH FORK RIVANNA RIVER BASIN

Formation	Explanation and Composition	% of Basin Area	
		Tye	Rivanna
Lovingston	Biotite granite, biotite gneiss and biotite,quartz monzonite	8	19
Marshall	Biotite, quartz, feldspar granite, gneiss and quartz monzonite	22	2
Pedlar	Granite, granodiorite, hypersthene granodiorite, syenite, quartz diorite, anorthosite, unakite	60	20
Striped Rock Granite	Biotite granite and syenite, including carsonville granite, fine-grained pink granite along northern border of striped rock granite	3	20
Unicoi	Conglomerate, shale and quartzite with basalt flows; Weverton formation, conglomerate shale and quartzite; Loudon formation, slate: tuffaceous, purple or gray spotted	7	2
Beekmantown	Limestone and dolomite, including nittany and Bellefonte formations in northern Virginia		10
Virginia Blue Ridge Complex	Biotite granite, biotite gneiss and biotite, quartz monzonite, biotite hornblende gneiss, feldspar granite		20
Leatherwood Granite	Biotite, muscovite granite (locally porphritic)		5
Igneous Rocks	Igneous granophyre, peridotite, and related rocks in Augusta, Highland and Rockingham counties		1
Old Rag	Quartz, feldspar granite		1

TABLE 3 LINEAR ASPECT OF THE RIVERS

Stream Order	Tye River		North Fork Rivanna River	
	No. of Segments	Total Length	No. of Segments	Total Length
1	26	33.3 mi.	9	18.9 mi.
2	5	13.3	3	12.1
3	1	11.4	1	4.0
Total	32	58.0 mi.	13	35.0 mi.

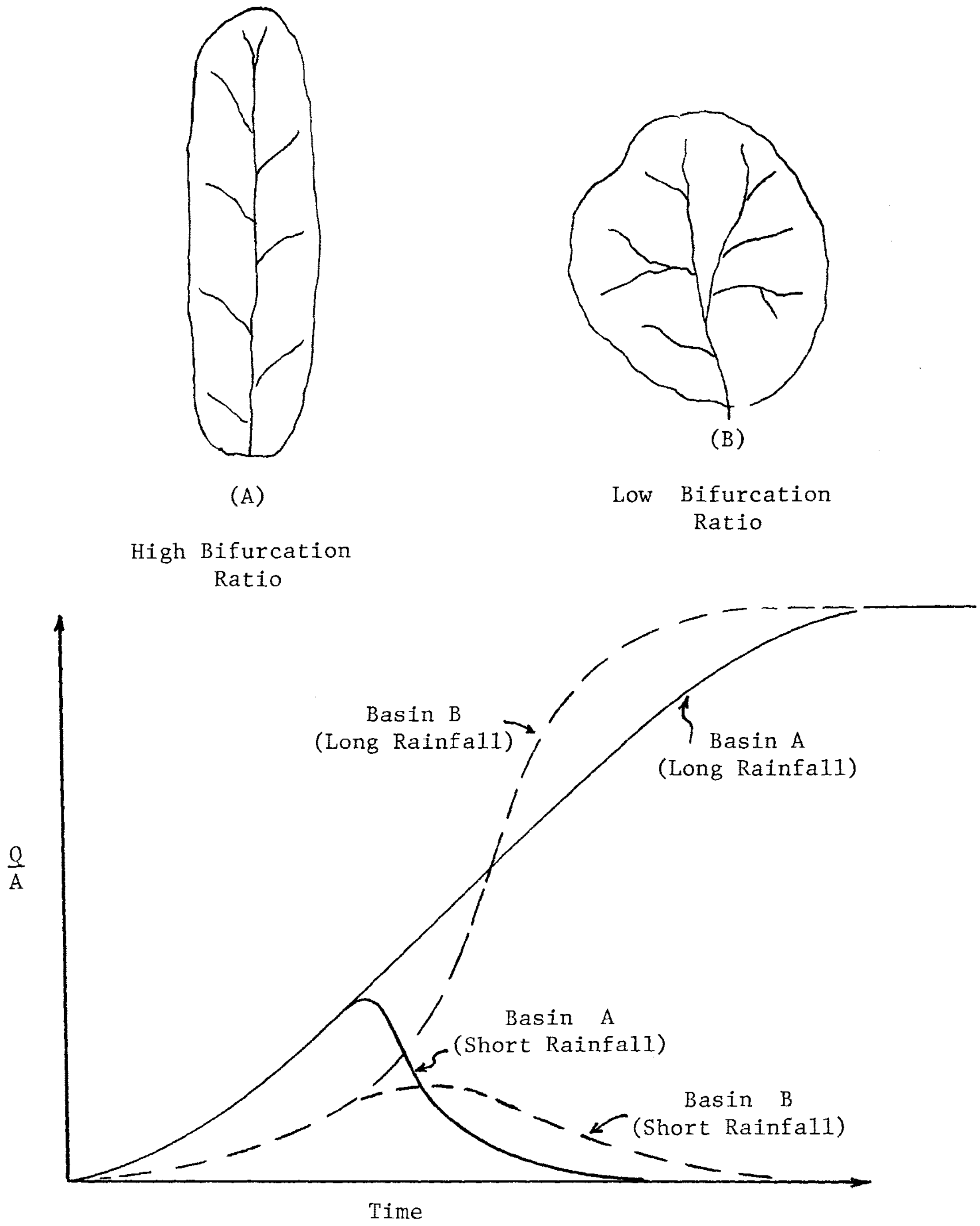

FIGURE 2 HYPOTHETICAL BASINS OF HIGH AND LOW BIFURCATION RATIOS, WITH SCHEMATIC HYDROGRAPHS

abnormally intensive storm usually lasts only a short period; therefore, a river with a higher bifurcation ratio is expected to be more troublesome during such short and intensive storms. The Tye River caused catastrophic damages to bridges during hurricanes Camille and Agnes. (It is recalled by villagers that eight inches of rain fell in a six-hour period over the area; official data at nerby stations showed 11 inches of rainfall in 12 hours for Hurricane Camille).

(2) Stream Length: Channel length was measured with a chartometer directly from a topographic map of the areas. The total length of the segments of each order are tabulated in Table 3. The total length of the Tye River is 58 miles as compared to 35 miles for the North Fork Rivanna River. Assuming precipitation, size and geology of the areas to be the same, the time of peak discharge would be shorter for the area with longer stream length. This is simply because of the fact that the velocity of flow in the stream is normally higher than that of the surface flow over the areas adjacent to the stream. Most water from the boundary of the basin would reach the main stream faster if more tributaries were in the area. Thus the longer the total stream length the shorter the concentration time becomes. For an intensive storm, for which precipitation time is ordinarily short, it is expected that a higher maximum discharge will occur in a stream system with longer total stream length. The hypothetical hydrograph would assume a shape as shown in Figure 2 for a stream system with higher bifurcation ratio (Basin A).

(3) Drainage Density: Horton [5] introduced drainage density to indicate length of streams. Drainage density is simply the ratio of total stream-segment lengths cumulated for all orders within a basin to the

basin area. The drainage density of the Tye River Basin is 58/58 = 1 mile per square mile and that of the North Fork Rivanna River is 35/54 = 0.65 mile per square mile.

In general, low drainage density is favored in regions of highly resistant or highly permeable subsoil materials, under dense vegetative cover, and where relief is low. High drainage density is favored in regions of weak or impermeable subsurface materials, sparse vegetation, and mountainous relief [1]. Subsoil material and vegetative cover are the same for both drainage basins; therefore, the higher drainage density of the Tye River Basin apparently indicates the higher relief of the basin, as will be discussed in a following section.

Horton [5,6] noted that drainage density combines all the geometric factors which determine the composition of the drainage net of a stream system into one expression.

C. Channel Cross-Section Geometry

The field observation of the geometry of the rivers revealed that the average width of the North Fork Rivanna River is narrower than that of the Tye River. This is also clearly indicated in the bridge data: the bridges over the North Fork Rivanna River are on the average shorter compared with those over the Tye River. Karaki and others [7] plotted river width versus meander width and found a linear relationship between them: for a wider river, meandering width is larger. This phenomenon is also observed in this study for the two rivers; the wider Tye River forms wider meanders and thus has a longer meander wavelength. According to Leopold and Maddock [11], Schumm [17], and Santos-Cayado [14]:

(a) Width of a river is directly proportional to water discharge and to sediment discharge.

(b) Meander wavelength is directly proportional to water discharge and to sediment discharge.

If this is the case, the Tye River ordinarily should have the larger water and sediment discharge. As observed by the writer in July 1974, and also true in the floods of 1969 and 1972, water discharge in the Tye River was much higher than in the North Fork Rivanna River. There exist no data on sediment transport, but it is generally true that larger sediment transport accompanies higher water discharge. With high discharge and meander in the Tye River, non-uniform sediment discharge along the river is quite obvious, and the river is always in the continuous process of erosion and deposit of large quantities of sediment. Here again the Tye River shows a characteristic of instability: wider width and high meandering pattern.

D. Ground-Surface Gradients

The gradients of the ground surface of a drainage area are closely related to its channel gradients and vice versa. In mountainous regions, where gradients are large, erosion intensity is correspondingly high. Steep slopes contribute large quantities of relatively coarse ground materials to channels.

The average ground-surface gradients for the two selected basins were obtained by using the random-coordinate method on a topographic map. Thirty points in each basin were selected by using a table of random numbers; the gradients were calculated and the average values found. The average ground-surface gradient of the Tye River Basin is 0.033 and of the North Fork Rivanna River 0.021. These values are very closely related to the average slopes of the main rivers which were found to be 0.034 and 0.022, respectively. The profiles of the main rivers are plotted in Figure 3.

Schumm [16] found that sediment loss per unit area is closely correlated to the ground-surface gradient. Maner [12] also found in the Red Hills area of Southern Kansas, Western Oklahoma, and West Texas that the ground-surface gradients yeilded a higher correlation with sediment delivery rate. With the steeper ground-surface slope of the Tye River Basin, it is expected to have a higher sediment loss, which means that the change in basin morphology is higher and the basin possesses a characteristic of instability.

E. Hypsometric (Area - Altitude) Analysis

Hypsometric analysis, or the relation of horizontal cross-sectional drainage-basin area to elevation, was developed in non-dimensional form by Langbein [9]. Application to small drainage basins of low-order rivers has been made by Strahler [18], Miller [13], Schumm [16], and Coates [2].

Figure 4 shows the hypsometric analysis of the Tye River Basin and the North Fork Rivanna River Basin. The relative height is the ratio of height of a given contour h to the maximum basin height H, both measured from the elevation of the mouth of the drainage basin. Strahler [18] and others found that the shape of the hypsometric curve varies in early geologic stages of development of the drainage basin, but once a steady state is attained (mature stage), it tends to vary little

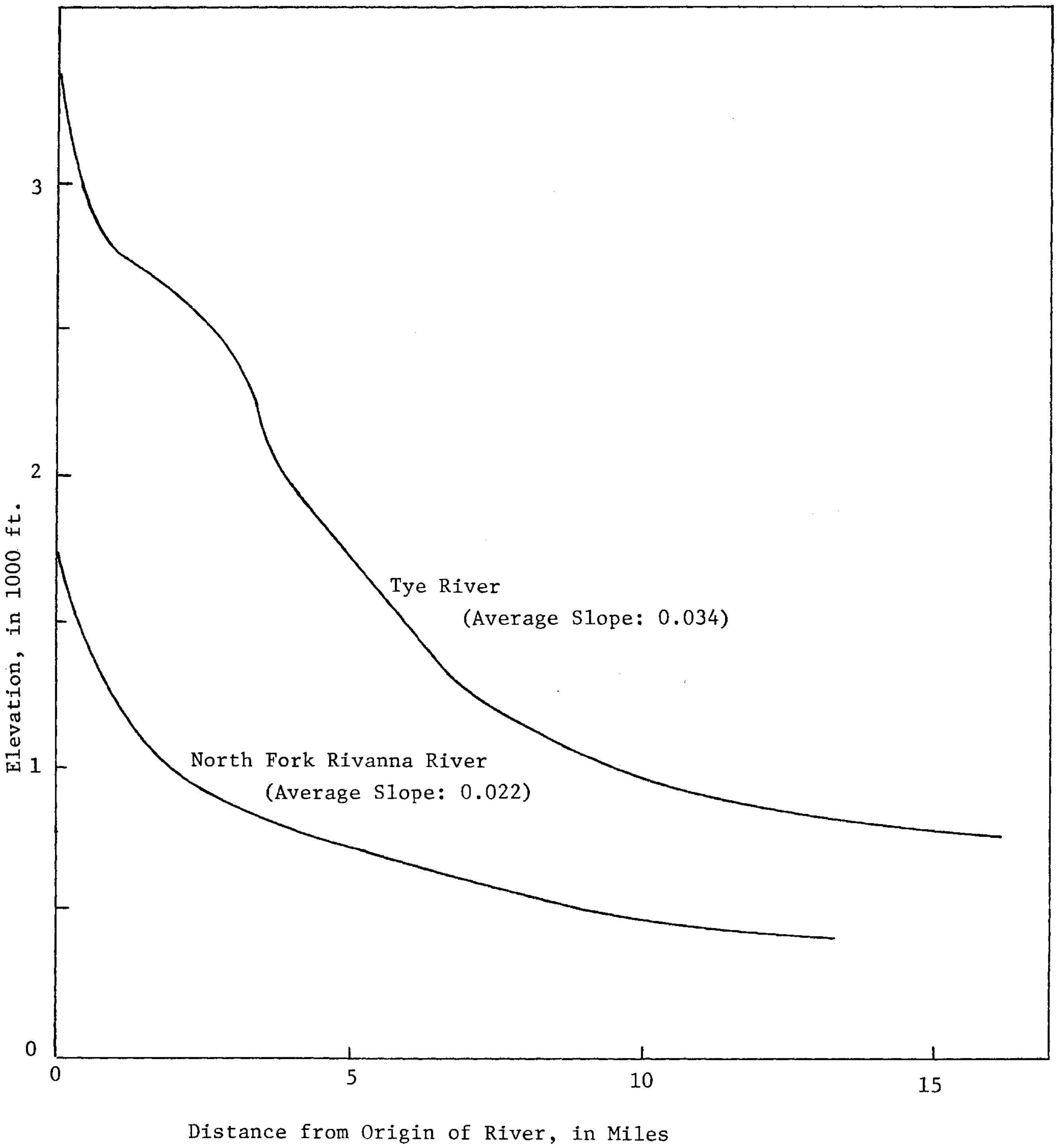

FIGURE 3 RIVER PROFILES OF TYE AND NORTH FORK RIVANNA RIVERS

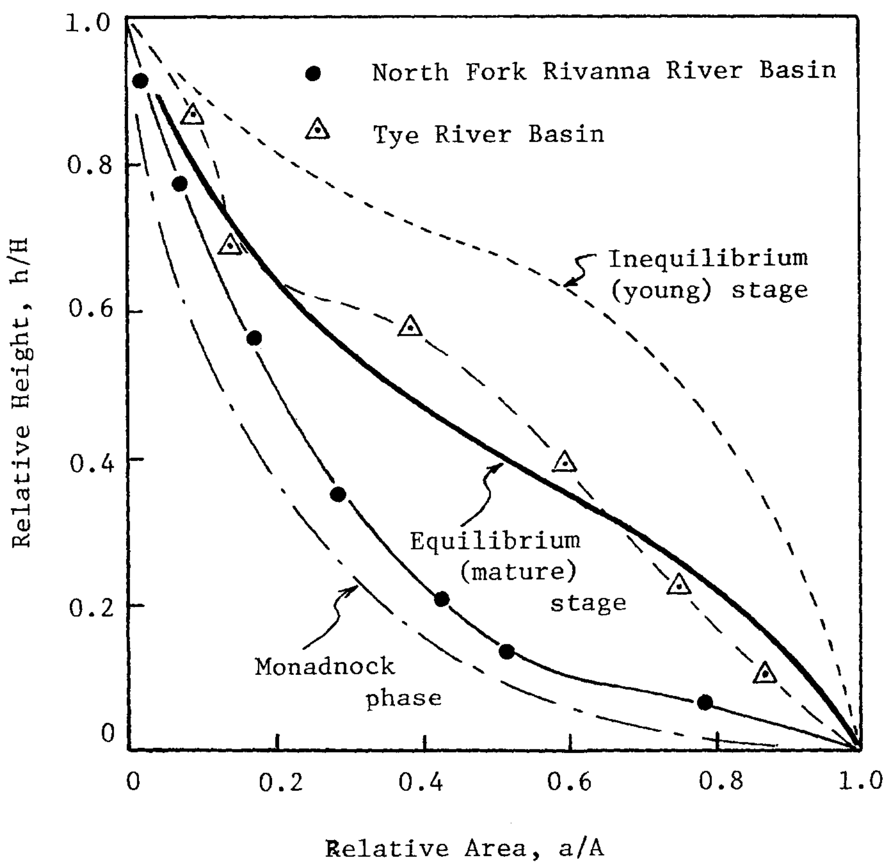

FIGURE 4 HYPSOMETRIC ANALYSIS

thereafter, despite lowering relief. Isolated bodies of resistant rock may form prominent hills (monadnocks) rising above a generally subdued surface; the result is a distorted hypsometric curve, termed the monadnocks phase. Strahler's schematic curves for young and mature stages and monadnocks phase are included in Figure 4 for comparison.

The North Fork Rivanna River Basin shows monadnock phase and the Tye River Basin is still between inequilibrium and equilibrium stages. Since the geologic formation of the two basins are nearly the same, the shape of the hypsometric curve of the Tye River Basin in the future may become somewhat similar to that of the North Fork Rivanna River Basin. It means that the Tye River Basin can be considered still in a changing stage. For higher elevation, the curve approaches that of the North Fork Rivanna River Basin, yet most of the area still needs adjustment.

Strahler [18] has observed a very strong relationship between valley side slope and the slope of the adjacent stream channel; this was found also for the two basins studied. Therefore, it is expected that the main channel slopes and the hypsometric curves show the same pattern as indicated in Figures 3 and 4.

RAINFALL PATTERN

The precipitation data of August 1969 and June 1972 were obtained from the Environmental Data Service, National Oceanic and Atmospheric Administration. The data of the precipitation recorded at the stations near the two drainage basins under investigation are reassembled in

Tables 4 and 5 for convenience. All ten stations are located on the eastern slope of the Blue Ridge Mountains of Virginia as shown in Figure 1. Among these stations, eight are located about 15 to 20 miles from the divide of the ridge, only two stations are located less than one mile from the ridge.

Hurricane Camille moved from Eastern Kentucky into West Virginia and towards Richmond, Virginia, as shown in Figure 1, dropping off the moisture on the lee side of the ridge and causing flooding. Hurricane Agnes moved northward across the Florida Panhandle, Central North Carolina, and then north through parts of Virginia. The path of Agnes was much further east of the basins and therefore not shown in Figure 1.

Only two stations were equipped with recorders that register hourly precipitation, those at the Montebello Fish Nursery Station and the North Garden Station. However, North Garden Station is new and the precipitation was not recorded for both storms. The eight other stations recorded the daily precipitation totals.

First, the daily precipitations of Hurricane Camille will be discussed. The storm moved from the West and dropped off the moisture on the lee side of the Blue Ridge Mountains. It poured a total amount of more than 13 inches of rain on the Montebello Fish Nursery. At the other stations, where the distance from the mountains is about the same, the total rainfall was about 5 inches except at Rapidan Station (1.85 inches) and Rockfish Station (13.12 inches). Possibly the eye of Camille passed through Montebello to Rockfish. Precipitation at Tye River Station and the Charlottesville stations, where the relative locations in regard to the distances

TABLE 4 DAILY PRECIPITATION DATA

August 1969(Camille)

Station	14	15	16	17	18	19	20	21	Total
Tye River	0.16	0.09	0.25	T	T		4.47		4.97
Rockfish	0.14	0.08	0.02			0.41	12.48		13.12
Montebello Fish Nrsy	0.10		1.21		1.40	6.05	4.88		13.64
Montebello 3NE	0.05	0.04	0.33		1.75	1.82	2,87		6.86
Charlottesville 1W			0.10				0.10	4.80	5.00
Charlottesville 2W	0.03		0.08	0.03	T	0.23	4.68		5.05
Free Union	o.04	0.07	0.09	0.10	T	0.16	3.75		4.21
Somerset	-	-	-	-	-	-	-	-	-
Rapidian	0.07		0.06		T	0.05	1.67		1.85

T: Trace - No Record Unit: inch

June 1972(Agnes)

Station	17	18	19	20	21	22	23	24	Total
Tye River	0.55	0.25	1.03	0.07	1.74	6.38	T		9.02
Rockfish	0.89	0.65	0.86	0.13	1.58	5.79	0.10	0.02	10.02
Montebello Fish Nrsy	2.60	0.4	3.7	4.0	-	-	-	-	(10.7)
Montebello 3NE	1.81	0.61	3.95	1.16	3.80	4.43			15.76
Charlottesville 1W	-	-	-	-	-	-	-	-	-
Charlottesville 2W	-	-	-	-	-	-	-	-	-
Free Union		0.80	0.28	0.04	1.23	6.30	0.44	0.04	9.13
Somerset	0.12	0.31	0.30	0.25	0.85	7.98	0.20		10.01
Rapidian	-	-	-	-	-	-	-	-	-

TABLE 5 HOURLY PRECIPITATION DATA AT MONTEBELLO FISH NURSERY STATION

August 1969(Hurricane Camille)

Hour Ending	1	2	3	4	5	6	7	8	9	10	11	12
-14 th-												
A.M.								0.02	0.02		0.01	
P.M.	0.01											
-15 th- No Precipitation												
-16 th-												
A.M.	0.46	o.o5								0.02	0.08	0.49
P.M.	0.11											
-17 th- No Precipitation												
-18 th-												
A.M.												
P.M.			0.95	0.41	0.03	0.1						
-19 th-												
P.M.							0.95	0.98	1.01	1.03	1.06	1.02
-20 th-												
A.M.	1.02	1.06	0.95	0.56	0.59	0.70						

June 1972(Agnes)

Hour Ending	1	2	3	4	5	6	7	8	9	10	11	12
-17 th-												
A.M.		0.4	0.2	0.6	0.5	0.2	0.1	0.2	0.1	0.1		
P.M.		0.1										
-18 th- No Precipitation												
-19 th-												
A.M.	o.5	1.3	0.9	0.7	0.1	0.1						
P.M.											0.1	
-20 th-												
A.M.	0.1	0.2	0.1	0.2	0.1	0.1	0.2	0.1	0.2	0.2		0.1
P.M.	0.3	0.3	0.2		0.1	0.2	0.5	0.2	0.1	0.2	0.1	0.2
-21 st-												
A.M.	0.5	-	-	-	-	-	-	-	-	-	-	-

from the center of the storm and the Blue Ridge Mountains are the same, registered both at about 5 inches. Free Union Station recorded 4.21 inches, which is about 15 percent less than that at Charlottesville. Considering that the precipitation was higher near the mountain divide, the total rainfall over the North Fork Rivanna River Basin is estimated at about 5 inches to 6 inches. The Tye River Station recorded 4.97 inches and Montebello registered 13.64 inches; since the Tye River Basin under investigation lies between these two stations, the average total rainfall over the Tye River Basin could be assumed to be about 8 inches to 10 inches. Lines of equal rainfall on 19 - 20 August 1969 [19] are plotted on Figure 1 for comparison.

For Hurricane Agnes, the total precipitations recorded at most of the stations were nearly the same (9 inches to 11 inches), except at the Montebello 3NE Station where it recorded 15.76 inches. At the nearby Montebello Fish Nursery Station, precipitation for June 21 was somehow not recorded. Since considerable amounts of precipitation were recorded at the other stations on June 21 and 22, it is reasonable to assume that the total precipitation produced by Hurricane Agnes over Montebello was about 14 to 16 inches and the two drainage basins under investigation located between Montebello and the other stations have received about 11 inches to 13 inches.

Hourly precipitation data were available only at Montebello Fish Nursery Station; they are tabulated in Table 5. Hurricane Camille started unloading moisture from about 7 p.m. August 19 to 6 a.m. of the next day with a total amount of 10.93 inches in 12 hours. For Hurricane Agnes, rain started at midnight of June 20 and ended at midnight of June 21, and the station measured 4.1 inches of rain in 25 hours. For Camille, the intensity of rainfall was very high (0.91 in./hr); for Agnes it was lower (0.164 in./hr). However, it can be noted that for both hurricanes, a similarity in the rainfall pattern can be recognized:

(a) Distribution of rainfall with respect to time was uniform.

(b) Rainfall was heavier near the divide of the Blue Ridge Mountains.

(c) Rainfall over the Tye River Basin was heavier than over the North Fork Rivanna River Basin.

Over the course of centuries there were probably many hurricanes of similar character, with rains over the Tye River Basin consistently heavier; this could be one reason why the two river basins under investigation possess quite distinguishable geomorphic differences, though the geologic formations of both basins are similar. Moreover, similar types of floods can be expected to occur in the future, and the Tye River Basin can be considered troublesome as compared to the North Fork Rivanna River Basin.

The data needed for calculating the geomorphic elements presented in this report were topographic and geologic maps of the area under consideration and the available stream discharge and precipitation data. In fact, the preliminary analysis of the geomorphic character of the basins could essentially be completed based on the topographic maps alone; geologic maps, discharge data, and precipitation records were used as supplements in finding whether the river should be considered stable or not.

A guide line for carrying out a similar analysis of other drainage basins is presented in Appendix A.

SUMMARY AND CONCLUSION

The intention of this study was to point out the importance of a geomorphic investigation of the drainage basin prior to bridge design or other drainage construction and prior to site selection. Another objective was to prove the hypothesis, at least for the two sampled drainage basins, that the present pattern of river basins and channel networks has been formed as a result of the integrated climatic, geologic, and hydraulic phenomena over many centuries and therefore the geomorphic pattern of a basin reflects the nature of surface runoff to a certain degree.

Two drainage basins, one with many bridge failures and the other without any failures during Hurricans Camille and Agnes, were selected to show the differences in the geomorphic elements. Significant geomorphic differences as related to surface runoff for these two basins are tabulated in Table 6. For the Tye River Basin, all geomorphic elements clearly point to the unstable character of the basin. The design of bridges and selection of location in the Tye River Basin ought to be made more carefully; the same design criteria cannot be used for both basins.

After the painful experiences in the two catastrophic floods of 1969 and 1972, D.H. Caulden, Jr., District Engineer in the Virginia Department of Highways, stated in his memorandum for repairs and reconstruction of damaged bridges over the Tye River: "This is the Tye River -- treat it

TABLE 6 SUMMARIES OF GEOMORPHIC CHARACTERS, PRECIPITATIONS, AND DISCHARGES OF THE TYE RIVER BASIN AND THE NORTH FORK RIVANNA RIVER BASIN

Item		Tye River	N. Fork Rivanna R.
Drainage Area(sq. mi.)		58	54
Length of Main Channel(mi.)		16.3	13.3
Average Slope of Main Channel		0.034	0.022
Average Groundsurface Slope		0.033	0.021
Hypsometric Analysis(Refs.1,18)		Inequilibrium	Monadnock Phase
Total Length of All Channels(mi.)		58	35
Number of Channel Segments		32	13
Bifurcation Ratio		5	3
Average River Width		Wider	Narrower
Geologic Formation(Details in TABLE 2)		Thicker Subsoil Granite, Biotite Quartz, Gneiss	Thinner Subsoil Monozonite, Granite Biotite, Gneiss, Limestone
Total Precipitation (in.)	Hurricane Camille	8 – 10	5 – 6
	Hurricane Agnes	11 – 13	11 – 13
Approximate Maximum Discharge (cfs/sq. mi.) Camille(Ref. 8)		1,060	500(Estimated from other stations)

with respect." This warning came too late; more than one million dollars were lost in this small area. If design engineers were aware of the unstable character of the Tye River and the design criteria were elevated from a 50-year to a 75-year flood estimate, for instance, these expenses would most likely be unnecessary.

With the two drainage basins selected for this study, the following two points are shown:

(a) There were distinguishable differences in the geomorphic characteristics of the two basins, and

(b) the Tye River Basin possesses the geomorphic character of an unstable river basin.

Since this study was intended to be preliminary in nature and thus the scope was limited, the findings are still tentative.

More studies of this type should be encouraged for many areas with various characteristics to determine more decisively and quantitatively, if possible, the criteria for stable and unstable rivers and further their degree of stability. Since topographic maps of most areas are available, no difficulties are anticipated in the pursuit of a study of this type.

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APPENDIX A

I. Data Requirements and Sources

A. Geological Parameters:

Basic rock formation and soil type have important effects on infiltration, surface runoff, sediment transport, and river regime.

1. Geologic Map -- U.S. Department of the Interior, Geological Survey;

   -- State Geological Surveys.

2. Soil Survey -- U.S. Department of Agriculture, Soil Conservation Survice (County Soil Survey Report);

   -- U.S. Department of the Interior, Bureau of Reclamation (Land Classification Report).

B. Hydrologic Parameters:

1. Precipitation Data -- National Weather Service Data Center.

2. Stream Flow Data -- U.S. Department of the Interior, Geological Survey (Water Supply Papers);

   -- U.S. Department of the Interior, Bureau of Reclamation (Hydraulic Laboratory Reports);

   -- U.S. Army, Corps of Engineers (Flood Control Studies);

   -- State Engineers reports, if available.

3. Sedimentation Data -- U.S. Department of the Interior, Geological Survey (Water Supply Papers and Geological Survey Circulars);

   -- U.S. Department of the Interior, Bureau of Reclamation (Hydraulic Laboratory Reports).

   Because of the complexity of the measurement, sedimentation data (suspended load) are taken only at a few stations. Total load data may be available at some stations where specific research is conducted.

C. Geomorphic Parameters:

1. Drainage Area

Drainage area is the area enclosed by the boundaries of the surface runoff system, sometimes called catchment. The boundary is a closed curve connecting natural ridge lines such that all surface runoff produced by precipitation falling within the curve leaves the area at one point (the mouth of the drainage area). The maps needed for this purpose are topographic maps with contour lines. A drainage boundary always intersects contour lines perpendicularly. An example is shown in Figure A-1.

2. Stream Order

The smallest fingertip tributaries are designated order 1 streams. Where two first-order channels join, a channel segment of order 2 is formed; where two channels of order 2 join, a segment of order 3 is formed, and so forth.

3. Bifurcation Ratio

The bifurcation ratio is the ratio of the number of segments of a given order to the number of segments of the next-higher order.

4. Stream Length

5. Drainage Density

Drainage density is the ratio of total channel-segment lengths cumulated for all orders within a basin to the basin area measured on the topographic map.

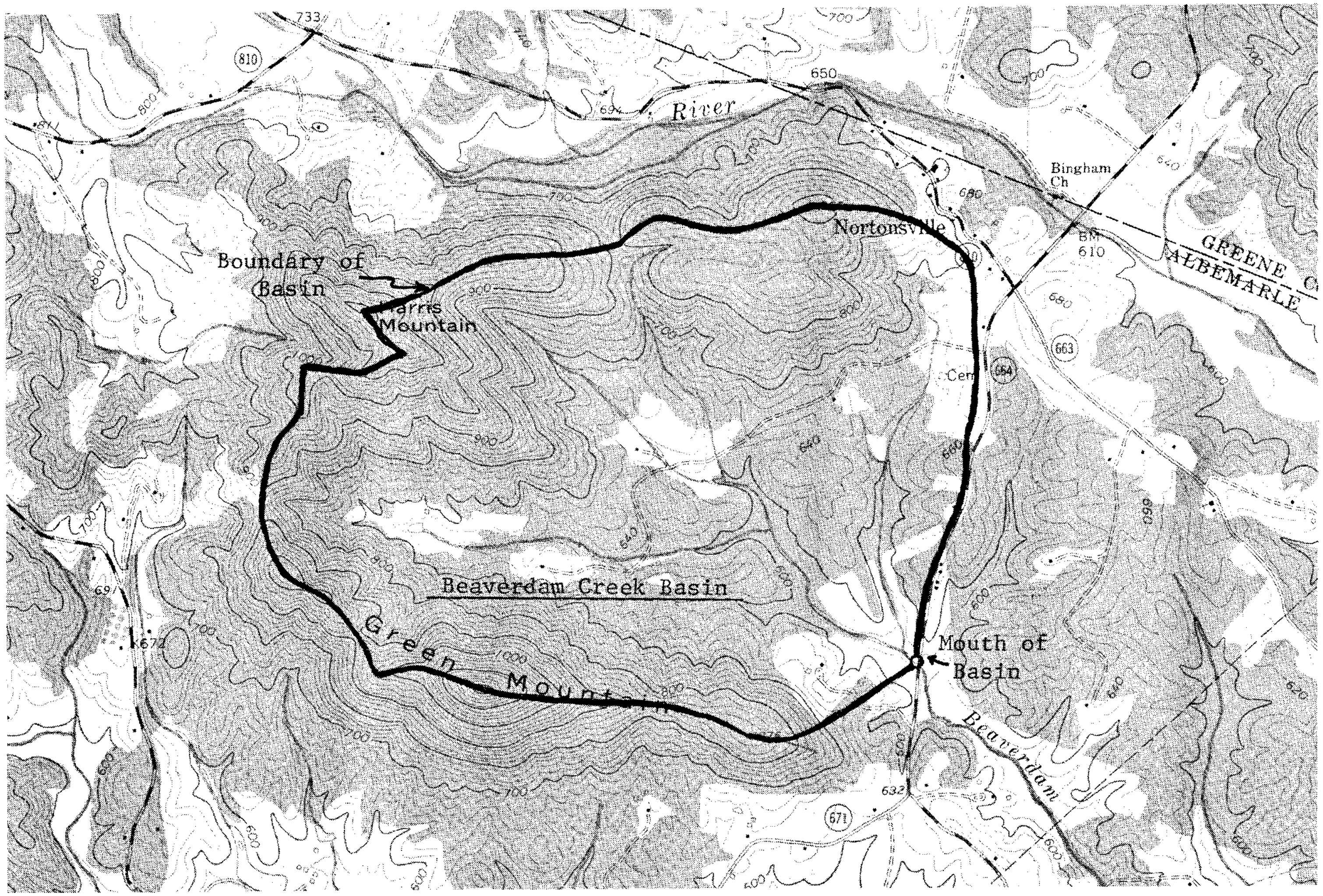

FIGURE A-1 BEAVERDAM CREEK BASIN

6. River Profile

The longitudinal profile of a river may be shown graphically by a plot of altitude (ordinate) as a function of horizontal distance (abscissa) measured along the river from the source.

7. Ground Surface Gradients

The inclination (or gradients) of the ground-surface elements of a watershed is closely related to the channel gradients and erosion intensity of the basin. The random-coordinate method is used to obtain information about the ground-surface gradients. A sample square is drawn on a good contour topographic map, with the drainage basin in the square and a scale divided into 100 units of length on each side. From a table of random numbers (available in most statistics texts), the coordinates of sample points are drawn for whatever size sample desired. At each point, the slope of the short segment of a line normal to the contours is determined; the analysis is based entirely on the slopes of these sample points.

8. Hypsometric (Area-Altitude) Analysis

The method of hypsometric analysis is described in the main report.

All items from 1 to 8 can be obtained by analyzing a good contour topographic map, available from the Department of the Interior, Geological Survey.

9. Physical Character of Channel

Mean channel width, meandering width, and meandering length data near the bridge site can be obtained from State Highway Departments or in-field surveying.

II. Presentation of Tables and Graphs

1. Precipitation Data
2. Stream Flow Data
3. Summary Table of Geomorphic Parameters (Table 6)
4. River Profile
5. Hypsometric Analysis

III. Suggested Literature for Study

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