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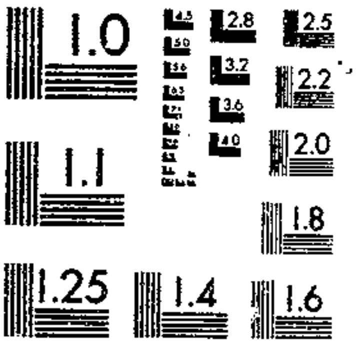

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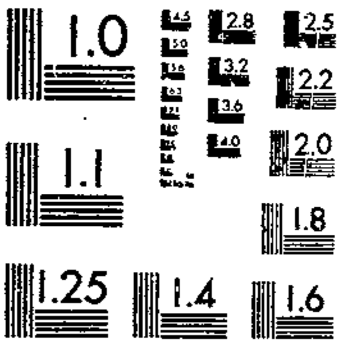

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UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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UNITED STATES DEPARTMENT OF AGRICULTURE

WASHINGTON, D. C.

SOME PRINCIPLES OF ACCELERATED STREAM AND VALLEY SEDIMENTATION[1]

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CONTENTS

INTRODUCTION

THE PROBLEM AND PLAN OF APPROACH

This bulletin presents some results of a study of the principles of stream and valley sedimentation under the influence of culturally accelerated soil erosion (*47, p. 505*).[2] It represents one step in a research project of which the ultimate objective is to develop a sound

[1] Submitted for publication March 4, 1939.

[2] Italic numbers in parentheses refer to Literature Cited, p. 116.

and scientific program to prevent or alleviate damage to valley resources by such sedimentation. In approaching this complex and far-reaching problem a modest beginning was chosen, for, as has been aptly expressed by Bucher (*14, p. 728*):

> In the descriptive sciences progress is possible only to a limited extent through experimentation. The recognition of general properties and broad principles which have the character of "natural laws" depends largely on the patient accumulation of materials and data, which leads to the summation of experience and the ultimate integration of knowledge.

The present report is based chiefly on detailed studies of sedimentation in the drainage basins of Tobitubby and Hurricane Creeks, in Lafayette County, Miss., which are representative of one of the areas of most severe soil erosion and associated sediment damage in the Gulf Coastal Plain. The first of the two main parts of the bulletin is devoted to a description of conditions in these valleys and their tributary drainage areas. In the second part, 45 principles developed by analysis of the results of the Tobitubby-Hurricane investigation and less detailed studies in other parts of the United States are outlined and discussed. The studies in the Tobitubby and Hurricane Valleys were begun in the latter part of 1935 and were continued during parts of the winter seasons of 1935–36 and 1936–37 as part of a research project of the Soil Conservation Service.[3]

Sedimentation is a natural and normal process in all streams and valleys within the United States, and under natural preagricultural conditions it was, on the whole, highly beneficial. All the fertile alluvial valley lands, such as those of the Ohio and Mississippi Valleys, as well as most of the irrigated valley lands of the Western States, were formed by sedimentation. These alluvial lands, except where left as terraces above overflow as a result of stream incision, are normally subject to further sedimentation, which commonly involves replenishment of plant-food constituents and is to that extent beneficial. Under certain circumstances, however, the sediment may be relatively infertile and may thus impoverish the land, or deposition may occur in sufficient quantities to damage improvements necessary for cultivation and human habitation. Bottom lands are also subject to destruction by lateral stream erosion, which involves damage even though new land is built on the opposite side of the stream by sedimentation.

Although sedimentation and stream-bank erosion are normal geologic processes to which most alluvial lands are subject, they usually proceed so slowly that the lands may be used with a reasonable assurance of stability of investments for years or even generations. As these natural phenomena cannot be entirely prevented by any known human means, the objective of control and protective works is to reduce the rates of harmful sedimentation and associated bank erosion. It appears that lowering the rate of sediment production by use of erosion-control practices generally offers the most promising opportunity for reducing sediment damage.

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[3] Investigations were started in accordance with plans formulated by the late Henry M. Eakin as part of work project B-3-2 of the Section of Sedimentation Studies. Instrumental surveys were made by W. F. Witzgall and E. H. Moser, Jr. The former also prepared most of the charts and maps. R. J. Lougee was in charge of the field work until March 1936. G. L. Anderson assisted during the 1935–36 winter season and M. P. Connaughton during part of the 1936–37 season. Temporary field and office assistants were supplied by the Works Progress Administration. Extensive criticism of the manuscript was made by F. F. Barnes, C. B. Brown, and G. E. Thom. J. Harlan Bretz, F. J. Pettijohn, and W. C. Krumbein each read parts of the manuscript and made helpful comments.

In many streams and valleys in various parts of the United States the rate of sedimentation has been excessively increased under modern conditions of land use. Where forests have been cleared and sloping lands carelessly cultivated or overgrazed, topsoils have been washed away and gullies gouged out by running water. Reconnaissance surveys indicate that the cumulative effect of such accelerated erosion has been to ruin about 50,000,000 acres of cropland for cultivation, to severely damage 50,000,000 acres more, to remove from half to all the topsoil from another 100,000,000 acres, and to menace land values and continuing production on an additional 100,000,000 acres (*9, pp. 592–593*). In consequence, streams draining areas of such excessive erosion are receiving sediment in much greater quantities than before the natural plant cover was disturbed. Erosion from highway cuts and fills and other artificially exposed surfaces and waste from hydraulic mining, sawmills, and other industrial operations, have also contributed to the increased sediment loads. Where the streams are unable to carry away all the sediment washed into them, it accumulates in the channel or on the flood plain and may cause considerable damage. Moreover, the damages may be expected not only to continue but to grow worse, because sediment accumulation is progressive. Numerous reports from various parts of the country indicate that such sediment damage has already become sufficiently serious to demand consideration in the development of an adequate national program for soil conservation and flood control.

The nature of the damages has varied from place to place. The filling of stream channels may increase flood hazards and may also be detrimental to the artificial or natural drainage of valley lands. In some places sediment accumulation between levees has impaired the effectiveness of floodways. Shoaling of channels has reduced the value of rivers for navigation. Depletion of reservoir storage capacities by sedimentation is a serious problem in many municipal water-supply and irrigation projects and, to a lesser extent, in hydroelectric and other water-power developments. Deposition of sediment has been a major factor in the damage to buildings and urban properties by floodwaters, as it was during the 1937 flood in the Ohio Valley. Obstructed drainage has resulted in ponding of streams and swamping of valleys, which have aggravated malarial conditions. In addition to making the land unfit for cultivation, swamping has, in some places, killed valuable standing timber. Fertile alluvial lands have been impoverished or ruined by burial under infertile sand or gravel. Damages due to stream-bank erosion may be partly chargeable to the effects of sedimentation in reducing the capacity of channels for carrying floodwaters. This has been especially true when efforts have been made to counteract the sedimentary filling by clearing brush and trees from the stream banks to increase the discharge capacity. When thus stripped of their natural vegetative protection the banks become much more vulnerable to lateral erosion, and destruction of valley lands may result (*66*).

The selection of Tobitubby and Hurricane Valleys for detailed studies was based in part on the fact that they are representative of an area of unusually severe soil erosion and valley sedimentation. They are also representative of many drainage areas in which almost no sediment coarser than sand is produced by erosion. Much sand is transported by the streams, in large part as bed load. But there is no sediment in the area so coarse that the streams cannot transport it rather easily, and in this respect the area is similar to large parts of the Atlantic and Gulf Coastal Plains but differs from many mountainous regions and others where gravel and boulders constitute a large part of the harmful sediment. The climate, including precipitation and temperature, and the land use system—which is dominated by one-crop cotton production, with the valley lands preferred for growing corn—are also fairly representative of a large part of the Southeastern States. Thus wide use may be made of the knowledge to be gained through study of the principles of culturally accelerated stream and valley sedimentation in Tobitubby and Hurricane Valleys.

HISTORICAL BACKGROUND AND PREVIOUS WORK

Although no comprehensive or critical study of the problem of accelerated modern stream and valley sedimentation has ever been made, its intimate relation to culturally accelerated soil erosion has long been recognized by students of the erosion problem. As early as 1801, for example, Moore (*56*) cited half-buried posts in low places and the silting taking place in creeks, millponds, and the heads of rivers as evidence of soil wastage from upland fields. Damage to navigable stream channels was cited in 1813 by Taylor (*73, pp. 172–173, 246*), who described the channels of Virginia seaboard streams as seldom retaining any appearance of their natural state, "being everywhere obstructed by sands, bogs, bushes, and rubbish." In 1835 Alexander (*2, pp. 9–16*) described the sedimentary filling of Piscataway Creek, Prince Georges County, Md., and proposed a system of canals along both sides of the creek to receive the surface drainage and prevent filling of the navigable channel.

Accelerated stream and valley sedimentation was recognized as a national problem at least as early as 1908 by Chamberlin (*16, pp. 77–80*). In 1911 McGee (*52, pp. 31–32*) briefly described the role of accelerated soil erosion in causing sediment damage and noted that the sorting action of running water was an important factor in causing different kinds of damage. In 1928 Bennett and Chapline (*8*) discussed soil erosion as a national menace and cited examples of sediment damages in various parts of the country as part of the harmful effects of soil erosion.

In Mississippi, in the general area with which this report is primarily concerned, Hilgard (*33, p. 293*) as early as 1860, only about 25 years after the area had first been opened to settlement, described the damage to branch bottoms by sand washed down from the cultivated hills. About the same time Humphreys and Abbott (*36, pp. 80–81*) ascribed the increasing turbidity of the Yazoo River floodwaters to increased cultivation of its banks. In 1884 Hilgard (*34, p. 310*) mentioned accumulations of 15 to 20 feet of sand on the original flood plains of the smaller streams of Marshall County, adjacent on the north to Lafayette County, in which the present studies were made. These sand deposits were said to support only a growth of willows, briers, and Bermuda grass. In 1922 Lowe (*49, p. 10*) stated that the Coldwater River had filled with sand as a result of upland soil erosion, so that the channel, which had formerly been navigated by freight boats as far upstream as Coldwater, had by that date become impassible to all kinds of boats. Concerning the Tallahatchie River, Lowe (*49, p. 10*) wrote: "Even as late as 1900 a small steamer drawing 4 feet of water plied on the Tallahatchie from Batesville downstream. Now the stream is choked with sand bars, and can be easily waded at almost any place."

The belt of loessial soils and underlying unconsolidated Coastal Plain sands, which together make part of northern Mississippi so susceptible to soil erosion and associated sediment damage, extends northward across western Tennessee, and similar erosional and sedimentation conditions developed there about as early as in northern Mississippi. In 1884 many reports to Safford (*64, pp. 423–434*) referred to the washing of uplands and the resultant damage to valleys. In 1910 Ashley (*3*) described conditions in the valleys of western Tennessee that gave rise to the need for artificial drainage and cited soil erosion consequent to deforestation as the cause of filling of channels with sand. At the same time, in a report proposing a plan for drainage and flood protection of parts of the Forked Deer and Obion Valleys, Morgan and McCrory (*57*) cited soil erosion, and especially erosion of roadside ditches, as sources of the sand that would have to be excluded from the proposed drainage ditches in order to insure their adequate operation. They discussed possible methods by which the drainage ditches might be protected by erosion control and sediment retardation.

Damage to valley lands in Wayne County, south-central Tennessee, by accumulation of chert boulders derived from gullying of steep hillsides was described in 1914 by Purdue (*60*). The chert fragments were carried into the creeks, where they clogged the channels and caused overflows by which the stream gravel was spread "some feet thick" over the small but valuable bottom-land fields. In the still more rugged northwestern part of the Appalachian Plateau in southern Kentucky, Wilson (*82, p. 399*) has recently described a practice of building rock or log dams across the minor valleys, or hollows, in order to catch sediment during the spring floods and thus augment the small areas of arable land. It is said that deposits 10 to 15 feet thick may accumulate, and that in one hollow, which has been settled over a century, the farmers no longer cultivate the slopes but concentrate their efforts on the alluvial land thus built up in the valley bottom.

The southeastern Piedmont has been one of the areas of most conspicuous sediment damage to valley land, and numerous county soil-survey reports have cited such damages. In Elbert County, Ga., for example, Fuller and Hendrickson (*27, p. 27*) have described the situation as follows:

> Some of the areas mapped as meadow were originally good areas of Congaree silt loam or Congaree fine sandy loam over which a mixed covering of sandy material has been deposited following the clearing of adjacent hillsides. The bottom land of Mill Shoal Creek about a mile from the county line is typical of this condition. It was reported that all the bottom was cultivated and the soil was Congaree fine sandy loam 12 years ago. At present the bottom land is a sandy wash with poor drainage and is covered with alders and willows.

The widespread occurrence of such conditions was recognized by Bonsteel in 1912 (*11, p. 11*), when he described the origin of the "meadow" soils as follows:

> Through some portions of the Piedmont Plateau the meadow soils are characteristic of that section and differ materially from soils similarly deposited in other regions. The main streams which flow through the plateau have their major

tributaries within the Appalachian Mountains or their foothills, and the gradient of the stream beds in their upper courses is very steep. They flow through a section marked by the deep weathering of the rocks and a consequently friable and incoherent condition of the surface soils and subsoils. Over extended upland areas along the headwaters of these streams and the courses of their Piedmont tributaries the granite and other crystalline rocks have become disintegrated to a depth of 20 or 40 feet and remain as a loose aggregate of mineral matter, thinly covered by true soil. The sudden torrential rains of winter and early spring frequently remove vast quantities of this disintegrated rock, which is further comminuted by its grinding passage down the stream beds. Such a sand-laden torrent may suddenly cover broad, fertile lowlands in the middle course of the stream with a deposit of white granitic sand having a depth of 2 to 15 feet. Destruction is doubly accomplished in such instances through the removal of soil-forming material from the eroded uplands and its deposition upon the fertile bottom lands. It is sparsely mingled with organic matter in its new position; it is completely washed of all fine earth suitable for the immediate sustenance of the economic forms of plant life; it covers and destroys growing crops; and it obliterates the fertile, tillable land whose surface it covers.

The cumulative effect of accelerated sedimentation in the Piedmont was summarized by Bennett in 1931 (*7, pp. 436–437*) as follows:

> Moreover, probably not less than 50 to 60% of all the formerly cultivated alluvial land in the lower stream bottoms of that region has been covered by erosional debris to depths ranging from a few inches to more than 6 feet. Much of the overwash now covering the original soil consists of sand and gravel, often loose and almost invariably much lower in productiveness than was the heavier, darker colored alluvial soil beneath, that is, the original alluvial soil, as it existed at the beginning of agricultural operations in the Piedmont. The deposits are so variable in texture and other characteristics, within narrow limits, that it has been impossible, generally, to make satisfactory soil-type separation of the numerous conditions on soil maps. Accordingly, much of this land has been classed and mapped as "meadow".
>
> * * * These profound modifications of the bottom lands particularly characterize the smaller streams, though the broader bottoms of the major waterways have been largely affected also.

The sedimentation problems of the Piedmont are complicated by the fact that many of the Piedmont streams rise in the southern Appalachian Mountains and are affected by conditions of run-off and erosion in their mountainous headwater sections. Glenn (*29*) investigated the effects of deforestation and erosion on the principal southern Appalachian rivers and concluded that floods had increased markedly in severity and frequency as a result of cultural changes in the drainage basins of these rivers and that much damage was being done to valley lands by the resulting increased bank erosion and deposition of sand, gravel, and boulders. He stated that these damages extended on downstream into the Piedmont but that no detailed study had been made to determine how far downstream the sedimentation, resulting from accelerated mountain erosion, was serious. In the mountain valleys, however, the damage was reported to be severe at least locally, and comparatively more serious because of the scarcity of arable land sufficiently smooth to be reasonably safe from excessive soil erosion.

Accelerated stream and valley sedimentation in southern Indiana was mentioned in 1911 by Cumings (*19, p. 144*), who wrote: "Torrential streams now emerge on the sides of broad alluvial valleys, building fans of coarse and sterile gravel out over the finer silt of the main stream flood plane."

In a discussion of soil conservation problems in Dearborn County, Ind., in 1915, Bigney (*10, p. 219*) stated that as a result of cultivation of hilly lands that had been forested until about 25 years previously new valley deposits derived from upland subsoil clays had covered the "rich soil, previously deposited" in the valleys and consequently had greatly decreased the productiveness of the valley land.

According to Culbertson (*18*), the Ohio Valley flood of March 1913 and the widespread erosion of farm lands resulting from the excessive rainfall that caused it produced damage by valley sedimentation at many places in that general area. Sediment deposition from the floodwaters was also an important factor in the damage to urban properties, as reported by Horton and Jackson (*35, pp. 86–87*), who described the effect of the sedimentation as follows:

> In simple inundation probably the most damage is caused by the yellow, slimy, fine, penetrating mud that is deposited everywhere. The effect of this mud in cities is almost inconceivable. There may be some gain in fertilization when it is deposited on farm land, but it is open to question whether or not its value as a fertilizer outweighs even the damage it does on the farm, to say nothing of its effect in cities and towns. Any consideration of this benefit to farm land appears simply an attempt to discover some small benefit in connection with the enormous loss.

The Driftless Area and contiguous parts of the upper Mississippi Valley have also been damaged considerably by sedimentation resulting from accelerated soil erosion on the steep slopes and on the extensive high sandy valley benchlands common in that part of the country. Bates and Zeasman (*5*) have described erosional conditions and associated sediment damages in the part of this area that lies in Wisconsin and have also reported the results of numerous measurements of the suspended load of streams and of the volume of deposits formed by outwash from particular gullies. This paper also describes the tendency of the coarser part of the sediment to accumulate in minor valleys and near the place of origin and calls attention to the effect of soil erosion in contributing sediment to the Mississippi River. On the basis of original data, estimates are presented of the net sedimentary output from various drainage basins tributary to the Mississippi. More recently, Cohee (*17*) has described the accumulation of boulders on lower slopes and valley fields, a type of sediment damage common in those parts of the Driftless Area where limestone talus has accumulated on slopes that are subject to gullying when cleared of their natural vegetal cover or are traversed by concentrated run-off from fields lying higher on the ridges.

According to Schockel (*65, p. 220*), in the 1830's the Galena River in the southern part of the Driftless Area was navigable for large steamboats as far up as Galena, except at extreme low water, and small steamers could go a few miles farther upstream. Because of sediment deposition, however, the channel became more shallow and tortuous until by 1863 navigation had practically ceased. The sedimentation was ascribed chiefly to the effect of increased soil wash caused by clearing and cultivation of steep slopes. In the same area, Trowbridge and Shaw (*76, pp. 156–158*) noted that flood-plain aggradation in the upper valleys had been followed by trenching, and they concluded that upland soil erosion due to agricultural use of the land had first caused valley sediment accumulation and that later, as the vegetal cover was also removed from the valleys by grazing, the concentrated run-off developed trenches. The authors noted that in some valleys the trenches were discontinuous, becoming smaller in size downstream until they ended in a grassy, undissected surface. Another active headward-growing trench might exist farther downstream. This relation apparently is the same as that which McGee (*51, pp. 261–273*) described as the process of "varigradation" in the Driftless Area of northeastern Iowa. The process of varigradation may be closely related to the phenomenon of valley "plugging" described in this bulletin.

The Missouri River is traditionally known as a muddy river, and sedimentation has been an important factor in many problems in various parts of its basin. An extensive and, in part, novel study of sediment transportation and deposition was made in 1929–31 in connection with preparation of a plan for improvement of the river for navigation and other purposes (*79, pp. 1,032–1,245*). It was concluded that normal or geologic erosion was responsible for much of the sediment load, a comparison of suspended-load records for 1879 with records for 1929–31 failing to show any increase in the sediment load of the Missouri River in spite of the severe soil erosion that has occurred during the intervening period in some parts of the drainage basin (*79, p. 1,086*). Control of gullying along the bluffs bordering the main stream, however, was suggested for inclusion in a plan for river improvement, particularly as a measure to reduce the rate of silting of proposed reservoirs (*79, p. 1,176*). This emphasis on the greater importance of erosion in minor drainage basins directly tributary to the main river is in accord with the findings of the present investigation. The bluffs bordering the lower Missouri River are largely developed on deep loess deposits that are susceptible to rapid erosion if not adequately protected. Sediment derived from these loess areas has been deposited on the valley lands in many places (*6, p. 695*). Brown (*12*) has described a case in Doniphan County, Kans., where a silting basin has been used to protect the Missouri River bottom lands from excessive flood and sediment damage.

In the semiarid western regions, stream and valley sedimentation is commonly a serious problem in flood control and irrigation engineering, but the relation to accelerated soil erosion is complicated by the fact that many of the western rivers may have been aggrading their channels and valleys before the inception of accelerated erosion. Under such circumstances it is more difficult to appraise accurately the extent to which the sediment damage is due to accelerated erosion. The problem is further complicated by the fact that in the semiarid regions climatic fluctuations appear to be very important in controlling geomorphic processes. Consequently, the effects of cultural land use and possible climatic fluctuations in modifying sedimentary processes and rates will have to be distinguished.

In this region stream aggradation was recognized at least as early as 1897 by Haworth (*32, pp. 28–29*). In describing the Arkansas River in western Kansas he stated:

> Within the last fifteen years a very noticeable filling in of the river channel has occurred. The various bridges which are built across the river at different places when constructed from eight to twelve years ago were usually built high enough so that a man on horseback could easily ride under them while sitting erect. At every bridge along the river the sands have accumulated until the most of them are not more than from 3 to 6 feet above the top of the sands.

In central New Mexico, just above the head of Elephant Butte Reservoir, Burkholder (*15, p. 52*) reported in 1928 that the bed of the Rio Grande had risen 12 feet since 1880. The rising bed of the river throughout the middle valley of the Rio Grande was cited as a major cause of increasingly serious flood dangers, swamping of valley lands, and a tendency of the river to widen its channel and thus destroy valley lands. Bryan (*13, p. 291*) has described recent trenching of the Rio Puerco Valley, a tributary of the Rio Grande, as a major cause of the rapid rate of sedimentation in the middle valley and in the Elephant Butte Reservoir at the lower end of the valley. Fortier and Blaney (*26*) in 1928 described in considerable detail the sediment problems involved in river control and irrigation engineering on the lower Colorado River in Arizona and California, before the construction of Boulder Dam.

A summary of the important literature bearing on the problem of stream and valley sedimentation in the Southwest would not be complete without mention of three papers and the accompanying illuminating discussions that have appeared in recent years in the Transactions of the American Society of Civil Engineers. In the first of these, Taylor (*74*) wrote primarily about the silting of Lake Austin in Texas, but discussions of the paper included descriptions of stream- and valley-sedimentation problems in various parts of the Southwest, including California. In the second paper, Sonderegger (*70*) called attention to the influence of human activities in modifying the normal course of physiographic events. Special consideration was given to the problem of channel stabilization in the Rio Grande Valley as a result of flow regulation by Elephant Butte Reservoir and to the erosional-debris problems on streams flowing from mountainous areas out across alluvial cones that have been developed for agricultural or urban use. The discussions of the paper provided much additional data on these stream and valley problems. In the third paper, Stevens (*72*) was chiefly concerned with problems of sedimentation in Elephant Butte Reservoir, Lake Mead, and other reservoirs, but he included a discussion of problems of sediment production and transportation. These subjects also received attention in the discussions of the paper.

A special form of sedimentation problem occurs where the alluvial fans or alluvial aprons bordering steep mountain slopes have been developed as urban areas or for intensive agriculture. The western base of the Wasatch Mountains near Salt Lake City and Ogden, Utah, and the southern base of the San Gabriel Mountains in the Los Angeles district, southern California, are two outstanding examples. Erosion is active in both mountain areas, and has been affected by deforestation or by burning of the plant cover. Bailey, Forsling, and Becraft (*4*) have described and summarized conditions in the northern Utah area, where much damage has been done by summer floods that overflow the improved valley lands and often cover them with thick deposits of mud and boulders. In the Los Angeles area large sums have been expended in construction of detention reservoirs in the mountains and debris basins and channel improvements in the alluvial-fan areas, where there are numerous cities and towns as well as highly valuable agricultural lands, chiefly citrus orchards. The sedimentation problems of the Los Angeles area, together with the associated flood and erosion problems, have been described at some length in a paper by Eaton (*23*) and in the discussions printed with it.

In the absence of any previous critical study of sedimentation due to accelerated soil erosion, particular interest attaches to the well-known case of accelerated sedimentation caused by hydraulic mining in the Sierra Nevada of California. During the period of extensive hydraulic mining for gold, the Yuba and American Rivers—and to a lesser extent other nearby streams draining westward from the Sierra Nevada to the central valley of California—became heavily overloaded with debris from the mines and were forced to aggrade their channels and flood plains. The sedimentation became serious shortly after 1860, and the resulting obstruction to navigation on the Sacramento River, the increasing threat of flood damage to cities, the burial of valley agricultural lands beneath sand and gravel, and the threatened shoaling of San Francisco Harbor by sediment accumulation finally led to the prohibition of hydraulic mining by State law (*31*).

Beginning in 1906, Gilbert (*28*), of the United States Geological Survey, made a study of the processes, extent, and effects of this abnormal sedimentation. Special attention was given to possibilities of a moderate resumption of mining, with control of the resulting debris to prevent damage to the streams and valleys. Gilbert made estimates of the rate of sediment production by natural processes as well as by highway and soil erosion in the drainage basins. Of particular interest is the fact that whereas the finer sediment carried as suspended load was very largely carried to and deposited on the Sacramento River delta at the head of Suisun Bay, the coarser sediment accumulated first in the stream channels and valleys near the mines and gradually moved downstream as a "wave" of sediment for many years. The progress of this wave of coarse sediment was marked by aggradation of the channels, with consequent increase in flood heights and coincident damage to flood-plain agricultural lands, which were covered by infertile debris during flood periods. Extensive and expensive engineering works were undertaken to protect the towns and agricultural lands by levees and to stabilize part of the deposit above the areas of greatest potential damage.

In the light of the known history of the debris in this California case, the question naturally arises whether continued soil erosion at present rates may produce a similar sequence of events in many other rivers and valleys throughout the country. The production of sediment was much more rapid in the Sierra Nevada than it ever has been in comparable areas of agriculturally accelerated soil erosion, yet it is pertinent to inquire whether the same processes may be operating elsewhere, although more slowly, as a result of agricultural soil erosion. If so, the ultimate extent of the sediment damage may not yet be entirely apparent, because the effects on major rivers are not yet evident. If this is the case, the potential damages to be anticipated as a result of soil erosion will be greatly increased. On the other hand, if it can be determined with assurance that such extreme damages are not probable in major rivers and valleys, it may then be possible to anticipate with greater assurance a larger future use of valley alluvial lands as an alternative to continued cultivation of sloping lands now subject to excessive erosion.

SEDIMENTATION IN TOBITUBBY AND HURRICANE VALLEYS

LOCATION AND GENERAL DESCRIPTION OF TOBITUBBY AND HURRICANE VALLEYS

Tobitubby and Hurricane Creeks have adjoining drainage basins in northern Lafayette County, north-central Mississippi (fig. 1). Both creeks rise near the town of Oxford and flow in roughly parallel courses approximately 12 miles northwestward to their junctions with the Little Tallahatchie River. The Little Tallahatchie flows generally westward toward the alluvial valley of the Mississippi, as do the Coldwater River to the north and the Yocona and Yalobusha Rivers to the south. These are the four principal tributaries of the Yazoo River, which together drain some 5,800 square miles of the dissected Gulf Coastal Plain, constituting the upland, or "hill" portion, of the Yazoo drainage basin. To the west and southwest of these

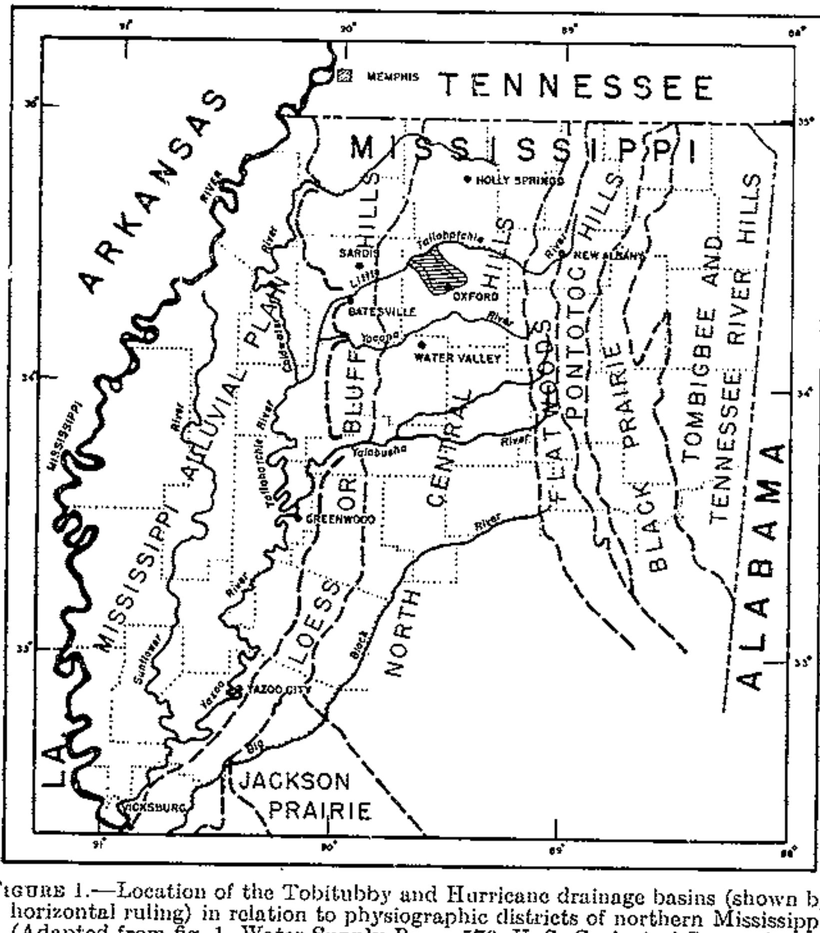


FIGURE 1.—Location of the Tobitubby and Hurricane drainage basins (shown by horizontal ruling) in relation to physiographic districts of northern Mississippi. (Adapted from fig. 1, Water Supply Paper 576, U. S. Geological Survey.)

uplands is the so-called "Yazoo Delta," one of the most productive agricultural regions in the world. Included in this delta area are about 6,600 square miles of the alluvial lands bordering the Mississippi River, but draining to the Mississippi through the Yazoo.

The drainage basins of Tobitubby and Hurricane Creeks are generally very similar, although Tobitubby and its principal tributary, Goose Creek, drain about 56 square miles and Hurricane drains only about 32. The valleys are submature, have first-bottom flood plains averaging over one-eighth mile in width for most of their length, and are cut in the maturely dissected North Central Hills section of the Gulf Coastal Plain (fig. 1). The local relief ranges from 50 to 150 feet, and the altitude ranges from about 230 feet above mean sea level at the mouth of Tobitubby Creek to about 600 feet at the highest point on the bounding divide, a knob which is known as Thacker Mountain.

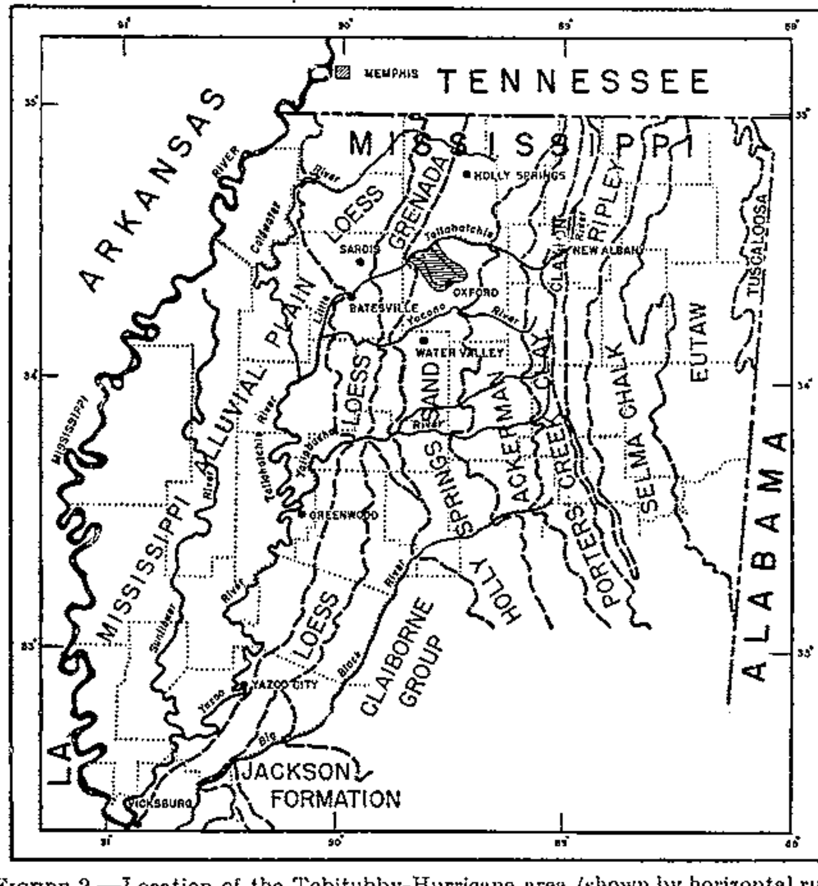


FIGURE 2.—Location of the Tobitubby-Hurricane area (shown by horizontal ruling) in relation to outcrop areas of principal geologic formations of northern Mississippi. (Adapted from pl. 2, Water Supply Paper 576, U. S. Geological Survey.)

The bedrock of both drainage areas is the Holly Springs formation of Eocene Wilcox age (fig. 2) (*50, pp. 64–100*). This formation consists dominantly of unconsolidated slightly micaceous sands, but it includes numerous lenses of clay. On the higher slopes and uplands the upper few feet of the bedrock is a thoroughly weathered, partly indurated reddish iron-stained zone, formerly known as the "Lafayette" formation (*50, pp. 86–88; 67, pp. 128–132*). Above the "Lafayette" weathered zone, or directly above the bedrock on the lower parts of the slopes where the weathered zone may not be present, there is a surficial mantle of a few feet of silt. This is believed to be a windblown loessial deposit, presumably derived from farther west during the Pleistocene or Ice Age (*46, pp. 64–68*), that was spread across the country after the ridges and valleys had acquired essentially their present forms.

As shown in the soil survey report of Lafayette County (*30*), the predominant upland soil is the light-brownish or buff-colored Memphis silt loam that has been developed on the loess. Much of the soil classed in 1912 as Memphis would now probably be classified as Grenada silt loam. There were, in addition to the Memphis silt loam, a few scattered areas of Ruston sand, sandy loam, and fine sandy loam and Orangeburg sandy loam derived from weathering of the Coastal Plain material. The terrace or second-bottom soil was light-brown or yellowish-brown silt loam of the Lintonia series. The first bottom soils were classified as Vicksburg silt loam, Thompson fine sandy loam, and Meadow, the Vicksburg and Thompson being brownish in color, the Meadow prevailingly gray. Table 1 gives the areas of the different soil types in the Tobitubby-Hurricane area as determined by planimeter from the soils map.

TABLE 1.—*Acreage and proportionate extent of soils in the Tobitubby-Hurricane area*

Soil type	Area		Soil type	Area	
	Acres	Percent		Acres	Percent
Memphis silt loam	43,975	77.6	Vicksburg silt loam	5,104	9.0
Ruston fine sandy loam	657	1.2	Thompson silt loam	1,207	2.1
Ruston sandy loam	521	.9	Meadow	2,805	4.9
Ruston sand	323	.6			
Orangeburg sandy loam	28	.1	Total	56,654	100.0
Lintonia silt loam	2,034	3.6			

At University (1 mile west of Oxford) during a 43-year period of record, 1887 to 1889 and 1891 to 1930, the average annual precipitation was 50.99 inches, the maximum and minimum being 73.35 and 40.73 inches, respectively. The average monthly rainfall varied from 2.24 inches in October to 5.83 inches in March. The precipitation data for the 43-year period of record are summarized in table 2. The temperature fluctuates about the freezing point during the winter months, but snow forms a very small percentage of the annual precipitation.

Although only about 18 percent of the land in Lafayette County is cultivated, the Tobitubby and Hurricane drainage basins have been somewhat more intensively farmed. The percentage of land devoted to tillage at any one time has probably never been much higher than at present, but nearly all the land has been cleared and cultivated at some time. Corn and cotton are the principal crops. Soil-conserving measures have been introduced on small portions of both drainage basins since 1934 by a Civilian Conservation Corps camp located at Oxford and operated under technical supervision of the Soil Conservation Service. In the Tobitubby drainage basin about 35 percent of the first bottom is cleared and is or has recently been in cultivation. In the Hurricane drainage basin the percentage of first bottom under cultivation is much less, being only about 10 percent.

TABLE 2.—*Minimum, maximum, and average monthly and annual rainfall at University (Oxford), Miss., 1887–1930* [1]

Rainfall	January	February	March	April	May	June	July	August	September	October	November	December	Annual
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Minimum	1.36	0.67	0.01−	0.10	0.69	0.25	0.70	0.10	0.00	0.01−	0.47	0.48	40.73
Maximum	16.15	8.80	12.89	11.63	11.38	12.35	14.14	9.70	8.71	9.20	12.25	12.32	73.35
Average	4.86	4.15	5.83	5.12	4.36	4.61	4.20	3.70	2.64	2.24	3.98	5.30	50.99

[1] Data from CLIMATIC SUMMARY OF THE UNITED STATES. SECTION 78, NORTHERN MISSISSIPPI. U. S. Weather Bureau.

As is common throughout the Southern States, where cotton is the cash crop that dominates the agricultural system and corn the staple food and feed crop, the uplands are preferred for cotton and the valley bottoms for corn. During the hundred years since the region was settled the sloping uplands have been subject to very severe soil erosion. As a consequence, the relative potential value of the bottom lands has steadily increased. But sand, derived chiefly from the innumerable gullies cut into the Coastal Plain sands that underlie the upland soils, has been washed in large quantities into the valleys and stream channels, and thereby serious problems have been created that must be solved if the valley lands are to be effectively utilized for agriculture.

The grades of the streams and the slopes of their flood plains were developed in response to run-off habits controlled by climatic conditions and by types of vegetal cover that prevailed before white settlement. Clearing of the forests and cultivation of sloping lands has greatly accelerated the rate of delivery of sediment from the uplands to the valleys and has caused corresponding changes in rates of run-off. Thus the grades of the streams and valleys have been thrown out of adjustment. As a result of the natural processes that tend to restore the balance by establishing a new, and in part steeper, longitudinal stream and valley profile, large quantities of sediment have accumulated in the upper parts of the streams and valleys.

The sediment has partly or completely filled the stream channels, thereby causing increased frequency and severity of overbank floods. Stream channels have shifted, and the ground-water table has been raised. Drainage of the valley lands has been impaired or obstructed, and large areas of bottom lands have been swamped. The growth of alluvial fans and deposition on the flood plains have been accelerated, and areas of fertile alluvial silt loam have been buried under less fertile sands. Such areas have commonly been withdrawn from cultivation and now support an essentially valueless growth, largely of willows, briers, weeds, and sedge. Various individual and group attempts to alleviate these conditions have been uniformly unsuccessful, and at the present time conditions in many places are worse than before the corrective attempts were made.

EXCESSIVE SEDIMENT PRODUCTION

Upland erosional debris becomes stream and valley sediment, and surface run-off waters from the uplands become the floodwaters of the lowlands; consequently erosional processes must be considered as basic factors in the problems of accelerated stream and valley sedimentation. Although this applies particularly to those erosional processes that have been accelerated or initiated as a result of man's cultural efforts, all geological processes of erosion must be included, for they continue to operate as sources of sediment production.

In the Tobitubby and Hurricane drainage basins, gullying, sheet erosion, and valley trenching, named in order of decreasing importance, have furnished practically all the sediment that has accumulated in the valleys during the period of cultural influence. Stream-bank erosion is not excessive, nor is it an important source of sediment, except locally. Soil creep and other mass movements are active but apparently have not produced much harmful sediment, except as they contribute to the growth of gullies or the widening of valley trenches. All these processes, with the possible exception of valley trenching, may be expected in any area of excessive soil erosion.

Sheet erosion has affected chiefly the loess that occurs as a surficial mantle a few feet thick over the uplands of both drainage basins. No attempt has been made to measure directly the rate of sheet erosion in the Tobitubby and Hurricane drainage areas, but plot investigations have been made on similar soils by the United States Forest Service at Holly Springs, Miss., 34 miles north of Oxford. During the 2-year period of study, October 1931 to September 1933, the erosion per acre from oak forest was 0.05 ton; from Bermuda grass pasture, 0.19 ton; from cultivated land (cotton) with rows on the contour, 69.33 tons; from cultivated land (cotton) with rows down the slope, 195.10 tons; and from barren abandoned land, 159.70 tons (*53, p. 12*). The removal of 195.10 tons per acre in 2 years is equivalent to the erosion of about 6 inches of soil in 10 years. A large part of the land in the Tobitubby and Hurricane drainage areas has slopes equal to or greater than the 10-percent slopes used in the studies at Holly Springs, and the erosion rates shown by those studies are probably reasonably representative of the rates prevailing for similar soil, slopes, and cover in the Tobitubby-Hurricane area. The similarity of the erosion in Lafayette and Marshall Counties has been brought out by the investigations of Lentz, Sinclair, and Meginnis (*43, 44, 69*).

Representative textures of the loess and bedrock and the average composition of the valley deposits are shown in table 3. The sediment derived from sheet erosion of the loess is chiefly silt and is transported as suspended load by the streams, being deposited only where there is a marked decrease in the velocity or the turbulence of the water. Analytical data indicate that about 75 percent of the sediment that has accumulated in the Tobitubby and Hurricane Valleys is fine-grained erosional debris. This fine material apparently causes only a small portion of the sediment damage to valley resources. Gullying of the slightly indurated Holly Springs sand is estimated to have furnished about 25 percent of the sediment accumulated in the stream valleys. In the major valleys this sand has accumulated principally in or near the stream channels, thereby reducing the discharge capacity of the streams and directly or indirectly causing the principal damage to valley resources. Much sand has also accumulated as alluvial fans along the valley sides.

Table 3.—*Texture of the loess and bedrock and of the modern valley deposits in Tobitubby and Hurricane drainage basins*

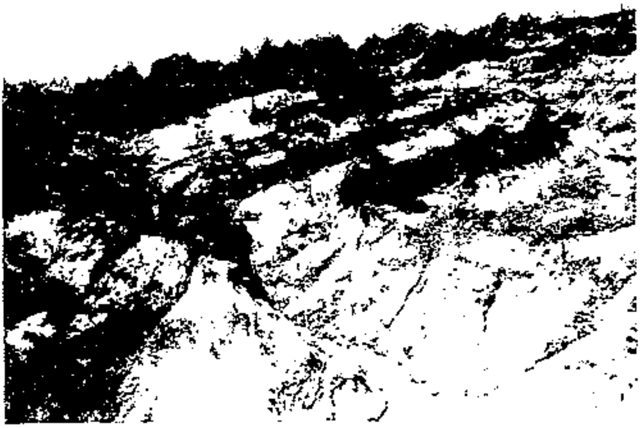
Type of material	Amount in indicated grain size											
	>1/2 mm.	1/2–1/4 mm.	1/4–1/8 mm.	1/8–1/16 mm.	>1/16 mm.	<1/16 mm.	1/16–1/32 mm.	1/32–1/64 mm.	1/64–1/128 mm.	1/128–1/256 mm.	1/256–1/512 mm.	<1/512 mm.
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Loess [1]					11.4	88.8	14.0	32.8	17.5	8.7	5.7	10.1
Bedrock [2]	35.7	38.4	0.8	3.8	87.7	12.3						
Modern valley deposits [3]	2.6	12.3	10.5	3.4	28.8	71.2	10.1	21.7	16.2	7.0	3.5	12.7

[1] Average of 3 samples. [2] Average of 7 samples. [3] Weighted average of 353 samples.

Of major significance is the greater importance of gullying, as contrasted with sheet erosion, in the production of harmful sediment. The concentration of water in gully channels permits transportation of coarser sediment than is readily moved by the less concentrated surface run-off that causes sheet erosion. Hence gullies, which scar nearly all abandoned fields as well as many of those still in use, are the source of large quantities of sand (pl. 1). Starting usually along a furrow or pathway, or following a natural sag in the sloping surface, the gullies deepen in the mellow loessial surface material, growing rapidly by retreat of the gully walls. When the gully channel is cut down through the loess, the rate of downcutting may be checked by the more resistant, indurated "Lafayette" zone, and the gully widened as a result of the relative increase in the rate of lateral cutting. Where the "Lafayette" zone is lacking, or after it is breached, the gullies cut directly into the underlying bedrock sands and clays. When this bedrock is reached, the production of harmful sediment is greatest, for the gully then grows rapidly by undercutting, caving, and slumping of the walls. Where there is a thick indurated "Lafayette" zone, this stage is postponed until the unconsolidated sands are exposed by the slower channel deepening through the resistant indurated zone. In such places the channel incision is usually by pot-hole deepening or headward migration of an undercutting overfall (pl. 2, *A*).

Gully development has been very extensive in some parts of the area. In one quarter section (NE¼ sec. 27, T. 7 S., R. 3 W.) tributary to Hurricane Valley, 41 separate gullies and gully systems were counted on aerial photographs. The largest of these gully systems covers 3 to 4 acres. In another badly gullied quarter section (SE¼ sec. 2, T. 8 S., R. 4 W.) tributary to Tobitubby Valley, 51 separate gully systems were identified.

Erosion is not confined entirely to the washed and gullied uplands and ridges. Channels have also been cut along the bottoms of valleys near the head of flood-plain development. These incised valley trenches are steep-walled, flat-bottomed channels that are dry except for short periods after heavy rains. They are similar to the arroyos of the Southwest. The valley trenches have a twofold effect on valley sedimentation, for (1) their formation and growth have contributed large quantities of sediment to the streams, and (2) they serve as flumes to transport sediment from the gullied and sheet-washed uplands past the upper parts of the flood plains, where much deposition



Intricate dissection of uplands in Tobitubby-Hurricane area near Oxford, Miss. Several feet of loess underlain by the more resistant "Lafayette" zone, beneath which is the unconsolidated Holly Springs sand.

A, Head of a gully that is being extended by headwater migration of an overfall, near Oxford, Miss. Loess overlying indurated dark red "Lafayette" zone, which is underlain by less resistant Holly Springs sand in the center of the view. The ax in right center shows scale. *B*, 2-foot aggradation gage, with graduated scale, in East Goose Valley. *C*, 3-inch Iwan auger used for test borings, with extra 4-foot pipe extensions, putty knife for cleaning auger, pipe wrenches, and paper on which samples are laid out for examination.

would otherwise occur, to the wider valley bottoms farther downstream.

Some of these trenches attain depths of 12 feet, local widths of 50 feet, and lengths of over one-half mile (pl. 3); consequently, the contribution of debris by valley trenching has been large. Compared with gullying and sheet erosion, however, valley trenching appears to be of secondary importance with respect to total volume contributed. The flumelike action of the trenches in transporting sediment down to the wider valley bottoms appears to be of much greater importance than direct contribution of debris produced by the valley trenching. In addition to the increased delivery of sediment to the wider valleys, the sorting of the debris during its transportation through the trench results in separation of the fine and coarse material, which formerly accumulated as more poorly sorted but valuable alluvium in headwater areas. As a consequence of this sorting, concentrated infertile sands are deposited at many places in the wider valleys.

METHODS OF INVESTIGATION OF VALLEY SEDIMENTATION

The investigation of accelerated sedimentation and its effects involves both the study of present processes and the study of existing deposits that by their character and distribution reveal the conditions under which they were formed. Because of the many difficulties involved in direct study of the processes, especially within the limited time available for the Tobitubby-Hurricane investigations, it was necessary to rely mainly on the study of deposits in place.

During the course of the investigation, however, much was learned from critical observation of surface run-off and stream flow and their effects on sediment transportation and deposition. The processes of underwater deposition could not readily be observed directly because of the turbidity of the water, but it was occasionally possible to watch the formation of deposits or the erosion and transportation of temporary accumulations. The fresh deposits left after overflows were an even more important source of information. Immediately after deposition the new deposits usually could be easily differentiated from the underlying or surrounding older material. Consequently the general distribution and approximate quantity of deposition by particular overflows could be determined by simple observation. In these ways qualitative comparisons were made between existing conditions and former conditions as indicated by the earlier deposits.

The period of study was too short and the available facilities were too limited to permit extensive direct measurements of rates of contemporary sedimentation. An attempt was made, however, to do this in a few critical localities. At one place in East Goose Valley (range EG–4) and at one place in Hurricane Valley (range H–9) concrete posts with flat concrete bases flush with the ground surface were set at intervals ranging from 100 to 300 feet along a line across the valley. One of these aggradation gages is shown in plate 2, *B*.

Gages were set on these ranges early in the spring of 1936, and at the same time others were placed on several ranges across the flood plain of the Little Tallahatchie River, above and below the mouths of Tobitubby and Hurricane Creeks. These gages are intended primarily to measure flood-plain aggradation in the future, as the 1-year period of the present studies has been too short to permit determination of contemporary average rates of accumulation.

During the period of approximately 1 year between the establishment of these gages and the close of field work in the area, however, visible accumulation occurred on the bases of a number of the gages. At no range did this occur on all of the gages across the valley, but it was confined either to the lower back-swamp areas of the flood plain, to the natural levees, or to alluvial fans. The greatest thickness of accumulation, about one-half inch, occurred on a small alluvial fan built into East Goose Valley. A very thin film was deposited on other gages on this line, chiefly in the back-swamp areas. At the range in Hurricane Valley, sediment accumulated only on the gages close to the stream channel. Several of the gages on the Little Tallahatchie flood plain also received a deposit less than one-sixteenth of an inch in thickness, and on one gage, in a shallow slough near the river, about one-half inch was deposited. On most of the Little Tallahatchie gages either no sediment was deposited or the sediment was washed away by rain or succeeding overflows. Precipitation at University (Oxford) during 1936 was 13.5 inches below normal. This may account in part for the small amount of accumulation.

The major part of the study has necessarily been devoted to determination of the effects of accelerated sedimentation as shown by the thickness and character of the sedimentary deposits accumulated during the period of accelerated soil erosion. This information has been obtained mainly by test borings. Borings were made along ranges crossing the valleys approximately at right angles to the valley axis, the ranges being spaced at intervals varying from ½ mile to nearly 2 miles. After field inspection of the area, ranges were located at places where they would yield critical information on the variations in sedimentation corresponding to different controlling factors, such as (1) confluences of major tributaries, (2) alluvial fans built by tributaries draining areas of unusally severe gullying, (3) variations in stream gradient and channel capacity, (4) width of valleys, (5) boundaries between cleared and wooded sections of the bottoms, (6) artificially straightened channels, and (7) channels completely filled by modern sediment accumulations. On each range, borings were made at variable intervals of 20 to 100 feet, the spacing depending on the irregularity in the thickness of the modern deposits and the difficulty in identifying the contact between modern and older deposits.

The ends of each range were permanently marked by capped iron pipes set in concrete. The pipes were stamped for identification, and a base map was prepared to show the location of the ranges (fig. 3). The elevation of the tops of pipes was established by leveling from standard Government bench marks, and detailed ground-surface profiles, including the surface elevation at the top of each test hole, were taken along the ranges. From these data, cross sections showing the present and premodern surface configuration along the range lines were constructed. The cross-sectional area of modern fill was measured by planimeter, and the volume of modern fill in the segments of the valley between adjacent ranges was computed by the Dobson reservoir formula (*20, pp. 7–9*), the areas of bottom land between ranges and the cross-sectional area of fill at each range being used.

The test borings were made with 3-inch Iwan-type soil augers (pl. 2, *C*) fitted with extensible iron-pipe handles that allowed pene-

FIGURE 3
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OF BULLETIN.

tration to a depth of 25 feet or more. The augers are of sheath type, and contamination from the sides of the hole is slight. Samples were taken from each 4-inch depth, a putty knife being used to clean the auger bit, and were placed upon sheets of paper near the hole for examination and field description. The color and texture, together with other pertinent characteristics thought to be significant, were noted. Representative samples were also collected and preserved for laboratory study, chiefly as a check on field identification of texture. Analyses of the mechanical composition of selected samples were made in the sedimentation laboratory of the department of geology, University of Chicago, through the courtesy of that institution. The field descriptions of texture were usually found to be consistent with the results of laboratory analyses.

The fundamental factor in the reliability of this method of study is the accuracy attained in determining the base of the modern deposits. In beginning the study, this was the problem of first consideration. It was known that in many small valleys where sediment is obviously accumulating at present, or is known to have accumulated within recent years, exposures in creek banks and artificial cuts show light-colored sediment overlying darker and finer material (pl. 4, *B*). Below this darker horizon, which commonly is dark gray or black, the material gradually becomes lighter in color, the transition being suggestive of a soil profile. In many places, especially where the deposition above the dark zone has been thin, the buried profile can be traced laterally until its continuity with dark-colored soil profiles now at the surface can be established. Clear examples of this relationship are found most commonly in the Middle West, where dark prairie soils are widely developed.

It was also known that in many sections of the country sand and gravel have been eroded in large quantities from gullies known to have developed during the period of cultivation. At some places these coarse materials can be traced directly from their source in gullies to valley bottoms where they overlie finer sediments capped by dark zones. In such places culturally accelerated erosion (gullying) is obviously the cause of burial of the dark bottom-land soil horizon. The first objective of the studies in Tobitubby and Hurricane Valleys was, therefore, to determine the extent to which these two criteria, dark color of buried soils and coarser texture of modern sediments, could be used in determining the thickness of modern deposits in the Tobitubby-Hurricane area.

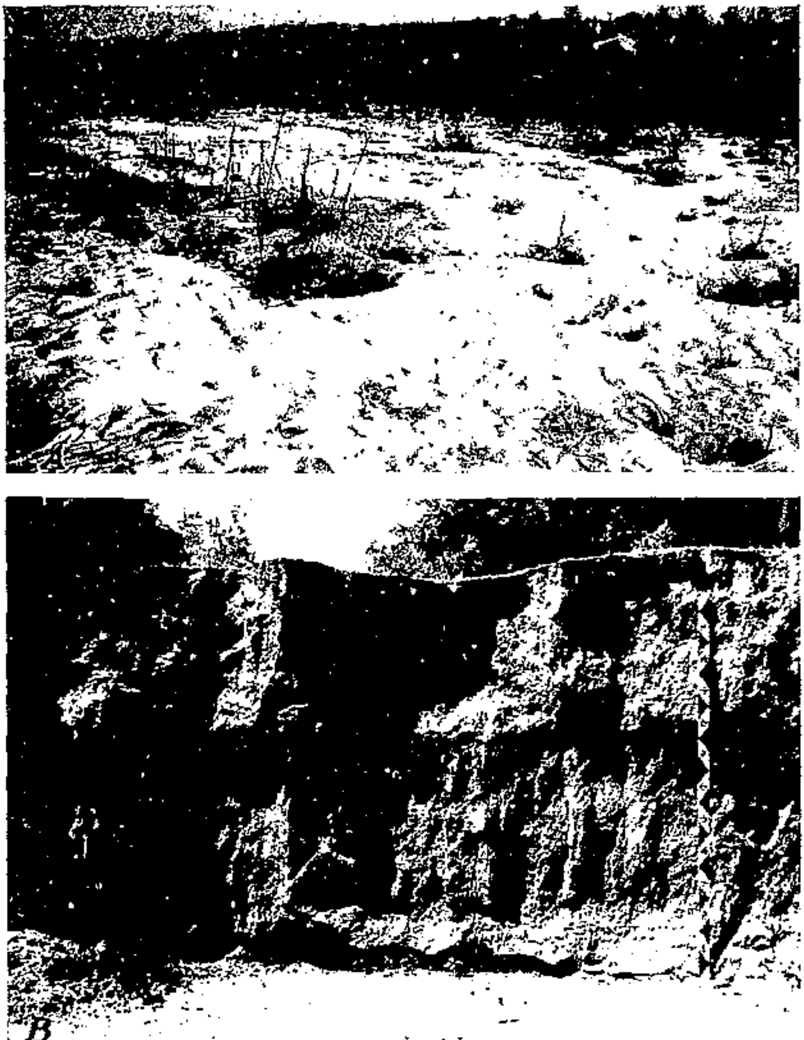
The first test borings were made in a part of East Goose Valley where sand had been deposited over a considerable surface area since the last annual growth of vegetation. This section of the valley was thus known to be an area of modern sedimentary accumulation. Testimony of local residents confirmed this visual evidence, as did the presence of partly buried fence posts and trees and a drainage ditch nowhere more than 3 feet deep, and in some parts completely filled with sand, which was known to have been dug to a depth of 6 feet some 15 years previously. These facts justified the assumption that borings would penetrate first through modern sediments of known character, thus providing a basis for comparison with any underlying older sediments accumulated under markedly different conditions.

Dozens of test borings were made in this part of the valley, and general similarity of sequence was found in all. The visible character of the surface sediments continued downward for at least several feet in most holes. Below this depth, color changes were usually noted, the reddish and chocolate-brown tints of the surficial material being replaced by lighter yellowish and brownish grays. The change in color commonly occurred near the level of the ground-water table and without regard to the texture of the material. At somewhat greater depth, the light yellowish-gray and brownish-gray colors usually changed abruptly to dark brown or dark gray, or even almost black. In some boring holes this darkening of color was accompanied by a notable change to finer texture. With greater depth the color became lighter, and a foot or more below the conspicuously dark horizon another sequence of light-gray colors occurred, which in some places could be distinguished from the series of light colors above the dark zone by bluish and greenish tints and a peculiar bleached appearance. In and below the dark horizons, small concretions, which may occur throughout the vertical sequence below the ground-water table, were commonly found to be too hard to be crumbled easily between the fingers. In contrast, the concretions found above the dark horizons at a few places were soft and could be crumbled easily between the fingers, except those in sands, which appeared to have been transported to their present location as concretions rather than to have been formed in place.

When plotted in proper relative position on cross sections of the valley, the darker horizons were at generally concordant elevations and depths below the surface. This was not true of any other recognizable textural or color sequences found in the different borings, except the change of color at the level of the ground-water table. At many places the dark horizon had a high organic content of woody or vegetal material. Furthermore, the dark horizon in some places rose gradually toward the valley side with uniform slope without showing any recognizable difference in color corresponding to its position above or below the water table. In some places it approached the present surface where very recent deposition had obviously taken place, and its hypothetical projection continued above the slope of the valley side from which the topsoil had been eroded and where residual subsoil material was exposed at the ground surface (fig. 4). These relations at the valley sides suggest a former, fairly stable, dark-colored topsoil horizon that extended down a colluvial slope and out across the surface of the former flood plain before it was buried beneath modern sediments.

On the basis of these findings it was concluded that the bottom lands had developed a dark topsoil zone prior to clearing and settlement and that this old topsoil had retained its distinctive color despite burial beneath modern sediments to depths of at least 10 feet in some places and despite the fact that in many places it is now beneath the ground-water table, which has risen as a result of channel aggradation and impeded drainage. In the records of the General Land Office surveys of 1834–36 prairies were reported in the upper parts of the Tobitubby and Hurricane Valleys. This suggests that the bottom-land soils were then dark colored, for prairie soils are characteristically dark. Subsequent test borings throughout these and other valleys have shown that generally similar characteristics and relationships occur elsewhere under similar conditions.

Typical trenched headwater valley in Tobitubby-Hurricane area. Three photographs taken at ½-mile intervals illustrate downstream decrease in depth and increase in width.



A, Sand splay deposited in cottonfield in East Goose Valley; *B*, light-colored, stratified modern sediment overlying black old soil horizon in tributary of Coon Creek, Vernon County, Wis.

Additional confirmation of these interpretations is the fact that between 1911 and 1936 an average of about 3 feet of sediment was deposited beneath the Illinois Central Railroad bridge across Hurricane Valley between ranges H–6 and H–7, as shown by comparison of surveys made in these years (fig. 19). Although the present surface sediment beneath this bridge is brown, the characteristic yellowish and light brownish-gray colors usually associated with the ground-water table occur in sediment shown by the surveys to have accumulated within the last 25 years, indicating definitely that this grayish sediment is modern. Nearby, at boring range H–7, the characteristic dark-gray old soil horizon was found about 8 feet beneath the surface near the channel and was underlain by the lighter gray bleached zone, which is thought to represent the old subsoil. It seems reasonable, and corroborative of the general theory, that the accumulation during the past 25 years should be approximately one-third as much as the

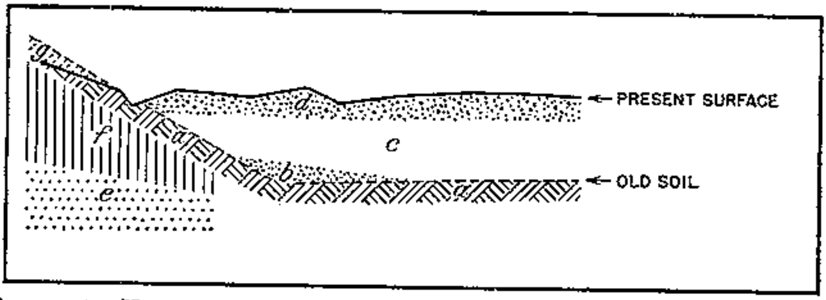


FIGURE 4.—Hypothetical cross section illustrating typical relations of modern valley deposits to buried old soil horizon and residual soils of adjacent upland slopes: *a*, Old silt loam soil (dark gray to almost black on premodern flood plain, dark brown on slopes where still at surface); *b*, early modern alluvial fan; *c*, modern flood-plain silt; *d*, very recent surface sanding due to complete channel filling; *e*, residual bedrock sand; *f*, residual loessial subsoil; *g*, topsoil removed by accelerated erosion. The thickness of modern deposits, as here illustrated, may be as much as 10 feet.

total accumulation during the period of accelerated soil erosion—about 100 years.

In some places no dark old soil horizon was found by boring. This may indicate either that the primeval soil was not dark, which would be a reasonable explanation of conditions in many places, or that it had been removed by flood scouring or by lateral migration of the stream. In many of these places, however, light bleached colors and hard concretions occur at depths correlative with those at which they were found underlying dark horizons in nearby holes. In such places these auxiliary criteria have been accepted as indicators of the maximum possible thickness of modern accumulation.

No textural criterion for differentiation between modern and older sediments has been found satisfactory, for in many places the variations within what appear to be unmistakably modern deposits are greater than the difference in texture between the dark old soil horizon and the modern sediment immediately above. In general, however, the modern sediments are distinguished from the underlying older sediments by greater coarseness and heterogeneity.

The old dark topsoil of silt is usually underlain by progressively lighter-colored silt, beneath which, at a depth of a few feet below the old surface, is sand. This sand is usually fairly clean, and apparently it is a stream-channel deposit. This sequence coincides with the normal vertical flood-plain sequence, in which finer material deposited from suspended load carried by overbank floodwaters overlies coarser materials deposited within the stream channel and largely composed of bed-load sediment. Streams that shift laterally at bends by bank cutting and frequently overflow their flood plains characteristically build flood plains comprising these two types of deposits, technically known as vertical accretion and lateral accretion (*25, pp. 89–91*). So far as known, the streams in question were of this type when the area was first settled. No other such vertical change in texture occurs at uniform depths within the flood-plain sequence, and it therefore appears evident that the silt-on-sand contact characteristically found below the dark horizon represents the base of the primeval flood-plain cover of vertical accretion. This is further substantiation of the conclusion that the dark horizon may be reasonably interpreted as the old soil developed upon the alluvium before the abrupt and great change in sedimentation rates that has taken place as a result of culturally accelerated soil erosion.

After the foregoing facts had been discovered and verified it was concluded that the contact at the base of the modern sediments could be determined with reasonable accuracy by the method of test borings. The results obtained indicate a total volume of modern accumulation equivalent to the erosion of a layer 5.4 inches thick from the entire upland part of Tobitubby and Hurricane drainage areas (table 7). In view of the high rates of sheet erosion found by experiment at Holly Springs, Miss., on similar soils and slopes (*53, p. 12*), and the facts that sheet erosion has been severe in large parts of the drainage basins and that deep and extensive gullies have intricately dissected parts of them, it seems reasonable to conclude that the volume of sediment accumulated in the valleys during the period of accelerated erosion, as determined by use of these criteria for the identification of the base of the modern deposits, could have been furnished from the contributory drainage areas. Plot results at Holly Springs as applied to the Tobitubby-Hurricane drainage area are discussed in more detail on pages 61–62. The results obtained are thus consistent with observed erosional conditions, which tends to confirm the reliability of the methods used.

TYPES OF DEPOSITS

Practically all the modern sediments in Tobitubby and Hurricane Valleys belong to one or another of four distinct genetic types of deposits, and at least two other genetic types are present in minor amounts. These six types are:

Channel-fill deposits.
Vertical accretion deposits.
Flood-plain splays.
Colluvial deposits.
Lateral accretion deposits.
Channel lag deposits.

Of these, the last two types are of little importance among the modern deposits, but they may have been more important under premodern conditions. There are practically no lacustrine deposits, for

FIGURE 5
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such ponding as occurs on the flood plains produces swamps rather than lakes, and the swamp deposits are usually indistinguishable from other vertical accretion deposits.

These genetic types of deposits occur in what may be called four distinct associations, as follows:

Normal flood-plain, or valley-flat, association.
Alluvial-fan, or alluvial-cone, association.
Valley-plug association.
Delta association.

CHANNEL-FILL DEPOSITS

The channel-fill deposits have accumulated in the stream channels where the transporting capacity has been insufficient to remove the sand as rapidly as it has been delivered. The process has not been a simple sorting out and deposition of the coarsest material, but a net accumulation from alternate scouring during rising flood stages and deposition during the falling stages. As the average amount of scour has been less than the average amount of deposition, the net result has been aggradation of the channel bed.

The process of channel filling has proceeded rapidly in the upper parts of both Tobitubby and Hurricane Valleys, in many places, or perhaps in most, in connection with the development of valley-plug deposits (described on pp. 29–31). The present stream beds are usually higher than the buried premodern flood-plain surface, and in some places they are higher than the present flood-plain surface on either side. At range T–2 [4] (fig. 8), for example, the channel bottom is more than 4 feet higher than the flood-plain surface 400 feet away and 11 feet higher than the lowest part of the buried premodern flood-plain surface. The extreme channel aggradation is partly due to thick growths of willows and other vegetation along the stream banks, which stabilize and promote upbuilding of the natural levees. Occasional channel training and cleaning operations by the landowners also tend to keep the channel confined to the same position on the flood plain. Eventually, however, the channel shifts to a new course during a flood. In places the abandoned aggraded channels may be recognized as low sandy ridges, upon which there is only a meager growth of vegetation. Such an abandoned channel is shown on the topographic map of part of East Goose Valley (fig. 5). Channel-fill deposits comprise only a small part of the total modern sediments, but they have been of great importance in causing increased overbank flooding and, consequently, increased flood-plain deposition and sanding of parts of the valley bottom.

The available evidence indicates that such rapid channel aggradation was not in progress before the area was settled. Dark soil horizons, ferruginous concretions, and extensive bleaching in parts of the premodern deposits and the fact that the buried dark-soil horizons occur over large areas at uniform elevation suggest that the flood-plain surface was comparatively stable, and hence that the channels were probably aggrading very slowly, if at all. Old flood-plain silts prevailingly overlie what appear to be channel sand deposits, and the thickness of the finer old sediment is generally fairly uniform. This relation also suggests that either the channels were aggrading slowly, if at all, or that lateral migration was more important than at present,

[4] T, H, WG, EG, and G refer to Tobitubby, Hurricane, West Goose, East Goose, and Goose Valleys, respectively.

so that the channel shifted from side to side and left a layer of channel sands at about the same elevation all the way across the valley, to be covered later by flood-plain deposits of vertical accretion.

VERTICAL ACCRETION DEPOSITS

In times of flood the stream channels have insufficient capacity to carry all the water delivered to them as surface run-off. The excess water overflows the banks and spreads widely over the adjacent flood plain. Because of greater frictional resistance, this spreading results in marked reduction in velocity and even greater reduction in transporting capacity. Part of the sediment carried in suspension while the water was confined to the channel is therefore deposited on the flood plain. As the velocity decreases the coarser material is dropped first and builds up the characteristically sandy natural levees that border the channels. Finer sediment is carried farther from the channel and deposited as a thinner layer over the entire flood-plain surface. This is the process of vertical accretion (*25*), and the deposits are composed almost entirely of sediment that was carried to the place of deposition as suspended load. In this respect they differ from the channel deposits, which are largely composed of bed-load sediment.

FLOOD-PLAIN SPLAYS

The regularity of flood-plain deposition is interrupted in those places where excess water leaves the channel through restricted low sections or breaks in the natural levees. In such places the velocity of the escaping water may be sufficient to carry along an appreciable quantity of relatively coarse sediment, which is carried farther from the channel than would otherwise be the case. The sandy sediment is commonly spread outward onto a fan-shaped area of the flood plain, across which it is moved forward at least partly as bed load. These deposits are here designated as flood-plain splays. They are essentially similar in origin to deposits spread out upon the flood plain when a crevasse develops in an artificial levee. Glenn (*29, pp. 39–40*) has described what probably is a form of splay as "fans of sand and cobbles * * * spread over the once fertile surface" at the ends of short, shallow distributaries leading from an overloaded small Appalachian stream.

Splays occur along many streams that are bordered by well-developed flood plains, but in Tobitubby and Hurricane Valleys their number and size have been greatly increased during the modern period. Although individually of small areal extent (pl. 4, *A*), in the aggregate they cover a large area and cause most of the harmful sanding of the bottom lands.

COLLUVIAL DEPOSITS

Accelerated colluvial deposits have accumulated in considerable quantity on the flood plain at the base of most slopes bordering Tobitubby and Hurricane Valleys, and perhaps in even larger quantities above the flood plains on the lower parts of the longer slopes. They have caused little damage, however, and have not produced any significant modification of the valley forms. These deposits are composed chiefly of the debris from sheet erosion deposited by unconcentrated surface run-off or slope wash, together with talus and other mass-movement accumulations. In Tobitubby and Hurricane Valleys they are dominantly of fine texture, reach maximum thicknesses of only a few feet, and rarely extend more than 100 feet across the valley bottoms from the base of the bordering slopes. They are most prominent in the narrow headwater sections of the valleys, where flood-plain deposition has been minimized as a result of valley trenching.

LATERAL ACCRETION DEPOSITS

The deposits of lateral flood-plain accretion are formed along the sides of channels, where bed-load material is moved by traction toward the inner sides of channel bends. Normally such deposits of lateral accretion are later covered by finer material of vertical accretion, as the channel shifts farther away by lateral bank cutting so that the slip-off slope on the inside of the bend is overflowed less frequently and with less velocity. The deposits of lateral accretion are coarser than those of vertical accretion, but they are finer, on the average, than the channel-fill or channel lag deposits because of a greater admixture of material deposited from suspension in the shallow water on the slip-off slope of the channel side. They may be composed largely of material eroded from the outside bank of the bend that has been moved diagonally down and across the channel bed by the currents associated with helical flow (*21*) and deposited on the opposite, or inner, bank of the same stream bend, or the next bend downstream.

In Tobitubby and Hurricane Valleys it is notable that the channel aggradation has been accompanied by little lateral migration of the channel by bank cutting, and, consequently, modern deposits of lateral accretion are of insignificant amount. The banks are generally well protected by vegetation and are fairly stable except where they have been artificially cleared. Several channel changes by avulsion[5] were in various stages of completion at the time of investigation, however, and this type of change is apparently more important than channel migration by lateral cutting.

CHANNEL LAG DEPOSITS

Channel lag deposits are composed of the relatively coarser materials that have been sorted out and left as a residual accumulation in the normal process of stream action. They are prominently developed in the beds of most streams but do not indicate channel aggradation, as do the channel-fill deposits. These lag sediments also tend to be mixed with the deposits of lateral accretion, but in many places there is a considerable residual accumulation of the coarsest sediment in the deeper parts of the main channel and in parts of the stream where lateral accretion is not active. Such residual accumulations are genetically distinct and often can be recognized texturally where exposed in cut banks after burial and reexcavation. They are typically found at the base of the vertical flood-plain sequence; although in an aggrading valley, lag deposits may be found in old buried channels at any vertical position in the valley alluvium below the latest surface cover of vertical accretion.

[5] Abandonment of one channel and development of another in a new location on the flood plain, as contrasted with migration of channels by progressive bank cutting on the outside of bends and filling on the inside of the bonds.

NORMAL FLOOD-PLAIN, OR VALLEY-FLAT, ASSOCIATION

The various types of deposits are usually found in characteristic association with each other, composing together the sedimentary accumulation within the valley. In what may be considered the normal flood-plain, or valley-flat, association of genetic types, deposits of vertical accretion occur as a cover over older coarser deposits of lateral accretion and perhaps also of channel fill. This flood-plain cover derived from vertical accretion forms a layer of fairly uniform thickness, whose surface slopes gently and smoothly down valley and somewhat less gently away from the channel banks toward the valley sides. The modern deposits of vertical accretion usually lie upon older deposits of similar origin, which in turn are typically underlain by sandy channel deposits that were accumulated when the channel occupied other positions than at present. These older channel sands may represent lateral accretion on the inside of gradually shifting channel bends, or they may represent filling of former channels abandoned by avulsions. More recent deposits of lateral accretion, in generally crescentic shapes along the inside of stream bends, may still be exposed at the surface but are typically lower than the surface of the adjacent older flood plain, which has been covered by deposits of vertical accretion. The deposits of vertical accretion form most of the fertile bottom-land soils in these valleys as well as in most others in the United States.

Modern channel-fill deposits occur in the present stream channels and in narrow linear strips winding through the flood plain along the courses of abandoned channels. So far as is known, they always extend downward at least to the top of older, premodern channel sand deposits. Lag deposits may occur in the bed of the present stream channel as well as in association with the older channel fill and with deposits of lateral accretion in old abandoned channels in various places throughout the alluvial fill, but they never overlie the uppermost stratum of vertical accretion deposits. There may also be various forms of transitory bars in the channel. The sand splays are, of course, immediately alongside the present or former channels, from which they extend outward and interfinger with or overlie the flood-plain deposits of vertical accretion. The colluvial deposits occur only along the immediate base of the valley sides, where they extend outward into the valley and interfinger with the deposits of vertical accretion. There is characteristically a low area between the natural levees bordering the streams and the colluvial slopes bordering the valley sides. This is the back-swamp part of the flood plain.

The characteristics of the different types of deposits in the normal flood-plain association are summarized in table 4, and their typical location in the valley accumulation is shown in figure 6.

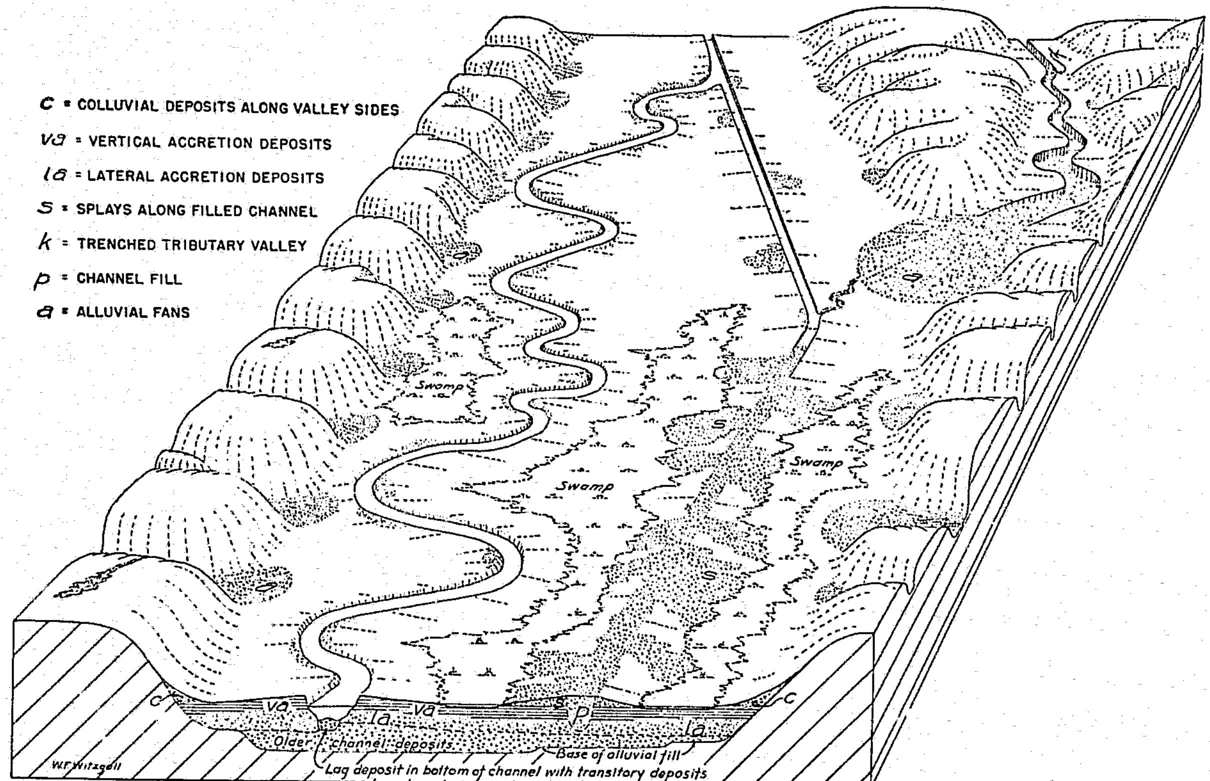

FIGURE 6.—Diagram illustrating typical relations of the various types of deposits in the valley accumulation. (Drawn by W. F. Witzgall.)

TABLE 4.—*Characteristics of genetic types of valley deposits*

Basis of comparison	Type of deposit					
	Colluvial	Fluvial				
		Vertical accretion	Splay	Lateral accretion	Channel lag	Channel fill
Dominant methods of emplacement.	Concentration by slope wash and mass movements.	Deposition of suspended load.	Deposition of bed load	Deposition of bed load always prominent, but suspended load may be dominant.	Deposition of bed load	Deposition of bed load and suspended load.
Usual place of deposit	At junction of flood plain and valley sides.	On entire flood-plain surface.	On flood-plain surface adjacent to the stream channel.	Along side of channel, especially on the inside of bends.	On channel bottom	Within the channel.
Dominant texture	Varies from silty clay to boulders.	Dominantly silt; often sandy, especially near channel; often much clay.	Usually sand; may be gravel or boulders.	Sand or gravel; may include silt or boulders.	Sand, gravel, and boulders.	Usually sand, silt, and gravel. May include clay or boulders.
Relative distribution in the valley fill.	Interfinger with the fluvial deposits, along outer margins of flood plain.	Overlie deposits of lateral accretion and channel deposits; overlain by or interbedded with splay and colluvial deposits; usually cover most of flood-plain surface.	Form scattered lenticular deposits overlying or interbedded with vertical accretion deposits adjacent to present or former channels.	Usually overlain by vertical accretion deposits; often underlain by channel lag or channel-fill deposits. May extend across entire flood-plain width.	Underlie channel-fill, or lateral or vertical accretion deposits; either as a nearly horizontal stratum, a veneer lying on the bed-rock floor, or in linear channel beds.	Usually form elongate deposits of relatively small cross section, winding through flood plain; may overlie lag deposits and underlie vertical accretion deposits.

ALLUVIAL-FAN, OR ALLUVIAL-CONE, ASSOCIATION

In addition to the characteristic positions of the various types of deposits, as listed above, there are three other common groupings or associations that produce characteristic surface forms, always occur in similar locations relative to the surrounding topography, and result from certain definite associations of causes. These groupings are alluvial-fan, or alluvial-cone, deposits, accumulations here designated "valley-plug deposits," and delta deposits.

Alluvial fans are well-known geomorphic phenomena, although they are better known by the surface form than by the nature of the deposits. Such fan, or cone, deposits are typically formed where the gradient of a stream is abruptly lessened as the stream enters a relatively low area of gentler slope, such as the valley of a larger stream. Alluvial fans are found at the mouths of most gullies and larger tributaries entering Tobitubby and Hurricane Valleys. Channel filling, vertical and lateral accretion, and splays are the chief genetic types represented among the alluvial-fan deposits, but they are usually so intimately intermixed that there is little systematic surface or areal distinction between them. Most of the larger fans appear to have originated before modern time, but they have been considerably aggraded and extended outward by accelerated sedimentation. In a few places the reverse has been true, and the old fans have been trenched by deepened erosional channels, and have therefore been aggraded only slightly or not at all in modern time. Many of the smaller fans apparently originated, or at least first attained significant size, during the modern period, usually as a result of accumulation of debris derived from gullies.

Large parts of the present alluvial-fan surfaces are excessively sandy and therefore of little value for cropping. The fans are inherently unstable and are subject to frequent overflow, because the channels that determine the location and growth of the fans are typically subject to aggradational filling and to rapid lateral migration by bank cutting.

VALLEY-PLUG ASSOCIATION

The valley-plug deposits are always associated with filling of the stream channel. When the channel has been completely filled at one place the locus of deposition progresses upstream by backfilling. At the same time all the water flowing in the channel is forced overbank, where it drains down valley through the back-swamp areas until it again collects into definite channels and eventually returns to the main channel below the zone of complete channel filling. This process causes greatly increased development of sand splays and, to a somewhat lesser extent, increases the rate of vertical accretion from the water forced overbank. Channel-fill, sand-splay, and vertical accretion deposits are thus all represented in the valley-plug associations, but all in greater amounts than in the normal flood-plain association. The surface form of a valley plug is somewhat similar to that of an alluvial fan, but it is more elongated than most fans, occurs in different topographic relations, and results from different causes.

In contrast to alluvial fans, which characteristically occur where the gradient is markedly decreased, valley plugs occur where the stream gradient is uniform or normal. There now are slight irregularities in the longitudinal profiles of Tobitubby and Hurricane Creeks (fig. 7) at ranges H–1, H–5, T–2, T–8, and WG–6, which cross valley plugs, but these irregularities appear to result from the aggradation of the channels caused by the plugging.

In general, the plugs are caused by decrease in the capacity of the stream channel downstream. In some places the decreased channel

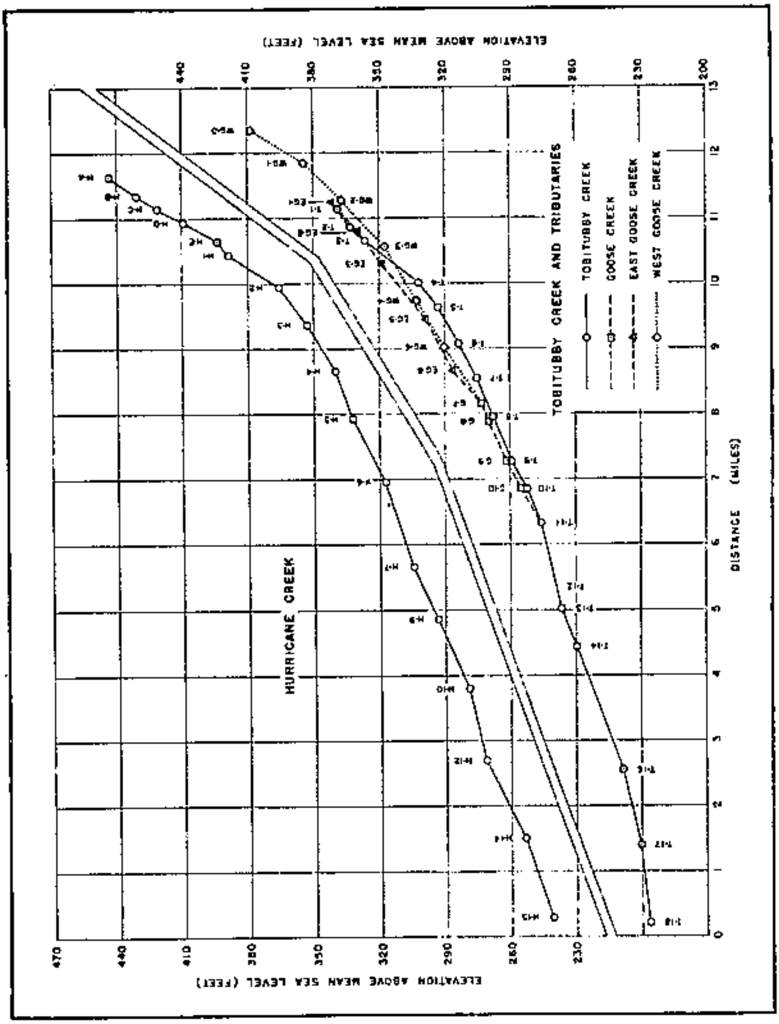

FIGURE 7.—Longitudinal profiles of Hurricane, Tobitubby, and Goose Creeks. The plotted elevations are the lowest points in the channel bed at valley ranges.

capacity results from artificial channel modification, as at the lower end of the Goose Creek drainage ditch, which emptied into a natural winding channel of smaller capacity than the ditch. In other places, as on Hurricane Creek below range H–5, the cause has apparently been delivery of sediment from a tributary in such quantities as to choke completely the main stream channel. The nature of the original channel obstruction is usually not evident, but at some plugs, jams of driftwood were probably a primary locus for sand accumulation in the channel. In this respect the process may be analogous to that by which the famous "rafts" of driftwood and sediment formerly choked the channel of the Red River in Louisiana. The development of plugs may also be similar to the kind of intermittent valley filling that McGee (*51, pp. 261–273*) described as part of the process that he called varigradation.

DELTA ASSOCIATION

Wherever the velocity of a sediment-carrying stream is checked as it enters a body of comparatively quiet water, deposition occurs and a delta forms. Deltas have long been recognized as characteristic sedimentary associations, and Twenhofel (*77, pp. 836–850*) has given a detailed summary of delta conditions and deposits. A typical delta is composed of bottom-set, fore-set, and top-set beds. The top-set beds include both subaqueous and subaerial deposits. The subaerial top-set beds are composed of the several types of fluvial sediments intermixed with lacustrine, paludal, and lagoonal deposits and merge upstream with the valley flood-plain sediments, from which they may be indistinguishable. Since most of the subaqueous top-set beds, as well as the fore-set and bottom-set beds, are formed below the level of the quiet water, they are not properly classified as fluvial deposits. A delta may, however, be built into a river (*77, p. 837*) or into a lake on the flood plain, and such delta accumulations become a part of the valley deposits. The deltas formed in valley lakes or stream channels, and the subaerial top-set beds of other deltas, are included in the present classification as a distinctive valley association. Thus deltas, although formed under characteristic genetic conditions and composed of a distinctive association of types of deposits, may be classed among lacustrine, marine, or valley associations, depending on their location.

The subaerial deltaic surfaces are similar to valley-plug areas, and the characteristic association of genetic types of sediments in the subaerial top-set beds is likewise very much like that in the valley-plug association, except that complete channel filling is less important. The fore-set and bottom-set delta beds are the peculiarly distinctive features that justify recognition of the delta complex as a separate type of association. The present valley studies have not yet afforded an opportunity for detailed attention to delta deposits, however, and a more complete discussion and description of the delta association will not be attempted at this time.

Deltas appear to have been unimportant in modern sedimentation in Tobitubby and Hurricane Valleys except as they have formed the initial obstruction in some of the channels that have been plugged. The evidence in these places is inferential in large part, for the sediment in both the delta and the channel fill is sand, and the beds are not exposed for detailed study. No important delta deposits are known to have formed in the shallow ponds on the flood plains. In other parts of the United States, however, deltas may be of much greater importance in valley sedimentation.

VOLUME OF MODERN VALLEY DEPOSITS

In order to determine the amount and distribution of sediment deposited during the modern period in the Tobitubby and Hurricane Valleys and the valleys of Goose Creek and its east and west forks, principal tributaries of Tobitubby Creek, test borings were made on 53 ranges across the valley bottoms. The location of these ranges is shown in figure 3, and the present ground surface and premodern surface, as determined by methods outlined on pages 18–22, are shown in figures 8, 9, and 10. The width, total cross-sectional area, and average depths of fill at each range, and the volumes of modern deposits in the segments between ranges, are tabulated in table 5. Computations by means of the Dobson reservoir formula (*20*) show a total modern deposit of 9,035 acre-feet in Tobitubby Valley (including Goose, East Goose, and West Goose Valleys) and 5,223 acre-feet in Hurricane Valley, making a total of 14,258 acre-feet. These quantities are equivalent to an average depth of fill of 3.1 feet for Tobitubby, 3.8 for Hurricane, and 3.3 for the two combined.

TABLE 5.—*Width, total cross-sectional area, and average depth of modern fill at each range and the volume of modern deposits in segments between ranges in Tobitubby and Hurricane Valleys*

Range	Dimensions of fill			Volume of fill in segment above range	Range	Dimensions of fill			Volume of fill in segment above range
	Width	Cross-sectional area	Average depth			Width	Cross-sectional area	Average depth	
	Feet	*Square feet*	*Feet*	*Acre-feet*		*Feet*	*Square feet*	*Feet*	*Acre-feet*
H-A	145	265	1.83	3.7	T-9	1,630	2,705	1.66	256.1
H-B	200	640	3.20	11.2	T-10 (part)	1,180	2,710	2.30	144.1
H-C	200	330	1.65	11.7	T-11	1,592	3,595	2.26	[2] 237.8
H-D	330	620	1.88	12.0	T-12	2,270	4,800	2.11	332.0
H-E	580	1,990	3.43	44.2	T-13	1,520	3,325	2.19	166.1
H-1	905	5,540	6.12	95.6	T-14	1,650	2,310	1.40	151.2
H-2	795	3,845	4.84	280.6	T-15	753	930	1.24	356.4
H-3	765	3,555	4.65	277.6	T-16	1,448	2,075	1.43	66.8
H-4	1,340	6,440	4.81	412.4	T-18	1,910	3,630	1.90	[3] 552.6
H-5	1,572	8,665	5.51	510.5	EG-1	747	2,475	3.31	66.3
H-6	1,085	4,750	4.38	515.1	EG-2	560	1,460	2.61	144.6
H-7	1,470	7,765	5.43	940.2	EG-3	1,080	1,975	1.83	117.8
H-8	1,360	5,800	4.25	323.3	EG-4	1,560	3,820	2.45	79.3
H-9	1,167	6,170	5.20	225.8	EG-5	1,860	7,265	3.91	417.9
H-10	1,094	1,795	1.64	490.7	EG-6	2,140	10,698	5.00	752.5
H-12	730	2,795	3.83	370.3	G-7	1,760	7,925	4.50	[4] 1,013.8
H-13	1,060	2,190	2.07	222.9	G-8	1,690	4,860	2.88	177.1
H-14	944	1,480	1.57	105.3	G-9	2,040	6,500	3.19	399.0
H-15	900	1,950	2.03	[1] 358.2	G-10 (part T-10)	1,380	3,310	2.40	214.8
T-1	1,265	4,955	3.92	102.1	WG-0	170	285	1.68	2.6
T-2	1,000	5,220	5.22	150.7	WG-1	300	800	2.67	44.0
T-3	1,290	10,035	7.78	171.9	WG-2	350	950	2.71	63.0
T-4	950	6,125	6.45	507.8	WG-3	880	1,425	1.62	138.1
T-5	1,025	4,375	4.27	276.4	WG-4	900	5,095	5.75	421.3
T-6	770	3,045	3.95	244.5	WG-6	921	5,470	5.94	436.3
T-7	870	3,785	4.35	227.1					
T-8	1,300	5,445	4.19	410.5					

[1] Includes fill between H-15 and junction of Hurricane and Little Tallahatchie flood plains.
[2] This segment is at the junction of Tobitubby and Goose flood plains. Includes fill on both flood plains.
[3] Includes fill between T-18 and junction of Tobitubby and Little Tallahatchie flood plains.
[4] Includes fill between G-7, EG-6, and WG-6.

DISTRIBUTION OF MODERN VALLEY DEPOSITS

The distribution of modern deposits is not clearly in[illegible] direct comparison of the volume of fill in the segments [illegible] ranges, for the ranges are not uniformly spaced [illegible] not of equal area. However, by plotting the [illegible] above each range against the distance [illegible] of the Tobitubby and Hurricane [illegible] flood plain, it is possible to d[illegible] [illegible]ate percentage of the total fil[illegible] [illegible] alluvial

FIGURE 8 FOUND AT END OF BULLETIN.

FIGURE 9
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FIGURE 10
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valleys. East Goose, West Goose, and upper Tobitubby Valleys have been considered separately as though each were the main stem, and the fill in Tobitubby Valley below their junctions has been incorporated in the calculation for each. The percentage of the total fill in each tenth of the length of the alluvial valleys is shown in figure 11.

The modern deposits show a marked concentration in the upper halves of East Goose, West Goose, and Tobitubby Valleys and also a slight concentration in the upper part of Hurricane Valley. The approximate percentages of the total valley fill concentrated in the upper half of the valley length of East Goose, West Goose, Tobitubby, and Hurricane Valleys, are 67, 61, 66, and 55, respectively. This concentration in the upper half of the valleys occurs even though less than 20 percent of the fill occurs in the comparatively narrow upper fifth of the length of the East Goose, West Goose, and Hurricane Valleys. The upper part of the main Tobitubby Valley, however, is relatively wide and the fill relatively thick, and there is marked concentration, amounting to about 45 percent of the total modern valley fill, in the upper 30 percent of the length of the alluvial valley. In the Hurricane, East Goose, and West Goose Valleys the greatest concentration occurs farther downstream, apparently because the narrow extreme headwater parts are less favorable areas for sedimentation. In these valleys, however, the tendency of the modern deposits to be concentrated in a small part of the valley length is no less marked. In Hurricane Valley about 45 percent of the modern sediment has accumulated in 30 percent of the valley length, in the fourth, fifth, and sixth segments from the upper end (fig. 11). In East Goose Valley about 52 percent of the modern fill is concentrated in 30 percent of the valley length represented by the second, third, and fourth segments from the upper end, and in West Goose about 49 percent occurs in the 30 percent of the valley length represented by the third, fourth, and fifth segments from the upper end.

The width of the valley and the thickness of deposit together determine the cross-sectional area of modern fill. The cross-sectional area, average thickness of modern fill, and the width of flood plain subject to modern deposition, in Hurricane Valley and the main Tobitubby Valley, are shown graphically in figures 12 and 13. A few ranges, notably T–12 and T–16, depart considerably from an orientation normal to the valley trend, and consequently the width of the flood plain and the cross-sectional area of filling for these ranges are higher than they would otherwise be.

The extreme headwater parts of the alluvial valleys, above the uppermost ranges shown in figure 3, have generally been trenched during the period of accelerated erosion. An average thickness of 1 to 2 feet of modern sediment occurs in these trenched sections. It consists of colluvial wash from the valley sides, together with some flood-plain sediment that accumulated before the channels had become too deeply incised to overflow. At the present time only colluvial material is accumulating on these trenched flood plains, for they are no longer subject to overflow from the main channel. The upper few ranges on West Goose Creek are in the zone of valley trenching, but there the incised channel has not attained sufficient size to prevent occasional overflow, and hence the flood-plain surface is still subject to aggradation from overbank waters. Only a small percentage of the

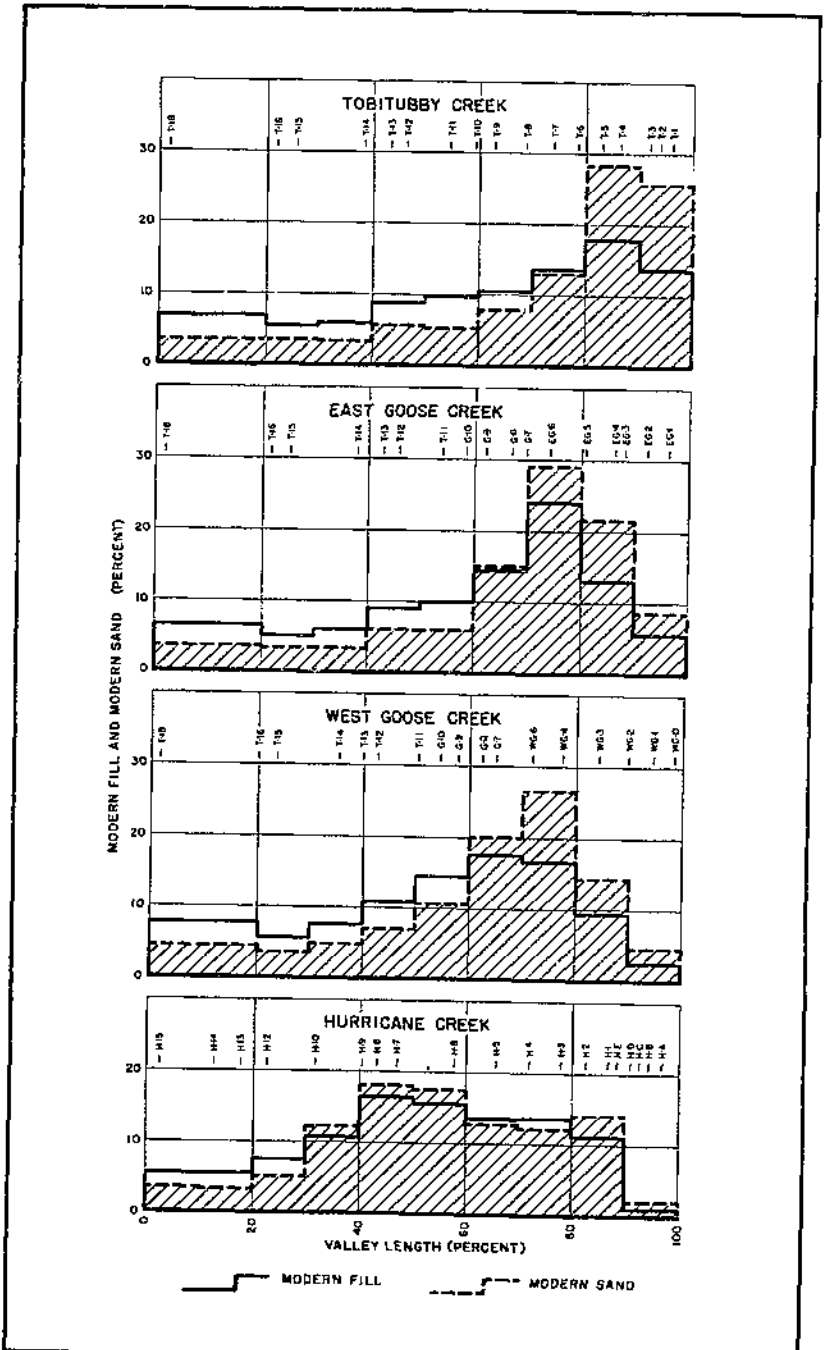

FIGURE 11.—Distribution, by tenths of valley length, of the total modern sand and the total modern sediment accumulated in Hurricane, Tobitubby, East Goose, and West Goose Valleys.

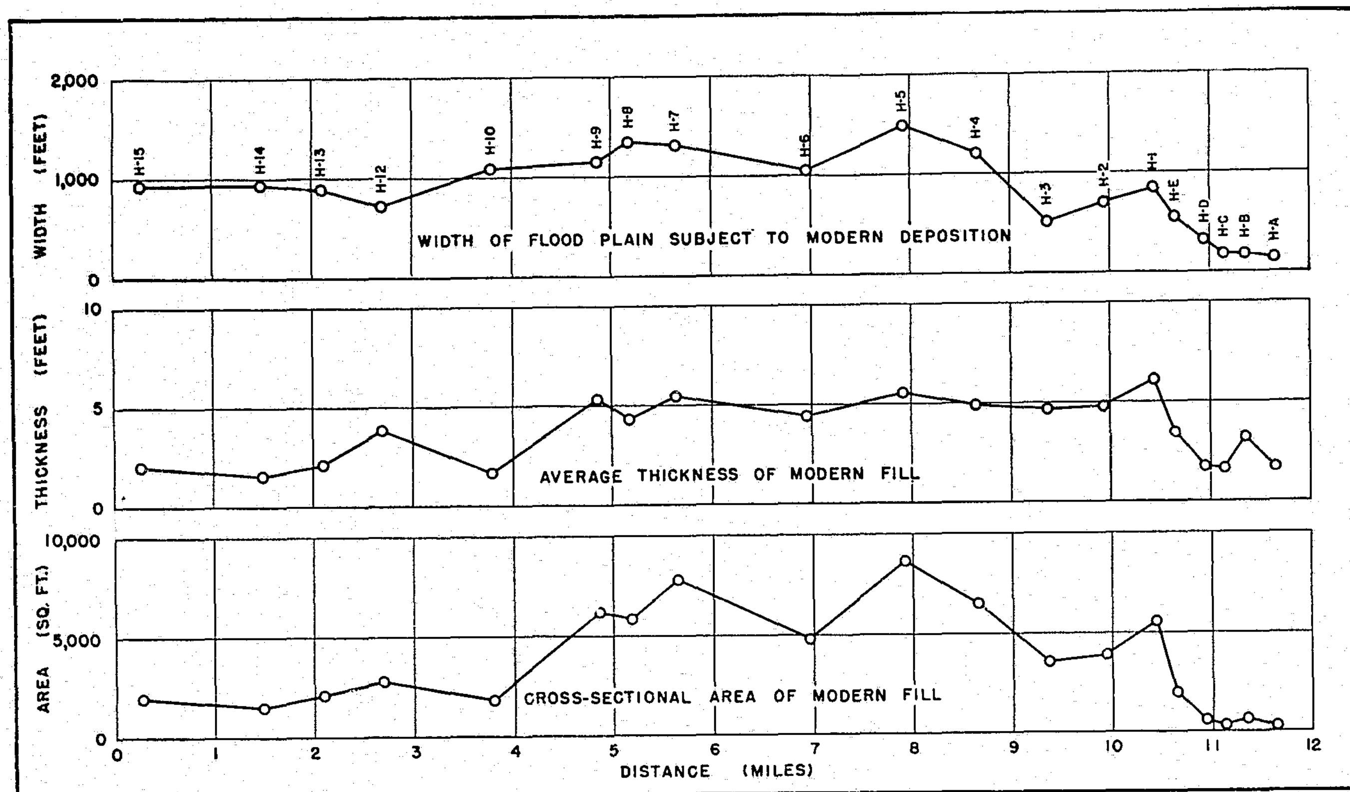

FIGURE 12.—Diagram showing width of flood plain subject to deposition, average thickness of modern fill, and cross-sectional area of modern fill in Hurricane Valley.

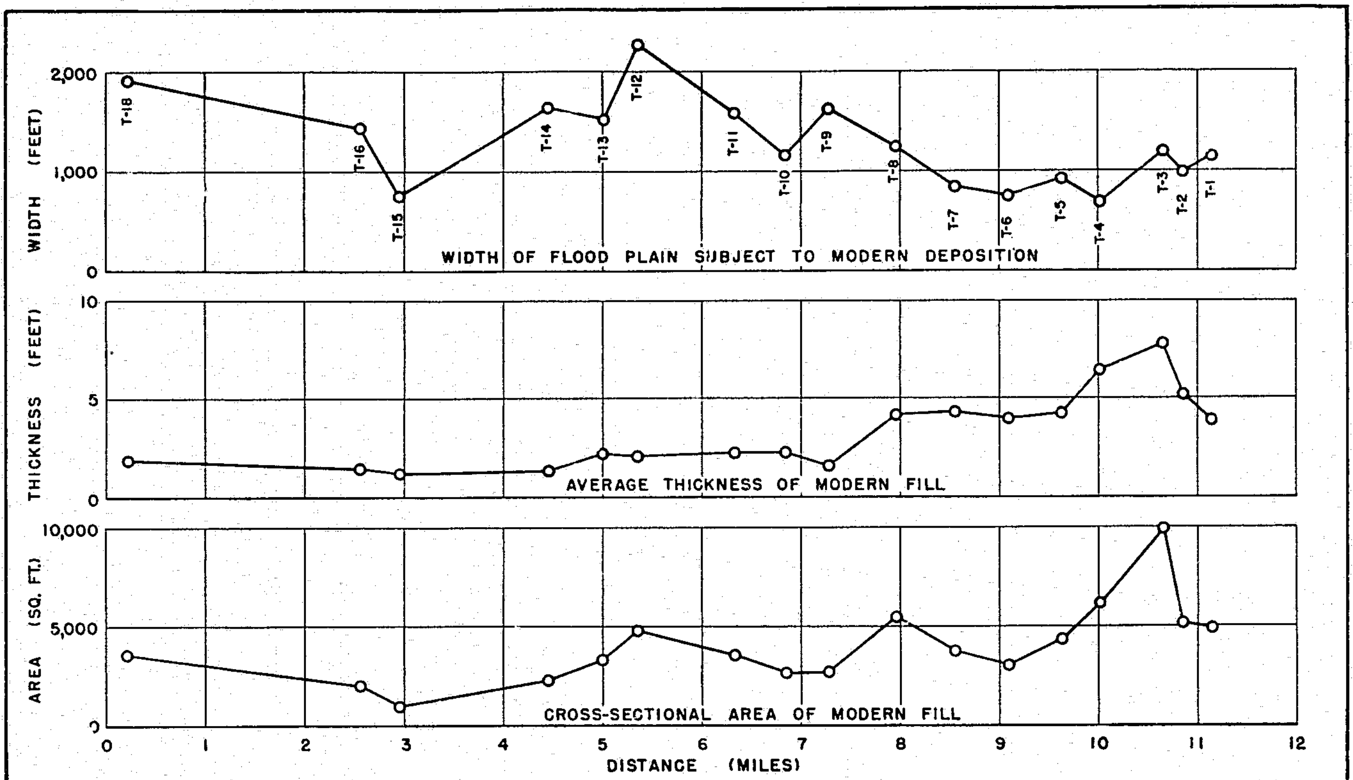

FIGURE 13.—Diagram showing width of flood plain subject to deposition, average thickness of modern fill, and cross-sectional area of modern fill in Tobitubby Valley.

total volume of fill has been deposited in these extreme headwater parts of the alluvial valleys, for the fill is relatively thin and the valleys are narrow.

Below the zone of trenched flood plains, the modern deposits thicken rapidly down valley. In Hurricane Valley, a maximum average thickness of 6.1 feet occurs at range H–1, which is about 1.6 miles below the head of flood-plain development and about 10.4 miles from the mouth of the valley. From this point, the average thickness remains fairly constant in the next 6 miles down valley and then decreases in the next 2 miles to an average of about 2 feet. This thickness, except at range H–12, where it is about 4.2 feet,[6] is maintained in the remaining 3.8 miles to the confluence with the valley of the Little Tallahatchie. Although the flood plain is slightly narrower below than above range H–10, the concentration of fill above that range is due mainly to a greater thickness of accumulation.

In the main stem of Tobitubby Valley the maximum average thickness of 7.8 feet occurs at range T–3, 0.8 mile below the head of flood-plain development and 10.6 miles above the valley mouth. The thickness gradually decreases—although with considerable variation in the cross-sectional area of fill—down valley to the junction of Goose and Tobitubby Creeks, where it is about 2.2 feet. The same general distribution exists in Goose Creek and its tributaries, except that the maximum average thickness is somewhat less and occurs relatively farther down the valley. Below the junction of Goose and Tobitubby Valleys, the average thickness is about 2 feet or less all the way to the confluence with the Little Tallahatchie.

In general, high average thickness is associated with valley plugs. This relation exists in Tobitubby, East Goose, West Goose, and the upper part of Hurricane Valley. Below range H–6 in Hurricane Valley the areas where the fill is unusually thick are not definitely known to be near plugs, although there is some suggestion of plugging at range H–7. The swamping of the valley below range H–9 may be the cause of excessive deposition at that range.

A consideration of the distribution of modern deposits, as shown by cross sections of the valley fill reproduced as figures 8, 9, and 10, reveals other important relations. At many of the ranges there is a marked increase in thickness near the present stream channels and those recently abandoned. This is particularly noticeable on ranges T–1, T–7, H–C, H–D, H–1, H–5, EG–6, and WG–6. In many places such differential aggradation has progressed so far that the bottom of the present stream channel is level with, or higher than, the surface of the valley bottom at the side. In other places the aggradation has resulted in abandonment of former channels and relocation of the streams. At range T–1 in Tobitubby Valley the channel location has shifted at least twice within the period of accelerated sedimentation, and present conditions are such that a third change in the channel location may be expected soon. A large part of the ditches in the Wells drainage district have also been completely filled with sand and old natural channels reoccupied or new ones formed through the back swamps (figs. 5 and 18).

[6] At range H–12 test borings were not made completely across the former terrace, which now forms part of the first bottom, and this may cause the computed average thickness of modern fill to appear abnormally high.

Alluvial fans built into the main valleys by tributaries are an important factor in the distribution of the modern sediments. They flank a large part of the valley sides, and in order to represent fans properly in the data on which volume computations were made, a number of the ranges were located so as to cross them. Cross sections T-4, T-5, and T-7; G-7, G-8, EG-5, and WG-3; H-2, H-3, H-4, H-5, and H-7, of figures 8, 9, and 10, respectively, show representative sections of various fans. At most of these ranges, fans were present before the modern acceleration of sedimentation, as shown by the slope of the old soil surface, and in these places there has been merely accelerated growth of the preexisting fan. At a few ranges, as illustrated by cross sections H-4 and T-7, the modern sediments have been deposited in fans where formerly there were none.

The presence of alluvial fans usually does not increase the average depth of filling of the ranges that cross them. At only 3 of 12 ranges (T-4, H-3, and H-7) that cross fans is the average depth of fill greater than would otherwise be the case. At the nine other ranges the average depth of fill on the fans is about the same or somewhat less than that on the rest of the flood plain.

Most of the fans extend only a few hundred feet into the main valleys, and they modify the surface configuration only locally. In the aggregate, however, they constitute a considerable part of the valley area. Some of the larger fans have partly obstructed the drainage of the main valley into which they are built and by so doing have induced greater sediment accumulation for some distance up the valley.

At places in the lower parts of the valleys the flood-plain surface has been aggraded until it now extends laterally across former terraces. In such places modern deposits of vertical accretion cover the former terrace surface to shallow depths, usually of the order of a foot or so. In these places the width of the zone of frequent flooding and attendant flood-plain sedimentation has been increased during modern times. The cross sections at ranges T-8, T-13, H-7, and H-12 (figs. 8 and 10) show former terraces that are now being covered by modern deposits of vertical accretion.

Comparison of the Tobitubby cross sections also reveals relations between present and former flood-plain surfaces that suggest that the low terraces now thinly covered with modern sediment on ranges T-12 and T-13 may represent the downstream continuation of the main buried flood-plain surface above range T-12. A similar relationship may exist in Hurricane Valley, but the evidence is less satisfactory because of uncertainty regarding the identification of old soil horizons at critical points, especially on range H-9. Figures 8 and 10 illustrate the conditions that lead to this suggestion.

If this interpretation is correct, it indicates that these valleys had once been graded to a level at their mouths higher than the present flood plain of the Little Tallahatchie, and had then been partially reexcavated and graded down to a lower level of the Little Tallahatchie flood plain before the inception of accelerated sedimentation, by which a new cycle of aggradation was started. The available evidence does not indicate whether this former period of valley excavation was still in progress at the time the modern acceleration of sedimentation began. The buried terraces apparently were definitely lower than, and not coextensive with, prominent terraces that now border the lower parts of the valleys and continue along the side of the Little Tallahatchie Valley. These present terraces are about 10 to 15 feet above the immediately adjacent parts of the present Little Tallahatchie flood-plain surface.

CHARACTER OF THE MODERN VALLEY DEPOSITS

COLOR

Throughout Tobitubby and Hurricane Valleys the sediments at the present surface of the valley fill are prevailingly brown or light brown in color.[7] Locally, especially in headwater areas or on alluvial fans, the brown is tinged with red, indicating that some of the erosional debris was subsoil. In many places, however, the brown color does not continue downward to the base of the modern deposits, but changes at depths of a few inches or more to lighter, dominantly grayish tints. In these places the contact between brown and gray sediment is usually at or near the ground-water level. In swampy areas gray sediment occasionally was found at the present ground surface, but where the modern deposits lie entirely above the ground-water table gray colors were not found.

In some places the contact of brown and gray material appears to be fairly sharp, as judged from test-boring cores, but usually there is a mottled transition zone between the two. The presence of this transition zone, in which the mottling transects primary sedimentary structures, and the close association usually observed between the ground-water table and the contact between brown and gray sediment indicate that the color of the sediment has been changed subsequent to its deposition. Presumably this diagenetic change is caused by reduction of the coloring oxides while the sediment was beneath the water table.

The deposition of light-grayish sediment during the early period of modern sedimentation, followed by burial beneath brownish material, was considered as an alternative hypothesis to explain the difference in color. In the Tobitubby-Hurricane area the surface material of the predominant upland soils is gray, but this color is very different in tint from the light-grayish colors of the sediments. This color difference, and the strong evidence for diagenetic origin of the gray color, indicates that the gray sediment almost certainly does not represent an accumulation derived by earlier skimming of upland gray topsoils, followed by burial beneath later sediment containing a larger admixture of brownish and reddish upland subsoil and bedrock materials.

There are also light-colored sand and clay beds in the Holly Springs formation, which have been exposed in gullies; but neither of these corresponds closely enough to the light-gray sediment to be a probable source of the gray sedimentary material. It would also be contrary to the history of modern sedimentation in the valleys to suppose that such light-colored debris from the gullies had been deposited at earlier dates and has since been covered by brownish sediments derived dominantly from the loess that overlies the bedrock sands and clays on the uplands.

Channel deposits and sand splays are commonly straw-colored or light tan, but they may be almost white in small areas. These light

[7] Color descriptions in this report are of moist material.

colors apparently are in part inherited from light-colored sands of the Holly Springs formation and are in part due to the notable downstream disappearance of reddish tints of the sand derived from areas where the exposed bedrock sand is strongly colored by iron oxide.

The older sediments of premodern age are usually gray or dominantly gray but may be mottled with brown or with light-greenish, bluish, or yellowish tints when the dominant color is very light gray. In many places the yellowish and brownish mottling is obviously associated with concretions. Presumably a change in color is involved in the development of concretions, the concretions themselves being yellowish brown when soft and dark brown or almost black when hard. The light-gray colors of the premodern deposits may be almost indistinguishable from some of the lighter grays in those modern deposits beneath the ground-water table. In most places, however, there is a distinct although slight difference in color, the older sediments being lighter or having more of a bleached appearance, especially when greenish, bluish, or yellowish in cast. Although these colors are so variable and differ so slightly that it is difficult to describe the distinctions accurately even by reference to a color chart, it is possible after some experience to differentiate between them in the field.

TEXTURE

Although both modern and older valley sediments have been derived from the same source materials, namely, the loess and the underlying Holly Springs formation, the texture of the present surface deposits is more sandy, on the average, than that of the premodern surface deposits. The present surface 4 inches of flood-plain material was classified as sand at 35 percent of the places where borings were made, but the old soil was classified as sand at only 10 percent of the places where it was identified. The greatest difference in texture occurs in the upper parts of the valleys, notably above ranges H–7, T–2, and G–8, where the surface 4 inches was sand at about 50 percent of the boring holes but only 11 percent of the old soil samples were sand.

The average texture of the total volume of modern sediments also is coarser than the average texture of the upper 4 inches of the old soil. It does not follow, however, that the total quantity of modern sediment is necessarily coarser in texture than the total amount of older sediment in the valleys. Under natural conditions, a progressive sorting of sediment has been in process in the streams and valleys for many years, by which the finer sediment tended to be carried on downstream and the coarser sediment accumulated in the valleys nearer its source. As a result, a large quantity of sand underlies the older flood-plain deposits of vertical accretion. No systematic effort has been made to measure the volume of these older sands, but their inclusion in any comparisons of modern and premodern deposits might make the average texture of the older sediment coarser than that of the modern sediment, for the latter has not been subjected to such prolonged sorting and sand concentration.

The modern deposits are composed of about 30 percent of sand and 70 percent of silt and clay (table 3). The texture varies greatly from place to place. Figure 14 shows the percentage of sand by weight

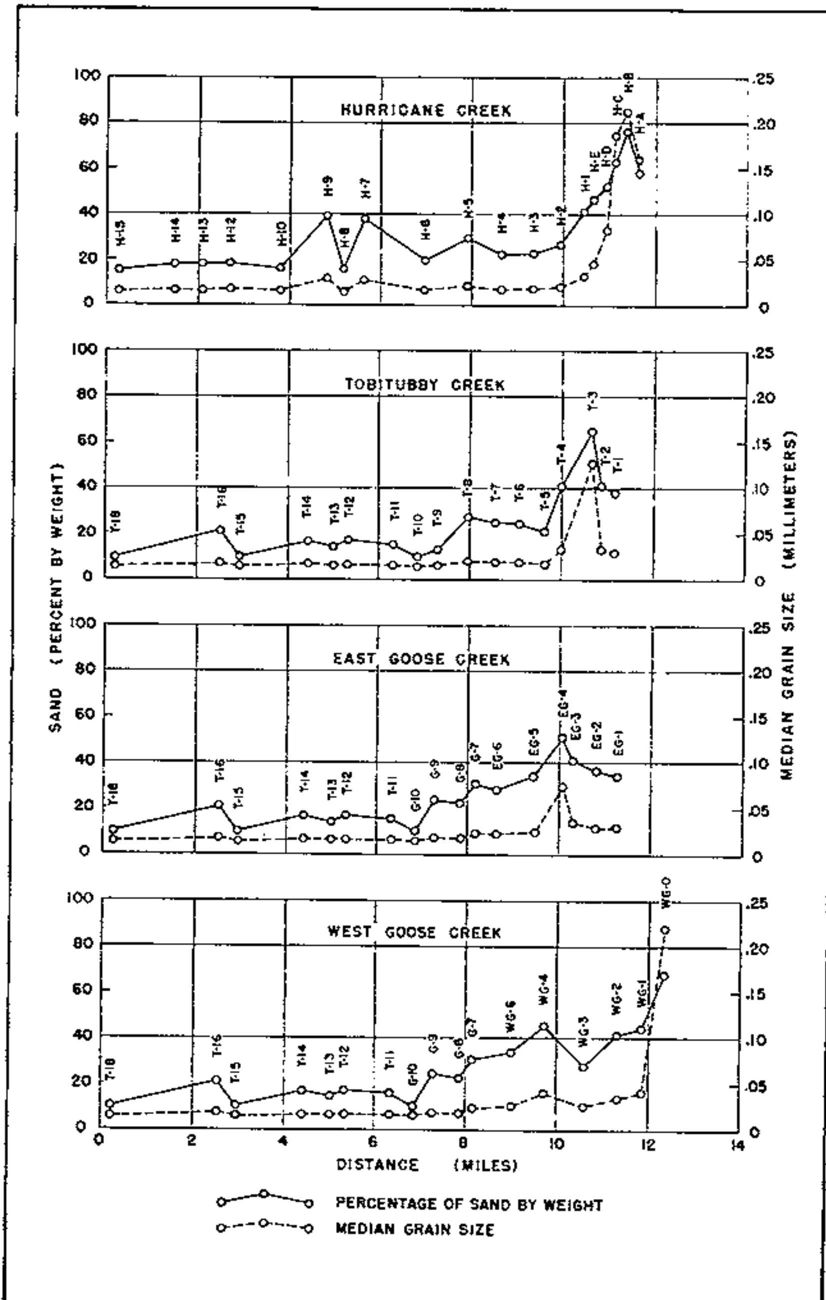

FIGURE 14.—Diagram showing percentage of sand by weight and median (average) grain size of modern deposits at test-boring ranges in Tobitubby and Hurricane Valleys.

and the median (average) grain size in millimeters of the deposits at each boring range.[8] It is apparent that the modern deposits in the upper parts of the valleys contain a higher percentage of sand than the deposits in the lower parts of the valleys. Only in West Goose Valley, however, is the extreme headwater range the most sandy, the maximum percentage of sand being at the third ranges in Tobitubby and East Goose Valleys, and at the second range in Hurricane Valley. The percentage of sand at these upper ranges apparently is related to the channel capacities, the capacity at the lower ranges having been reduced by aggradation, and the capacity at the upper ranges, especially H–A, possibly having been increased by valley trenching. Consequently, the channel is adequate to bring more sand past the uppermost ranges than can be readily carried past the wider parts of the valleys.

The volumetric distribution of sand, or of silt and clay, is determined not only by the percentage of sand and the median grain size at each range (fig. 14), but also by the volume of fill in various parts of the valley. Thus, where the volume of fill is small, because the valley is relatively narrow or the fill is relatively thin, or both, the volume of sand will be small even though the percentage of sand in the fill is relatively high. Conversely, where the percentage of sand in the fill is relatively low, but the volume of fill is large, the volume of sand may be relatively large.

The percentage of the total volume of modern sand and the percentage of the total volume of modern fill in each tenth of the alluvial valley length is shown diagrammatically in figure 11. It is apparent (1) that the modern sand is definitely concentrated in the upper half of the valleys, (2) that the concentration differs in amount and place in the different valleys, and (3) that the modern sand and total modern fill diagrams are generally similar in shape, but that the sand is concentrated somewhat farther up the valley than the total fill. If the texture of the fill were uniform throughout the valley, the two histograms would be identical. Consequently, since they are different, the concentration of sand farther up valley is due to the greater percentage of sand in the fill in the upper valleys.

The concentration of fill in the upper parts of the valleys is not, however, due only to the concentration of the sand. In Hurricane Valley about 53 percent of the total volume of silt and clay is in the upper 50 percent of the alluvial valley length; in Tobitubby, 61; in West Goose, 56; and in East Goose, 63 percent. If the percentages of silt and clay in each tenth of the valley length were plotted, the histogram would be very similar in shape to that of the total volume of fill in figure 11, although it would be flatter and show the concentration to be somewhat farther down valley.

In the Tobitubby, East Goose, and West Goose Valleys there appears to be a close relation between the location of valley plugs and the distribution of the total volume of modern sand. In Tobitubby Valley about 40 percent of the total volume of modern sand is in 10 percent of the valley length between ranges T–1 and T–4; in East Goose Valley about 46 percent is in 16 percent of the valley length between ranges EG–4 and G–7; and in West Goose Valley about 47 percent is in 19 percent of the valley length between ranges WG–3 and G–7. As may be seen on figure 15, these segments of the valleys

[8] See appendix for method of determining these values.

FIGURE 15
FOUND AT END
OF BULLETIN.

are in areas of plug development. Inasmuch as sand is deposited in large quantities as splays above the heads of the completely plugged channels, these sandy areas extend on the average about three-fourths of a mile above the heads of the completely plugged channels.

In Hurricane Valley the relation of sand concentration to known plugs is less apparent. The main difficulty in relating high percentage of sand volume to plugs lies in the fact that 32 percent of the total modern sand is concentrated in the 17 percent of the valley length between ranges H–6 and H–9. No plug has been recognized in this part of the valley, but there is some suggestion that backfilling due to plugging may be or may have been operative, for the channel capacity is notably lower at range H–7 than at range H–6, and a large swamp extends from a point just below range H–9 to a point just above range H–12. The concentration of sand may also be due in part to delivery of relatively large amounts of sand from the three major tributaries that join the master valley between ranges H–6 and H–9. Delivery of sand to Hurricane Valley from relatively short side tributaries may be a very important factor in the accumulation of a large percentage of the total volume of sand relatively far downstream, as compared with Tobitubby, East Goose, and West Goose Valleys, where short tributaries contribute less sand in the lower part of the drainage basin.

Within the modern deposits, the distribution of sand transverse to the valley length is variable. Figure 6 illustrates the principal places of sand concentration, namely, (1) alluvial fans that interfinger with the flood-plain deposits from the sides, (2) present and abandoned stream channels, and (3) areas extending outward from the banks of present or former stream channels, where lenses or layers of sand interfinger with finer sediments. The third of these corresponds to the sand-splay type of deposit, and occurs chiefly in the upper parts of the valleys, and especially where valley plugs have developed.

In vertical section, the distribution of sand in the modern deposits is also variable. It is a fair generalization to say that in the Tobitubby Valley above range T–11 and in Hurricane Valley above range H–11 the modern sediments become coarser in texture upward. Below these ranges little vertical change in texture occurs. In some places the modern deposits are slightly coarser upward; elsewhere they are slightly finer or they may show no appreciable vertical change. In most parts of the upper valleys, the vertical change is not truly gradational but results from the increasing number and thickness of sand layers interbedded with the silt.

SORTING

In considering the sorting of modern and premodern deposits, it is desirable to distinguish between two uses of the term "sorting." In a genetic sense the term may be applied to the dynamic process by which material having some particular characteristic, such as similar size, shape, specific gravity, or hydraulic value, is selected from a larger heterogeneous mass. In a descriptive sense, the term may be used to indicate the degree of similarity, in respect to some particular characteristic, of the component parts in a mass of material. The degree of sorting within a mass is not necessarily a true measure of the amount of sorting that occurred to produce that mass. If, for example, a sedimentary deposit is composed of grains having a small range in size, it is relatively well sorted texturally in the descriptive sense. Depending on the similarity or dissimilarity of the sedimentary deposit to the source material from which it was derived, however, little or much sorting may have taken place during transportation. It is also possible that material that has been subject to little sorting, such as colluvium washed from a residual clay soil derived from weathering of a fine-grained basalt, may have a small range in particle size, and may therefore be considered better sorted in a descriptive sense than material that has been derived from more heterogeneous material and represents a more selective separation of similar particles from the original mass.

It is possible, by visual observation of the relative amounts of the various-sized grains present, to classify a sediment as to its degree of textural sorting. For more precise evaluation, however, three statistical measures, based on particle-size distribution as determined by mechanical analysis, have been suggested. The arithmetic quartile deviation as used by Krumbein (*39, pp. 401–402*), the geometric quartile deviation as used by Trask (*75, pp. 70–72*), and the log quartile deviation as suggested by Krumbein (*41, pp. 99–107*), each is a statistical expression of the range in particle size in that half of the sample between the first and third quartiles.[9] Trask (*75, p. 71*) designated the geometric quartile deviation as the "sorting coefficient." The geometric quartile deviation is the square root of the quotient obtained by dividing the first quartile by the third quartile. On the basis of 170 analyses Trask found that a sorting coefficient of less than 2.5 indicates a well-sorted sediment, and a sorting coefficient greater than 4.5 indicates a poorly sorted sediment.

The sorting coefficient has been calculated for all samples of fluvial deposits from Tobitubby and Hurricane Valleys that were analyzed. Of the 206 samples of modern sediment, 129 are well sorted and only 1 is poorly sorted by Trask's classification (table 11, in appendix). Of 147 samples of premodern sediments, 103 are well sorted, and only 1 is poorly sorted. Each sample represented a 4-inch thickness of the flood-plain deposit and consequently was usually composed of more than one individual layer. These individual layers would be better sorted than the composites of two or more layers, which usually constituted the samples used.

Trask's classification, however, was based mainly on marine and lacustrine sediments, and for this reason it may not be equally applicable to the range of sorting in all types of deposits. If Trask's method (which designates as well sorted that 25 percent of the sediment with the lowest sorting coefficients and as poorly sorted that 25 percent with the highest sorting coefficients) is applied to the fluvial sediments in the Tobitubby and Hurricane Valleys, however, those sediments having a sorting coefficient less than 1.9 are classed as well sorted and those having a coefficient of more than 2.7 as poorly sorted. These limits would not necessarily apply to all fluvial sediments, for the size range in the Tobitubby-Hurricane deposits is limited because the source materials have a rather small size range.

The size distribution in the Tobitubby and Hurricane sediments also serves to illustrate a weakness in the use of coefficients based on

[9] The first quartile is the size at which one-fourth of the sample is coarser and three-fourths finer; the third quartile is the size at which three-fourths of the sample is coarser and one-fourth finer.

quartile deviation to describe the degree of sorting. The sediments are composed of varying proportions of sand and silt derived, respectively, from the Holly Springs sand and the loess, neither of which has a large percentage of sediment between one-eighth and one-sixteenth of a millimeter in diameter (table 3). The deficiency in this size is reflected in the fluvial deposits, and the cumulative curve of the size distribution is markedly flattened in this size range. When this flattening occurs near the quartile line, a wide range in the sorting coefficients may result from very small differences in the amount of sand in the sample. This effect is shown by the two analyses plotted in figure 16. Although the difference in the amount of sand in these

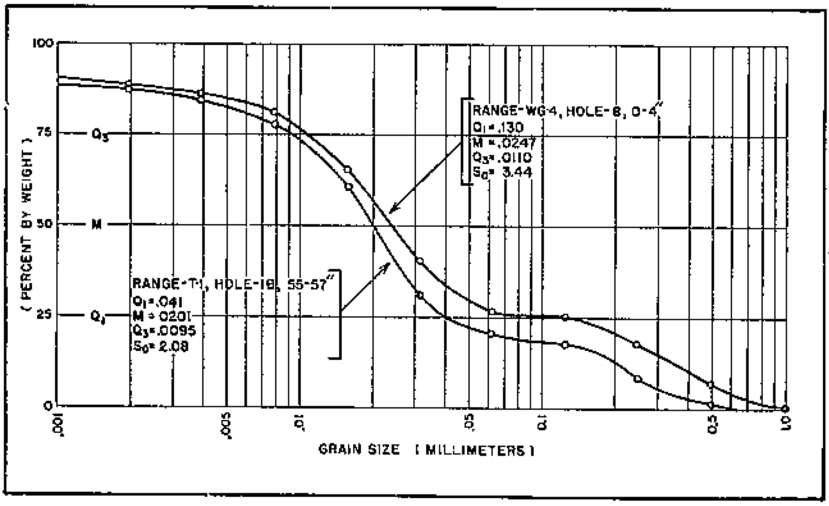

FIGURE 16.—Cumulative curves showing particle size distribution in two samples from Tobitubby and West Goose Valleys. This diagram illustrates the effect of slight differences in mechanical composition on the value of the sorting coefficient.

two samples is only about 6 percent, the sorting coefficient is 2.1 for one sample and 3.4 for the other.

The classification based on quartile deviation does, however, permit a comparison of the degree of sorting in the modern as contrasted with the premodern deposits, and of the modern deposits in different parts of the Tobitubby and Hurricane Valleys. Of the 353 samples analyzed, a greater percentage of the modern than of the premodern samples are well sorted in a descriptive sense, a smaller percentage are moderately well sorted, but a larger percentage are poorly sorted. Thus it would appear that the range in sorting of samples of the modern sediments is greater, but on the average they are about as well sorted as similar samples from the older deposits. It is possible, however, that some types of premodern sediments, especially the apparently well sorted premodern channel sands, were not adequately sampled, and consequently that the premodern sediments, as a rule, may be somewhat better sorted than the analytical data now at hand would indicate.

A comparison of the present and premodern surface samples indicates a very different relationship. At 37 of 51 boring holes on ranges

T–1, T–11, T–18, H–4, H–8, and WG–4, sorting is better in the premodern than in the present surface samples. At 8 holes the modern and premodern sediment are about equally well sorted, and at only 6 holes the modern sediment is better sorted. Apparently no consistent relation exists, however, between the comparative sorting in the modern and premodern surface deposits on the one hand and the location in the valleys on the other. As a general rule, therefore, the premodern old soil was apparently much better sorted in a descriptive sense than the modern material forming the present surface of the first bottoms.

In contrast, if all samples of modern and premodern sediments are considered, those from the lower part of the valley, ranges T–11 and T–18, are not so well sorted as those farther up the valley. Of 86 samples from these ranges, only 5 are well sorted and 29 are poorly sorted by comparison with the average for Tobitubby-Hurricane Valleys; whereas of the 267 samples from the upper valleys, 83 are well sorted and 59 poorly sorted.

If the average composition of the modern deposits at each range is considered, the sorting of the modern sediments, as measured by the sorting coefficient (table 11, in appendix), is poorer in the upper parts of the valley. At all 12 ranges below T–10 and H–10 the sorting coefficient is less than 2.5, but at the 37 ranges above T–10 and H–10 the sorting coefficient is less than 2.5 at only 6 and is greater than 4.5 at 14. The variation in sorting in the upper valleys tends to show about the same irregularity as the percentage of sand.

The Tobitubby-Hurricane deposits are also well sorted in the genetic sense of representing a selection of similar material from a more heterogeneous mass. The source material is dominantly silt and sand, derived mainly from the loess and the Holly Springs sand, respectively. Erosion delivers both types to the streams, but in the valley deposits the separation of sand from silt is fairly complete. This does not mean that the deposits at any one locality are all sand or all silt, although a marked concentration of sand does occur in the upper parts of the valleys, but that the individual beds of the deposit are either dominantly sand or dominantly silt. These layers represent the result of sorting action, and a deposit consisting of interbedded layers of sand and silt must be considered genetically better sorted than a deposit of the same bulk composition in which there has been no separation into layers. Viewed as a whole, however, such a well-stratified deposit, composed of various layers that are individually well sorted but very different in average grain size, may appear to be very poorly sorted in a descriptive sense.

Good sorting in the genetic sense may be undesirable agriculturally, for sorting out and deposition of certain types of material, such as sand or gravel, may cause considerable damage. On the other hand, the sorting out of sand and gravel may, by concentrating their deposition fairly close to the source, reduce sediment damage to more valuable valley resources farther downstream.

DAMAGES

The damages directly due to excessive sedimentation in Tobitubby and Hurricane Valleys are of three principal types, according to origin. These are (1) increasing frequency and height of overbank floods resulting from sedimentary filling of stream channels and aggradation of flood-plain surfaces, (2) swamping of valley lands as a result of obstructed surface run-off and the rising ground-water table caused by aggradation of the stream beds, and (3) sand deposition on the former silt loam bottom lands, with consequent loss in the productive capacity of the land. In addition, direct damages also result from the genetically closely related processes of (4) valley trenching in headwater areas and (5) stream-bank erosion. The areas affected by the three principal types of damage associated with excessive sedimentation are summarized in table 6.

TABLE 6.—*Areas damaged by excessive flooding, swamping, and sanding, in Tobitubby and Hurricane drainage basins*

Nature of damage	Area affected	Total bottom land
Sanding only:	*Acres*	*Percent*
Tobitubby, Goose, East Goose, West Goose, and Hurricane Valleys	340	4.9
Other tributaries	600	8.6
Sanding and swamping	10	.1
Sanding and excessive flooding [1]	450	6.4
Swamping only	30	.4
Swamping and excessive flooding	510	7.3
Excessive flooding only	2,240	32.1
Total area now seriously impaired or worthless for agricultural use	4,180	59.8

[1] "Excessive flooding" as here used denotes land that, because of the frequency or time of flooding, cannot be used for agriculture with expectation of a satisfactory return.

INCREASED FREQUENCY AND HEIGHT OF OVERBANK FLOODS

Erosion-plot studies conducted by the Southern Forest Experiment Station, at Holly Springs, 25 miles north of the Tobitubby-Hurricane area, have shown more frequent and larger amounts of surface run-off from bare or cultivated slopes than from similar slopes under forest or grass cover (*53, p. 10*). These tests were made on soils and slopes similar to those that predominate in the Tobitubby and Hurricane drainage areas. It is, therefore, reasonable to suppose that as a result of the clearing of the natural forests and cultivation of the sloping uplands water is delivered to the valleys more frequently and in greater volumes.

There is no evidence that the capacities of the stream channels have been increased except in the short headwater stretches where the valleys have been trenched. On the contrary, the accumulation of sediment—mostly sand—in the stream channels has in many places greatly reduced their capacity for carrying floodwaters. This aggravates the flood problem because storms that otherwise would cause only a minor rise now cause overbank floods. As the stream beds and natural levees have been built up by sedimentation, the rate of return of overbank waters to the channels has also been retarded. This has caused more prolonged, and therefore more harmful, flooding of the valley lands. Because of lack of adequate data on conditions in earlier years, it is impossible to determine quantitatively the extent to which stream-channel sedimentation has thus aggravated the flood problem, but at many places the evidence of channel filling is obvious and unquestionable. Channels in which the water flows several feet above the fields on either side are common. At some places the channels have been completely filled, and consequently all the surface flow of the stream is turned out across the valley. Such conditions are proof that sedimentation is an important factor in causing valley flooding.

At the present time practically all the first bottoms and parts of the low terraces, or second bottoms, are subject to frequent and severe floods. It is estimated that 3,200 acres, or about 46 percent of the bottom lands of the two drainage basins, is uncultivated because of the danger of floods. In general, the flood damage becomes progressively more serious downstream. About 450 acres of the flood area is sanded and about 510 acres is swamped, but the remaining 2,240 acres, or 70 percent of the total, is damaged only by excessive flooding and would therefore be available for profitable cultivation if floods were less frequent and severe. Frequent late spring floods delay planting, so that cotton often cannot be planted early enough to escape serious damage in years of severe boll-weevil infestation. Corn is the principal bottom-land crop, primarily because it is better suited to withstand the flood dangers, but it also may be damaged by summer floods.

The filling of channels is a real threat to the continued usefulness of several existing highway bridges, and the frequency and height of flooding necessitates provision for extensive fills and expensive bridges in the construction of main roads that cross the valleys. The frequent flooding also causes relatively rapid aggradation of the flood-plain surface, thus necessitating replacement of fences that have been partly buried (pl. 5, *B*). The true cost of such damages cannot be readily evaluated from existing data.

The cost of the filling of channels in the Wells drainage district can be more definitely established. This district comprises about 1,500 acres in Tobitubby, Goose, West Goose, and East Goose Valleys. About 11 miles of drainage ditches were excavated in 1920. The ditching was financed by a $27,000 bond issue. The total cost, including interest on the bonds, was $55,000. This was to be met by special taxes to be collected over a period of 23 years ending in 1943. The cost of the improvements exceeded the estimates, however, and an additional $10,000 worth of bonds was authorized. Legal difficulties arose regarding these additional bonds, and taxes for their redemption are not being collected.

The need for drainage was due mainly to the clogging of stream channels by sand washed from the tributary uplands, but no provision was made to protect the new ditches from such sand accumulation, and they filled rapidly. Within 5 years, according to the reports from local residents, the ditches had ceased to function adequately. In 1927 the county drainage board inspected the district and reported that work was needed to reopen the ditches, but no funds were available for the purpose. In 1937 about one-half of the ditches were completely filled with sand (pl. 5, *A*), and about half of the remainder had been so much reduced in capacity that they did not furnish adequate drainage or flood control. Thus, in addition to the loss of productive capacity of the bottom lands that were to be improved and protected, an investment of $55,000 became practically worthless before the costs were entirely paid.

The quantitative effect of sedimentation in aggravating flood danger is most clearly shown in places where the flood plain has been built up to or nearly to the level of former terraces. In such places the decrease in capacity for discharging floodwaters without overflow of the terraces may be computed with sufficient accuracy to establish the correct order of magnitude of the results. Such computations, even if rough approximations, are nonetheless much more precise than the qualitative generalizations that, in the absence of accurate data on flood conditions before or during the early years of the modern period, usually have been the basis for discussions of this factor in the flood problem.

Range 13 in Tobitubby Valley provides the necessary physical setting and data for such computations. As shown by the cross section (fig. 8), there formerly was a narrow, low flood-plain surface about 300 feet wide and about 5 feet below a second bottom, or terrace, more than 1,200 feet wide. As a result of modern sedimentation, the entire flood-plain surface has been built up until the old second bottom has been buried to a depth of 1 to 2 feet, and the former lower flood plain has been entirely obliterated. The present flood-plain surface is approximately level across its entire width of about 1,500 feet, and a part of it is under cultivation. A few feet higher is a broad, prominent terrace (not shown on the cross section), which is under cultivation and is one of the best areas of agricultural land in the drainage basin.

The cultivated fields on the present flood plain are inundated whenever the flow of Tobitubby Creek is greater than the immediate channel can accommodate. No measurements have been made in the field to determine this channel capacity, but from the cross-section data, gradient, and known channel conditions, reasonable assumptions can be made as a basis for computation of its approximate discharge capacity. Such a computation has been made by the Manning formula:

$$Q=\frac{1.486R^{2/3}S^{1/2}A}{n},$$

in which Q is discharge capacity in cubic feet per second, R is hydraulic radius, S is water-surface slope as determined from the average channel gradient (10 feet per mile), A is cross-sectional area in square feet, and n is the roughness factor, which is taken as 0.05. For the channel at range 13,

$$Q=\frac{(1.486)(2.83)(0.0435)(210)}{0.05}=768$$

According to this computation, and the assumptions and estimates on which it is based, a flow of more than 768 cubic feet per second will now cause Tobitubby Creek to overflow at this place and to begin flooding cultivated farm land.

Before the period of modern accelerated sedimentation, channel overflow at this place would first affect only the narrow first bottom. The lower terrace, which was at least four times as wide as the first bottom and approximately at the level of the present cultivated flood plain, would not have been overflowed until the discharge exceeded the capacity below the level of the lower terrace. Thus, in addition to the channel capacity, an overbank cross-sectional area of about 1,500 square feet would have been available for flood discharge before the lower terrace was inundated. Considering only this area of overbank

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discharge, a computation based on Manning's formula, with an assumed value of 0.1 [10] for n, gives the following result:

$$Q=\frac{(1.486)(2.86)(0.0435)(1{,}500)}{0.1}=2{,}773$$

From this it is evident that, even if there had been no permanent channel, the overflow of cultivated agricultural lands on the lower terrace would, under premodern conditions, take place only when the flood discharge became more than three and one-half times as great as that now required to produce such overflow. Unfortunately, no satisfactory data are available on channel conditions at this place before modern accelerated sedimentation, but it is known that sedimentation has reduced the size of channels at many other places in these valleys. If the premodern channel is assumed to have had a discharge capacity about the same as the present channel, the flood discharge required to inundate the lower terrace would have been about four and one-half times that required at present. If the channel capacity was greater than at present, as is known to have been the case in some places, the discharge necessary to flood the lower terrace would have been even greater.

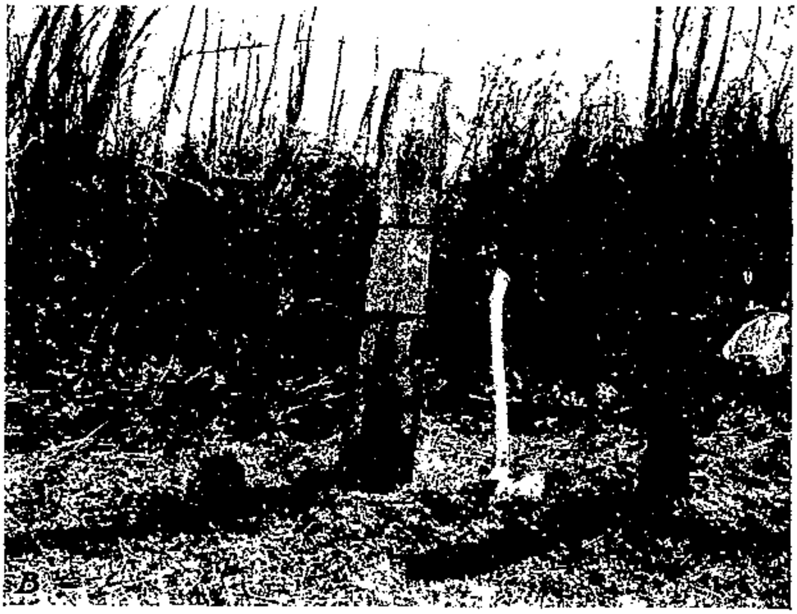
The earlier narrow first bottom would probably have been of little agricultural value, and hence its inundation would have caused little, if any, damage. It is also probable that the loss in value of this relatively small area of lower flood plain would have been more than compensated by the greater protection of the second bottom against flooding. Of even greater importance to the farmers now cultivating the upper terrace is the fact that continued accelerated sedimentation will progressively decrease the protection against overflow now afforded to the upper terrace lands by the overbank discharge capacity of the present first bottom below the terrace level.

In the above computations the assumed values for n are the principal possible sources of error, but no reasonable change in these values would materially affect the order of magnitude of the results. Except for the change in cross-sectional area and a small difference in the hydraulic radius, the factors are the same in each computation. Thus it seems certain that at this place, and regardless of any increase in the frequency of flood discharges that may be due directly to more rapid run-off from cleared and cultivated sloping uplands, sedimentation must have caused a marked increase in the frequency of flooding of agricultural land during the modern period. Quantitatively, as indicated by these computations, the capacity of Tobitubby Creek at range T–13 to discharge floodwaters without overflow of agricultural land has been reduced about 80 percent, or to about 20 percent of its premodern capacity, if the present and former channel capacities are assumed to be the same.

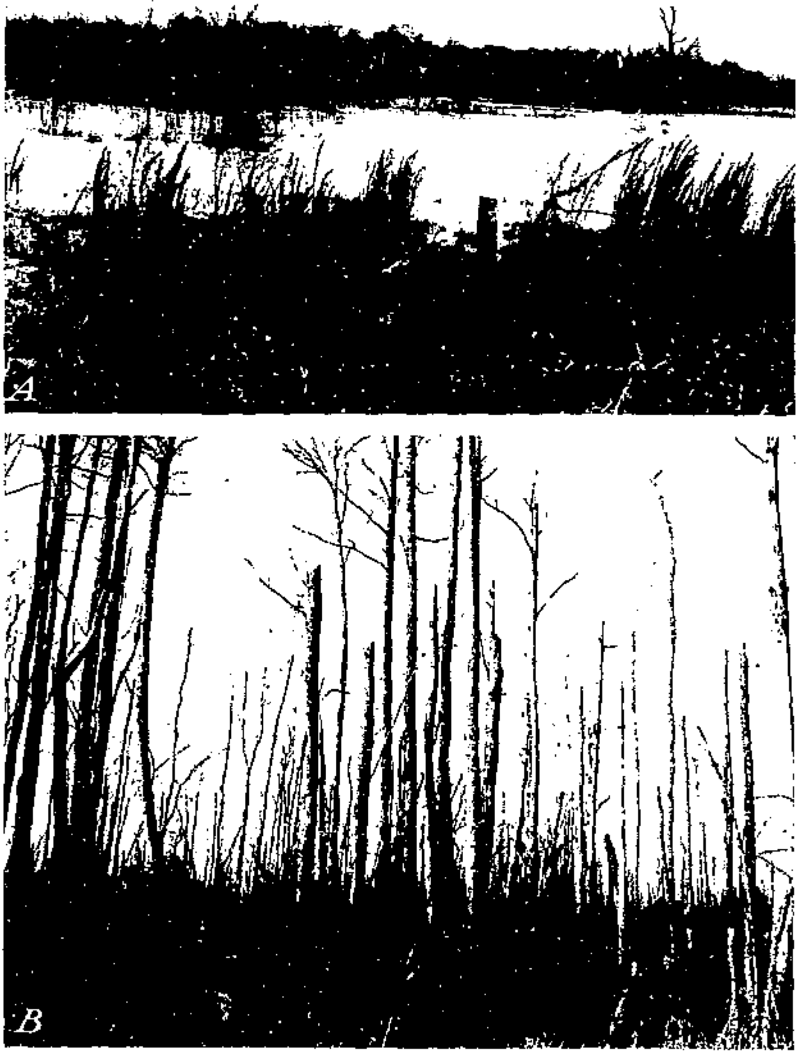
SWAMPING OF VALLEY LANDS

Swamping as a result of excessive sedimentation is estimated to have affected about 550 acres, or 8 percent of the total bottom lands of the two drainage basins. Of this area, 10 acres are severely

[10] The roughness of the flood plain would ordinarily be greater than that of the channel, in the sense here used.



A, Wells drainage district ditch filled with sand, in East Goose Valley just below old Batesville road. B, Three generations of fence posts near boring range H–E, Hurricane Valley. Newest post is in center; post of earlier fence on right; and oldest post on left.



A, Pond formed as a result of accelerated sedimentation at boring range EG-4, East Goose Valley; *B*, trees in Goose Valley, between boring ranges G-7 and G-8, killed by the high water table caused by filling of the Wells drainage ditch.

sanded and 510 subject to excessive flooding. The swamping has been due (1) partly to aggradation of the stream channels, which in turn has caused the ground-water table to rise until in places it is at, or its projection is above, the flood-plain surface, and (2) partly to the aggradation of natural levees and alluvial fans, which obstruct the free run-off of water down the valley and to the channel. In some places permanent ponds have been formed. Such ponds occur between ranges H–2 and H–3 and between ranges H–8 and H–10 in Hurricane Valley. There are also ponds at range EG–4 (pl. 6, *A*) in East Goose Valley and below range WG–6 in West Goose Valley.

Standing timber has been killed by swamping (pl. 6, *B*), and elsewhere swamped areas have not developed a profitable tree crop after logging or after abandonment of cultivation but support only a growth of willows and other relatively worthless types of vegetation. Considerable areas of formerly cultivated fields have also been abandoned, and yields in even larger areas are low and uncertain. In addition, much of the uncleared bottom land that now supports some sort of tree growth has been rendered unfit for clearing and cultivation because of the high water table. Of the 1,500 acres of bottom land in the Wells drainage district, about 250 acres, or 17 percent, are now so badly swamped as to be useless for cultivation, and on perhaps one-quarter of this area either the standing timber has been killed or the present growth consists of willows and worthless brush.

The development and growth of swamps and ponds on the flood plains also furnishes additional breeding places for mosquitoes, and thus tends to aggravate the malaria problem, which is serious in this area. In general, throughout the eastern United States, clearing of forests and cultivation of the land have reduced the extent of swamplands and thus reduced the area of breeding grounds for malaria-carrying mosquitoes, but in Tobitubby and Hurricane Valleys this beneficial process is being reversed at the present time. No figures are available to determine the importance of swamping in increasing the malaria incidence in the Tobitubby-Hurricane area, but figures are available for a similar case reported by the Tennessee State Planning Commission [11] in an area about 100 miles to the north. There, as a result of swamping and ponding caused by clogging of a drainage ditch in 1929, malarial deaths in the adjacent area increased more than 50 percent during the period 1929–35. Perhaps no such abrupt increase has occurred in Tobitubby and Hurricane Valleys, but this Tennessee case occurs under sufficiently similar conditions to afford definite indication of the serious effects of swamping and ponding of the type that has occurred, and is increasing, in Tobitubby and Hurricane Valleys.

SANDING OF VALLEY LANDS

The damage to bottom lands by surface sanding results chiefly from sand-splay formation, and it is most severe on alluvial fans and in and immediately above the plug areas (pl. 7, *A*). Where sand is spread out in splays it often covers older silt deposits, and if the sand is more than 6 inches deep, it causes a marked decrease in productive capacity of the land affected. In addition to the loss of fertility, the tendency of the sanding to occur in relatively narrow

[11] TENNESSEE STATE PLANNING COMMISSION. DRIFT, FLOOD MENACE WEST TENNESSEE AREA. Plan Topics, 1: 7. 1936. [Mimeographed.]

strips 100 to 300 feet wide along the stream channels produces marked variations in soil characteristics within areas usually worked as single fields. It is therefore inconvenient and more costly to cultivate such fields because of the varying physical conditions, especially as they affect tillage requirements during periods of drought or heavy precipitation.

Serious permanent damage to valley lands by sanding is apparently less widespread than might be supposed from cursory examination alone. In much of the affected area damage by sanding is associated with less obvious but serious damage by swamping and frequent flooding. Furthermore, test borings indicate that many places that were surfaced with raw and infertile sand at some time during the past hundred years have since been covered with relatively fertile silt deposits. Production from such silty soils in various parts of these and other nearby valleys indicates that when cultivated they are capable of producing fine crops if protected from flooding and swamping.

Locally, however, the damage by sanding has been severe, especially in the upper valleys. It is estimated that in 1937 about 940 acres were worthless or seriously impaired for agricultural use because of sanding alone. This estimate includes 340 acres in the main and tributary valleys, in which detailed boring surveys were conducted, and 600 acres in other tributary valleys, for which separate estimates have been made from much less complete data. An additional 450 acres could not be reclaimed by control of the swamping and excessive flooding that now make them worthless because the sand already deposited would continue to make them unproductive. About 10 acres outside the area of excessive valley flooding are both sanded and swamped. The total area of sanding is thus about 1,400 acres, or about 20 percent of the total bottom lands, in the two drainage areas. As pointed out above, not all these sanded lands are certain to continue to be unproductive but if present conditions continue, any sanded areas that may be improved by silt deposition will probably be more than counterbalanced by other additional areas that will undoubtedly be covered by sand in the future.

VALLEY TRENCHING

Trenching to depths of 3 to 12 feet (pl. 3) has caused several kinds of damage in the upper parts of the valleys. The difficulty of working the lands has been increased, and in some places construction of bridges for the transfer of farm implements from one side of the valley to the other has been necessary. Trenching has also lowered the water table in these areas and thereby aggravated drought damage in years or seasons of unusually low rainfall. As drainage was comparatively good and flood damage small in these headwater areas under natural stream conditions, little benefit has been derived from the enlarged channels and more rapid run-off resulting from valley trenching. The trenches have, on the other hand, been an important factor in transporting sediment, especially sand, down to the wider and more valuable parts of the valleys, and thus increasing the damage by sand deposition there.

FIGURE 17
FOUND AT END
OF BULLETIN.

STREAM-BANK EROSION

Stream-bank erosion is not generally severe or serious in the Tobitubby and Hurricane Valleys. Locally, however, it has been considerably accelerated where the banks have been cleared in attempts to counteract the effects of sedimentary filling of the stream channels. A good illustration is afforded by a section of the West Goose Creek drainage ditch. For a distance of about 1,000 feet the banks have been kept cleared for a number of years, and this section of ditch has widened to an average width of 43 feet. For a distance of 2,000 feet downstream the average width is only 27 feet. Bank erosion caused by bank clearing has thus destroyed about one-third of an acre of bottom land and removed about 1,800 cubic yards of sediment in this 1,000-foot section of valley. Figure 17 illustrates these relations. The greater width upstream from the 1,000-foot section is due to a winding stream pattern above the original head of the artificially straightened channel.

The widening by bank erosion may be accompanied or followed by notable aggradation of the stream bed, so that loss of land by erosion is not fully compensated by increased discharge capacity of the channel. Plate 7, *B* shows such local widening of West Goose Creek.

LOCAL CONTROL AND RECLAMATION EFFORTS

Individual landowners and farm operators have made numerous attempts to improve drainage in the middle and upper parts of the Tobitubby and Hurricane Valleys. At some places sand has been plowed or shoveled out of the channels and some improvement thus effected. Owing to the rapid accumulation of sand, however, the channels must be periodically reopened.

The same methods have been used to start new channels or to straighten the old ones, in the hope that the small dug or plowed ditches would be enlarged by bed and bank erosion. Such artificial channels may be helpful for a short time, but usually the desired enlargement fails to take place, and instead the channel fills with sand. Because the scope of such channel cleaning and straightening is limited, the benefits are always local, and such measures are not known to have been effective at any place over any long period of time. On the other hand, some of these improvements have caused channel incision or trenching in the headwater sections of the valleys and progressive migration of waterfalls or rapids upstream into the uplands. As a result, old gullies have been rejuvenated and new ones formed.

Attempts have also been made to improve the channels by clearing brush and trees from the banks. An increase in capacity may result from this practice, but the benefit is only temporary unless the banks are kept clear by frequent cutting. The benefits are not known to have been maintained at any place more than a few years, except in some of the sandy headwater areas where considerable widening of the stream channels by lateral erosion has occurred. The most conspicuous example of such widening is on West Goose Creek, where the artificially straightened channel, kept cleared for a distance of 1,000 feet, has increased in average width from 27 feet to 43 feet (fig. 17). Concurrently with the widening, the channel bed was aggraded, and thus increased channel capacity was achieved only by a comparatively large increase in channel width and the destruction of about one-third acre of fairly good bottom land.

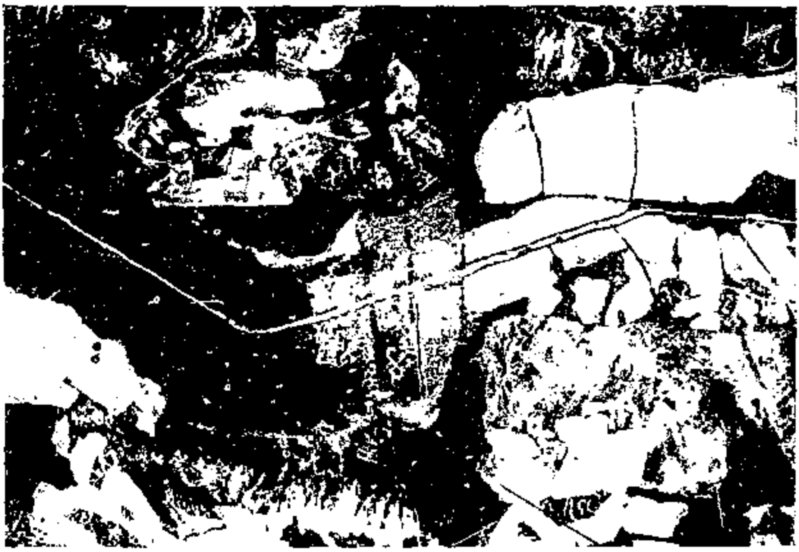
In some areas of serious flood-plain sanding, local efforts have been made to protect valuable fields by construction of brush dikes a foot or two in height. These are built parallel to the stream on top of the natural levees, the brush being laid parallel with the channel and held in place by stakes or trees. Such dikes are especially useful where the natural levee is low or where it has been breached by overflow waters or by a path or farm roadway. The brush dikes retard the velocity of the water sufficiently to induce sand deposition. The brush pile is soon stabilized, and the height of the bank is raised sufficiently to reduce the amount of water and sediment carried out upon the adjoining field. Large areas cannot be protected by such measures, however, for the sand is diverted from one field only to be delivered to another place of deposit. Locally, however, the method appears to have considerable value, for the fields from which sand is excluded tend to be built up by accumulation of finer and more fertile sediment, and thus tend to be maintained in relatively good condition for at least a few years. Commonly, however, the brush dikes have been so carelessly and poorly constructed that the actual benefits have been far less than might have been obtained by more careful workmanship.

In the Wells drainage district, which includes about 1,500 acres of bottom land in Tobitubby, Goose, West Goose, and East Goose Valleys, a more extensive attempt has been made to improve the bottom land. This district was organized in 1919, and in 1920 about 11 miles of drainage ditches were excavated by blasting and spading. The ditches ranged from 10 to 14 feet in top width and averaged 6 feet in depth.

The Wells district ditches did not prove effective, apparently in part because of inadequate outlet for the water at the lower end of the district. Instead of enlarging by erosion, as was anticipated, the ditches soon began to fill with sand. Within a few years, according to reports of local residents, they were completely filled at the lower ends. Backfilling continued, and by 1937 about 52 percent of the original ditches were completely filled and another 20 percent were so nearly filled that they were inadequate to carry off ordinary freshets without overbank flooding. The extent of filling of the ditches is shown in figure 18. A large part of the bottom land within the district is now practically worthless for farming and is abandoned to swamps and brush. Plate 8, *A* is an aerial photograph of a part of West Goose Valley near boring range WG–6 showing several stages in this progressive abandonment. A part of the valley where the ditch is entirely filled has been abandoned and is completely grown up to willows. Farther upstream, where active overbank deposition is now in progress, the land has been recently abandoned and has partially reverted to willows and briers, but where the ditch is still partly effective the flood plain is cultivated. The present appearance of the ditches, where completely filled by sediment, is illustrated by plates 5, *A*, 8, *B*, and 9, *A*.

In conjunction with the demonstration program of the Soil Conservation Service, erosion-control treatment has been given to a small

A, Sand splay in abandoned field alongside filled ditch shown in plate 5–*A*, East Goose Valley. *B*, West Goose Creek where it is being widened by active bank erosion. The widening of the channel has been accompanied by shallowing as a result of sand deposition. Above range WG–3, West Goose Valley.



A, Progressive abandonment of bottom land at head of plugged, back-filling Wells ditch near Range WG-6, West Goose Valley, 4 miles west of Oxford, Miss. The ditch, which appears as a broad white line extending from right to left, is completely filled at the left, and the swampy, wooded bottom land appears as a dark area; in the center are three recently abandoned fields, with dark clumps of brush scattered among fresh sand splays; at the right, where the ditch is still partly effective, the light areas of regular shape are cultivated fields. (Aerial photograph by courtesy U. S. Army Engineers). *B*, View down completely filled drainage ditch at Range WG-6, within the area shown in *A*.

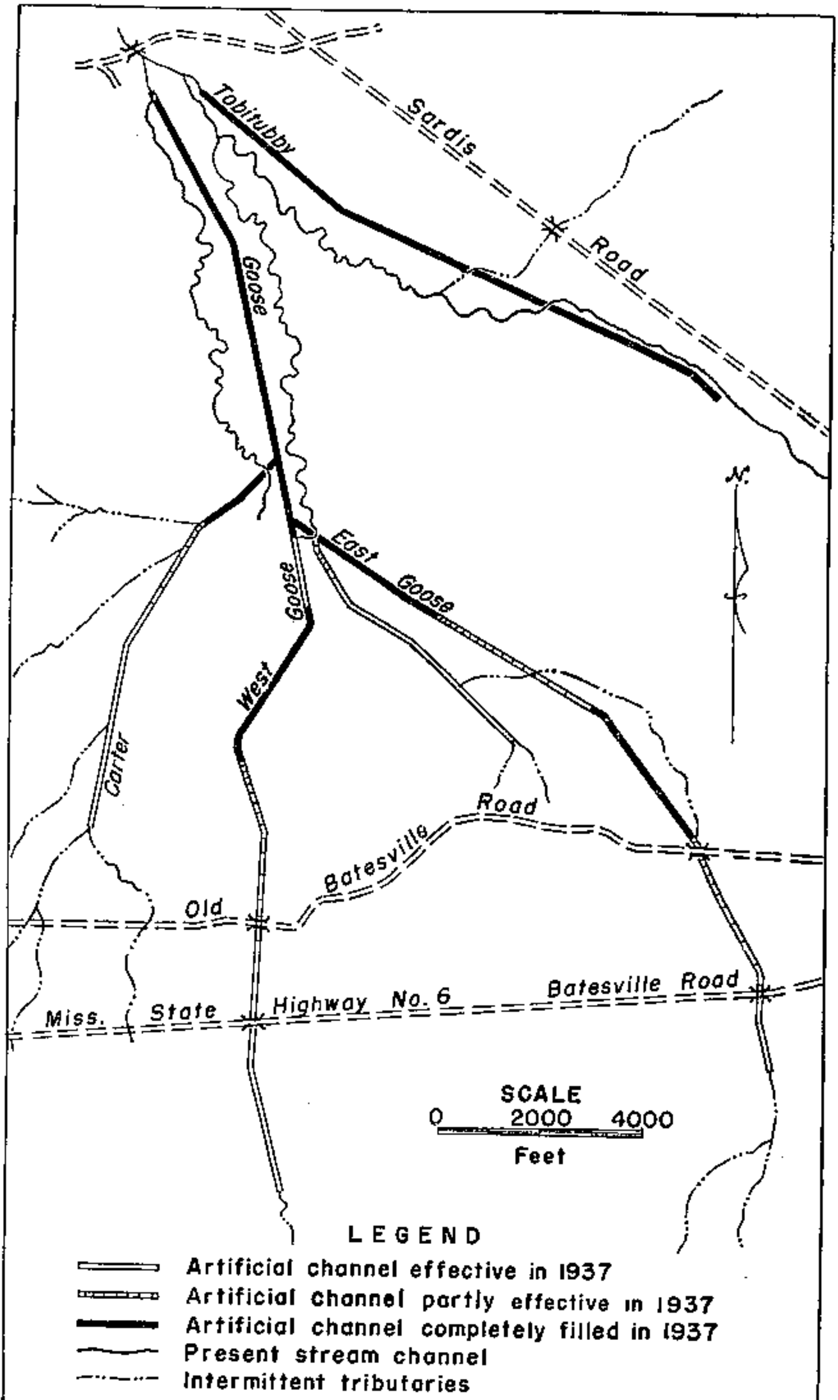


FIGURE 18.—Extent of filling of Wells drainage district ditches in 1937.

part of the uplands of the tributary drainage areas since 1934. These practices, in addition to reducing the rate of sediment production, also reduce the rapidity of run-off from the upland surface. The application of such practices is still too limited to provide much benefit to the valleys. Before the demonstration work of the Service, little application had been made of upland conservation practices and no specific attempt had been made to protect the bottom lands from harmful sedimentation and destructive flooding by reducing the rates of upland soil erosion and surface run-off.

RELATION TO DOWNSTREAM FLOOD PROBLEMS

Tobitubby and Hurricane Creeks are tributaries of the Little Tallahatchie River, one of the principal headwater streams of the Yazoo drainage system. The lower part of the Yazoo Basin consists of about 6,600 square miles of fertile alluvial lands commonly called the Yazoo Delta. According to the report of the National Resources Committee (*80, p. 440*): "The chief water problems are the protection of lowlands from headwater floods and a system of drainage for the Yazoo Delta." To make most of these alluvial lands reasonably safe from flood damage, large sums have already been expended by local interests, and further expenditures by both local and Federal agencies are anticipated.

Many past attempts to improve drainage and control floodwaters have failed or have been seriously hampered by excessive sedimentation. The gradients of the streams in the delta are low, and therefore many of the streams are unable to carry the large loads of sand and gravel delivered from the rapidly eroding uplands of the basin. In several places dredged drainage canals have been partly or completely filled, and floodways confined between levees have lost much of their capacity and have thus become ineffective (*78, p. 139*). Sand delivered to the Little Tallahatchie River by Tobitubby and Hurricane Creeks has probably contributed to such conditions in the delta, and particularly to the partial filling of the channel of the Panola-Quitman floodway, which carries the Little Tallahatchie water.

For the protection of the delta from floods that originate in the hilly upland part of the drainage basin, Congress has authorized construction of reservoirs on the principal tributaries of the Yazoo. As a part of this program the Sardis Reservoir is now (1938) being constructed on the Little Tallahatchie River at a cost of about $14,500,000. The estimated capacity of the reservoir will be 1,570,000 acre-feet, and the contributing drainage area will be 1,545 square miles.[12] The reservoir basin will include the lower parts of Tobitubby and Hurricane Valleys.

Even though the Sardis Reservoir will be operated primarily for flood control, and deposition of sediment within it will thus be minimized, only the very finest of the erosional debris produced in the drainage basin above the reservoir will be carried to the delta by the Little Tallahatchie River. In addition to the control of floodwaters, the reservoir will thus protect drainage and flood-control works in the delta from damage by this coarser debris. The sediment impounded in the reservoir will reduce its capacity for withholding floodwaters,

[12] Letter from the Chief, U. S. Army Engineers, dated February 14, 1939.

however, and if sediment accumulation is excessive the continued effectiveness of the reservoir may be seriously impaired.

Soil erosion in a large part of the uplands tributary to the reservoir, including the Tobitubby and Hurricane drainage basins, has been unusually severe. The sediment output has been correspondingly high, and it will continue to be so if present cultural and erosional conditions remain unchanged. The fact that a large part of the erosional debris now collects in the upper parts of the valleys is advantageous in the protection of the reservoir, for the amount of sediment annually transported to the reservoir basin is thereby materially reduced. It is important, therefore, that in any plans for alleviation of sediment damage in the valleys or of erosional damage in their tributary uplands the effects on sediment contribution to the Sardis Reservoir should be considered.

(1) It is significant that channel plugging and backfilling are major processes of valley sedimentation. It does not appear likely that the present stream gradients have become so steep that plugging and backfilling will diminish greatly in the near future. Hence, other factors being unchanged, the proportion of the total erosional debris that lodges in the upper parts of the valleys will probably be as great in the future as during the past century.

(2) Lateral stream-bank erosion is of little importance in these valleys. Therefore, under present conditions the sedimentary deposits in the upper valleys are not subject to excessively rapid erosion and further downstream movement, although they are, like all valley deposits, potentially unstable. Consequently, it may be feasible to reduce the rate of reservoir sedimentation by encouraging sediment accumulation in the upper valleys, provided care is taken to avoid any large increase in the erosive capacity of the stream. This may require that the channel banks be protected by vegetation and that any drainage projects be sufficiently restricted to prevent large increases in channel velocities.

(3) To the extent that upland erosion-control measures reduce the contribution of sediment, they will reduce future damage to the valleys and to the reservoir. In many parts of the uplands where the land has been so severely damaged by erosion that control measures could not be justified solely on the expected benefits to the uplands, the protection of the reservoir from sedimentation and the protection of the valleys from excessive sanding, flooding, and swamping may justify an extended soil and water conservation program. This is a matter deserving of more investigation than has been possible in the course of the studies here reported.

EROSION AS MEASURED BY VALLEY SEDIMENTATION

The volume of sediment accumulated in Tobitubby and Hurricane Valleys since the inception of accelerated soil erosion may be used as a minimum measure of the extent of erosion in their dranage basins during that period of approximately 100 years. In addition to the volume of sediment in the main valleys, as determined by boring surveys, estimates have been made of the additional quantity of sediment lodged in their various tributaries, as well as that which has been carried out of the main valleys. By including these estimates, the true average rate of net upland erosion in the Tobitubby and Hurricane dranage basins may be approximated more closely. For this purpose it was assumed that both deposited sediment and the upland soil from which it was derived had the same weight per unit volume and that 85 pounds of suspended load represented 1 cubic foot of upland soil. The basic data and computed erosion rates are summarized in table 7. In addition to average rates for the entire Tobitubby and Hurricane drainage areas, separate computations are included in the table for the several headwater areas where, so far as can be determined from the available data, erosion has been most severe.

TABLE 7.—*Minimum average rates of upland erosion in the Tobitubby and Hurricane drainage basins, as determined from sedimentation data*

Drainage basin	Area			Volume of sediment					Rate of upland erosion		
	Total	Bottom land	Upland	Measured in valleys surveyed	Estimated in tributaries not surveyed	Estimated to have been deposited on Tallahatchie flood plain	Carried beyond Greenwood as suspended load	Total sediment production	Indicated average erosion of upland surface	Rate per year	Time required for erosion of 1 inch
	Acres	*Acres*	*Acres*	*Acre-feet*	*Acre-feet*	*Acre-feet*	*Acre-feet*	*Acre-feet*	*Inches*	*Inch*	*Years*
Tobitubby	36,141	4,817	31,324	9,035	3,803	638	840	14,316	5.5	0.055	18.2
Hurricane	20,513	2,160	18,353	5,223	1,820	362	177	7,882	5.1	.051	19.6
Total	56,654	6,977	[1]49,677	14,258	5,623	1,000	1,317	22,198	5.4	.054	18.5
Tobitubby above range 10	10,692	1,237	9,455	2,551	1,659			4,210	5.3	.053	18.9
Goose Creek above range 10	10,092	1,496	8,596	4,490	524			5,014	7.0	.070	14.3
West Goose	3,748	414	3,334	1,614				1,614	5.8	.058	17.2
East Goose	3,487	568	2,919	2,085				2,085	8.6	.086	11.6
Hurricane above range 7	9,502	927	8,575	3,121	885			4,006	5.6	.056	17.9

[1] Includes an estimated 3,800 acres of terrace land.

As listed in table 7, the computations show an average depth of erosion of 5.5 inches, or 1 inch in 18.2 years, for Tobitubby drainage area; 5.1 inches, or 1 inch in 19.6 years, for Hurricane drainage area; and 5.4 inches, or 1 inch in 18.5 years, for the two areas combined. These figures are conservative, for, although computed as accurately as possible with the data available, conservative or minimum values have been used for factors that could be measured only within certain limits of variation. In addition, these figures apply only to the erosional debris that has reached the valleys from the uplands. The total displacement of upland soil material has been much greater, for much material that has been moved by the erosional processes has not yet reached the valleys.

HIGHER EROSION RATES IN HEADWATER AREAS

In computing average rates of surface erosion for various headwater parts of the drainage areas, as given in table 7, no allowance was made for sediment carried beyond the headwater area under consideration. This was done because of the tendency of sediment to be concentrated in the upper parts of the valleys. For this reason these headwater areas may not have contributed as much of the sediment found farther downstream as other areas of equal size that drain more directly into the larger valleys. In spite of this limitation in the sediment measurement, average erosion rates for these headwater areas are notably higher than those for the drainage basins as a whole. The highest is 8.6 inches during the past 100 years, or 1 inch in 11.6 years, from 3,487 acres in the drainage basin of East Goose Creek. Longer, steeper slopes and more complete clearing and cultivation of land near the town of Oxford are probably partly responsible for the higher rates of erosion in these headwater areas.

EROSIONAL DEBRIS DEPOSITED WITHIN TOBITUBBY-HURRICANE DRAINAGE AREA

In making the computations, the volume of sediment in the main Tobitubby and Hurricane Valleys and the surveyed tributaries was determined from cross sections on which the thickness of modern sediment had been plotted at the minimum depth in all doubtful cases; and therefore the total volume thus determined is itself a minimum figure. This is the only part of the sediment that was directly measured in connection with the present study. If only this volume of sediment is considered, it accounts for about 65 percent of the computed erosion (as shown in table 7) in both Tobitubby and Hurricane drainage basins, and for an even higher percentage of the computed erosion in the surveyed tributaries that have higher indicated rates of erosion than the entire drainage basins. This is evidence that the erosion rates in table 7, which include estimates based on less precise data, are of reasonable magnitude.

In making estimates of the quantities of modern sediment lodged in the principal tributaries that have not been surveyed in detail, the average thickness of modern sediment was assumed to decrease regularly from the mouth of the tributary upstream to the head of its alluvial valley. The area of alluvial land in each tributary has been determined from aerial photographs, and the volume in each tributary has been calculated by the formula $V=\frac{5}{9}\,h\,A$, V being the volume of fill, h the average depth of modern filling at the mouth, and A the area of alluvial bottom land. This formula is developed from the assumption that the body of sediment approximates in form a combination of wedge and pyramid, and assumes, in effect, an average thickness of modern sediment equal to five-ninths of the average thickness at the mouth. For three tributaries, Pine Grove Branch, Plants Branch, and Summerville Branch, the results have been weighted to allow for observed departures from the assumed average sediment distribution. In view of the general tendency of the sediment to be concentrated in the upper part of the valleys, especially above plugged channels, which are common in both Tobitubby and Hurricane Valleys, the computed totals are probably somewhat below the true figures. On the basis of these estimates, however, about 25 percent of the total sediment, as used in the erosion computations, is deposited in the tributary valleys that were not studied in detail.

EROSIONAL DEBRIS CARRIED OUT OF TOBITUBBY-HURRICANE DRAINAGE AREA

From preliminary boring surveys, it is estimated that an average of 1 foot of modern sediment has been deposited on the 30 square miles of flood plain of the Little Tallahatchie River below the mouth of

Hurricane Creek and above the point where the Little Tallahatchie enters the Yazoo Delta. The drainage area tributary to this part of the Little Tallahatchie is about 1,700 square miles. If the modern sediment on this part of the Little Tallahatchie flood plain had been derived equally from all parts of its tributary drainage area, a total of 1,000 acre-feet would have come from Tobitubby and Hurricane drainage basins. This accounts for about 4 percent of the estimated total erosional debris used in the computation of erosion rates. Actually, however, the Tobitubby and Hurricane areas, which are nearby and have been more severely eroded than most of the tributary drainage area, have probably contributed more than the average from the entire drainage basin. Because of this and because no allowance is made for similar deposition on the flood plain farther downstream in the Yazoo Delta where no investigation has yet been made, this estimate is also presented as a minimum figure.

The only basis for estimating the quantity of sediment carried entirely out of the Little Tallahatchie Basin is data obtained by suspended-load sampling of the Yazoo River at Greenwood, Miss. (fig. 1), by the United States Army Engineers, during the periods from September 23, 1930, to July 10, 1931, and January 25 to April 29, 1932. Computations [13] based on these data indicate that the average suspended-load discharge was about 133 pounds per second. At this rate, the total suspended load would be about 2,100,000 tons per year. This would be equivalent to 0.43 ton from each acre of the 7,700 square miles of drainage area above Greenwood. If the soils average 85 pounds per cubic foot in weight, the average volume of soil required to produce this amount of sediment would be 10.12 cubic feet per acre per year. This is equivalent to the average removal of 0.28 inch from the surface of the watershed in 100 years, or about 6 percent of the total erosion as here computed.

Probably the sediment load of the Yazoo has been greater in the past few years than in the early part of the period of accelerated erosion, but this consideration is balanced, if not more than balanced, by the facts that (1) no allowance is made for bed load; (2) a large part of the drainage area above Greenwood is alluvial land that has not contributed any important quantity of sediment; (3) the period of sampling was one of subnormal rainfall, as shown by United States Weather Bureau records, and therefore was probably a period of subnormal erosion; and (4) the Tobitubby and Hurricane drainage basins are in the most severely eroded and actively eroding part of the drainage area above Greenwood, and hence probably contribute relatively more sediment than the average for the entire Yazoo Basin. It therefore seems safe to assume that the Tobitubby and Hurricane drainage

[13] These computations were made as follows: The sediment discharge in pounds per second was plotted graphically against the time in days. The area under the discharge curves was measured separately, by planimeter, for the periods September 23, 1930, to January 25, 1931; January 25 to April 29, 1931; April 29 to July 10, 1931; and January 25 to April 29, 1932. The average sediment discharge for each of these periods was determined by dividing the area under the curve by the length of the abscissa. An approximate average, weighted, annual sediment discharge for the entire period was calculated from the formula

$$ASD = \frac{t_1d_1 + t_3d_3 + \frac{(t_2d_2 + t_4d_4)}{2}}{t_1 + t_3 + \frac{(t_2 + t_4)}{2}},$$

where ASD is the average sediment discharge and d_1, d_2, d_3, and d_4, and t_1, t_2, t_3, and t_4, are, respectively, the average sediment discharge and the time in seconds for the periods September 23, 1930, to January 25, 1931; January 25 to April 29, 1931; April 29 to July 10, 1931; and January 25 to April 29, 1932.

basins have contributed an average of 0.28 inch from their combined surface area to the sediment load carried down the Yazoo during the past 100 years. That amount is therefore included in the erosion figures in table 7.

EXCLUSION OF COLLUVIAL DEPOSITS

In the calculation of rates of erosion, no allowance has been made for colluvial sedimentary deposits except where they occur along the margin of the main valleys and have been included in the cross-sectional areas of deposits measured by boring surveys. In the aggregate the volume of colluvial deposits is believed to be large, but quantitative data from which their volume can be estimated are not available nor could such data be obtained during the study without unduly costly surveys.

COMPARISON WITH EROSION MEASUREMENTS

It is interesting to compare the erosion rates as computed from sediment volumes with the results of similar computations based on rates of sheet erosion measured at Holly Springs, about 25 miles north of the Tobitubby-Hurricane area, by the Southern Forest Experiment Station (*53, p. 12*). The Holly Springs results should be applicable to the Tobitubby-Hurricane area, for the climatic conditions, soil types, slopes, and other factors are similar. The extrapolation of plot results to much larger areas, however, presents several difficulties.

Actually the plot results prove only that a certain amount of material has been removed from a sloping surface of the length of the plot. It is known from observational evidence that a large part of the debris eroded from a plot area would ordinarily be transported farther than the lower end of the plot. Hence, application of data from plot tests to a drainage basin, on the assumption that the only material carried off the upland part of the drainage basin would be that derived from an area one plot length in width around the base of all slopes in the basin, would yield figures obviously too small. This method of computation, nevertheless, does provide a means of establishing the lower limit of possible variation in the true figure.

It can also be assumed that a drainage basin is composed of a large number of plots, and the plot results can be applied to the drainage basin in proportion to the areas of various land use. The depths and rates of erosion calculated in this way are not necessarily maximum figures, however, for the effect of concentration and greater volume of run-off on longer slopes might cause greater erosion per unit area than would be indicated by the results from shorter plots. The results of this method of computation, however, will approach a maximum value and will represent values for the simplest method of extrapolation of plot results to large areas.

Studies of erosion from plots of different lengths are in progress and may be expected to yield information that will permit more accurate determination of the actual erosion from longer slopes (*58*). As the length of the plots is increased, however, it becomes more and more difficult to obtain uniform slopes and soil conditions, and these and other variable factors make comparison more difficult. It is therefore desirable to apply other tests. The information on rates of erosion as measured by valley aggradation in the Tobitubby-Hurricane area provides such an opportunity, within the limits imposed by the extent of the available data.

Based on the plot investigations at Holly Springs, the sheet erosion from the uplands of the Tobitubby-Hurricane area is estimated, by extrapolation of the plot results to the entire upland, to have been 10.2 inches in 100 years. In computing this upper figure, and the lower limiting figure given below, the plot results were arbitrarily reduced by one-fifth in an attempt to compensate for the 25 percent excess of rainfall during the period of experiment. Also the percentage of land in different land use classes, as estimated from aerial photographs, was modified to compensate for the smaller areas of abandoned cultivated lands during the early part of the 100-year period since settlement.

In estimating the lower probable limit of the amount of sheet erosion, the lengths of slopes from the ridge tops to the channels or valley bottoms were measured on aerial photographs and found to average about 300 feet. The length of the plots (12 feet) divided by the average length of slope (300 feet) is equal to 0.04, which represents the proportion of the average length of slope from which the plot studies show erosional debris to be removed. Thus, the average removal from the entire slope under any particular land use would be 4 percent of the removal from the plot at the base of the slope. Application of this figure to the Tobitubby and Hurricane uplands in proportion to the areas of various land use indicates a minimum erosion of 0.4 inch.

These figures from the Holly Springs plot data are for sheet erosion. The average depth of erosion of 5.4 inches for the Tobitubby-Hurricane area as computed from sediment data (table 7) includes both gully and sheet erosion. These sets of figures are therefore not directly comparable. It is known, however, that about 25 to 30 percent of the sediment accumulated in the valleys is sand, which must have been derived largely by gullying of the Holly Springs formation. Before erosion of the sand, however, the overlying loess must have been removed, usually in part by gullying. It is therefore estimated that about 40 percent of the sediment in the valleys has been derived from gullying. If this proportionate correction is made, the average removal by sheet erosion in the Tobitubby and Hurricane drainage areas has been about 3.2 inches in 100 years.

If the corrections for the extent of gully erosion are reasonable, this 3.2 inches will be a minimum measure of the sheet erosion, for the debris accumulated in colluvial deposits above the alluvial valleys has not been measured. Thus in the Tobitubby-Hurricane areas an estimate based on sediment data indicates that the rate of sheet erosion lies about half way between the two extreme values computed from plot data.

SOME GENERAL PRINCIPLES OF STREAM AND VALLEY SEDIMENTATION

PURPOSE AND SCOPE OF THE SUGGESTED PRINCIPLES

The preceding part of this bulletin presents the results of detailed studies of modern sedimentation in Tobitubby and Hurricane Valleys. The ultimate objective of such detailed studies, in these as well as in other valleys is (1) to verify and elucidate the controlling physical principles that govern excessive stream and valley sedimentation, and

(2) to evaluate the major factors in the complex interrelationship between stream and valley sedimentation and soil erosion, so that there may be a sound scientific basis for planning alleviation and protection of valley resources from excessive stream and valley sedimentation. The chief importance of the results of the detailed studies thus lies in the general principles that may be disclosed or verified. In the pages that follow, an attempt is made to classify and state in concise form certain general principles that have been developed by analysis of the results obtained in the Tobitubby-Hurricane area or suggested by less detailed studies in other areas of modern stream and valley sedimentation.

Forty-five statements of fact have been listed as "principles," with an explanatory discussion directly following each principle. The principles are not all of equal order of importance, nor are they all presented in equivalent form. They are grouped under eight headings, as a convenient subject-matter classification, and the same basic fact may underlie more than one principle in order to emphasize different practical applications or effects. Hence these principles are not intended to be limited to statements of basic natural laws, but are practical considerations in the field of stream- and valley-sedimentation problems.

The basic facts upon which these principles are founded are believed to be well established, but the particular form in which the principles are here stated must be considered as tentative. Not enough research has yet been done to determine how widely and how consistently the various apparent truths will hold true. It is hoped that by further work these principles may be more rigorously tested, progressively revised, improved, and supplemented until a concise and fully verified summary of the most important facts in this particular field of knowledge is developed.

SIGNIFICANCE OF CRITERIA FOR RECOGNITION OF MODERN VALLEY SEDIMENTS

1. Buried dark soil horizons afford an accurate and practicable basis for identifying the contact between modern and underlying older alluvial deposits.

Of first importance in the study of accelerated sedimentation is the identification of the modern sediments and their differentiation from similar deposits formed at earlier dates. Before 1935, when the present investigations were begun, it had occasionally been suggested, or assumed, that where a relatively light-colored alluvial soil was underlain at depths of a few inches to a few feet by a darker horizon, the darker horizon was a former topsoil layer that had been buried beneath later deposits resulting from accelerated erosion. This sequence of light-colored sediment overlying darker material had been observed in flood-plain deposits at many places in the eastern part of the United States.

One of the most important results of the investigations in Tobitubby and Hurricane Valleys has been the substantiation of the validity of this hypothesis. The evidence has been presented in considerable detail in an earlier section (pp. 18–22). However, the possibility that deposition of the overlying, lighter-colored sediment may have been started in many places somewhat earlier than culturally accelerated soil erosion cannot be entirely eliminated. But the Tobitubby-Hurricane findings are supported by similar unpublished findings in various parts of the southeastern Piedmont and the upper Mississippi Valley. It has been established that the dark horizons actually are old soil horizons by tracing them from beneath the lighter-colored overlying flood-plain sediments into lateral continuity with surface colluvial or upland soils bordering the valleys. Burial of fence posts and various articles related to the present culture shows that a large part of the sediment overlying the dark soil horizon has been deposited during the modern period. The modern deposits below such buried "fossil" objects are similar to the deposits above, but are markedly dissimilar to the premodern deposits underlying the dark soil horizon.

In these other areas, as in the Tobitubby and Hurricane Valleys, the change from dark-colored, poorly stratified, usually fine-textured sediment to light-colored, generally well-stratified, commonly coarser-textured sediment must reflect a marked change in the regimen of the streams. The widespread occurrence of similar conditions points to a common cause and origin. A marked acceleration in the rate of upland erosion has occurred in these areas. In some parts of all areas in which investigations have been conducted, the source of the overlying modern sediment is undoubtedly the nearby cultivated fields that have been subject to accelerated soil erosion. There is no evidence that there have been climatic, diastrophic, or other changes of such widespread and drastic effect and of such recent date as would be required to account for these changes in stream and valley sedimentation. It is therefore justifiable to conclude that accelerated soil erosion is the common cause of the similar conditions throughout the area where they occur. It appears, therefore, that dark horizons can be used with assurance in the eastern part of the United States to identify the contact between modern and premodern sediments.

Stream- and valley-sedimentation studies by the authors in the western part of the United States have been limited to the middle Rio Grande Valley in New Mexico. These investigations consisted mainly of instrumental resurveys of previously established profile lines across the valleys, and therefore the extent to which dark horizons may be useful as a criterion in the Western States is not yet known. Because of the more arid climate, however, dark soils may not have been as widely developed as in more humid parts of the country. It is also possible that dark horizons due to diagenetic processes occur in the alluvium of arid regions, and that, in the Southwest at least, climatic cycles may have been a major factor in causing periodic aggradation of valleys.

The establishment of the dark horizon as a valid criterion of the top of the premodern deposits has a twofold significance. It makes possible (1) the recognition of other characteristics that will serve to distinguish between the modern and older sediments where the original surface soils were not dark or where the dark horizons were developed but have subsequently been removed by erosion or modified by cultivation and (2) the differentiation of premodern and modern sediments in other valleys where the surface soil was dark and where conditions are generally similar to those in Tobitubby and Hurricane Valleys.

In many places where undoubted old black soils were found by boring in the Tobitubby and Hurricane Valleys, hard ferruginous concretions occur in or below the old soil horizon but not in the overlying modern deposits, except where they apparently have been redeposited rather than developed in place. In many places very light bleached or pastel colors were present below but not above the dark horizon. Thus two additional criteria were established that can be used to identify the premodern sediment and thereby establish the maximum possible thickness of modern deposits where the dark horizon is poorly developed or missing.

2. Distinctive bleached colors and hard ferruginous concretions are common in the premodern valley sediments but have not been found in the modern sediments. Where present, they provide a reliable and practicable means of identifying the older or premodern sediments, even where no buried dark soil horizon is present at the top of these older deposits.

At places in Tobitubby and Hurricane Valleys where the contact between the modern and premodern sediments could be definitely identified by dark soil horizons, study of the vertical sequence of the flood-plain deposits showed that hard ferruginous concretions and bleached colors may occur in the premodern sediments but are not present in the overlying modern deposits.[14] Furthermore, when these two criteria were used to supplement the criterion of dark horizons, the thicknesses of modern fill so determined were consistent and reasonable (figs. 8, 9, and 10). Therefore, ferruginous concretions and bleached colors were adopted as supplementary criteria for distinguishing between modern and premodern deposits.

Subsequent study of flood-plain deposits in several other parts of the United States has confirmed the validity of these criteria and indicated that they are of general application as a reliable and practicable means of identifying the older or premodern sediments. In the Piedmont of North Carolina and South Carolina hard concretions apparently are rare in the premodern valley deposits, but bleached colors are common, and when these criteria are used they yield consistent and reasonable results. In the few places where hard concretions were found in the Piedmont valleys, they were always in the premodern sediments. In Wisconsin, ferruginous concretions developed along root channels have been found below but not above dark horizons. The presence of concretions and bluish-gray colors in alluvial soils has been recorded in many Bureau of Chemistry and Soils reports covering counties in various parts of the eastern United States. It appears, therefore, that the criteria of concretions and bleached colors will be useful in many parts of the eastern United States.

It must be clearly recognized that the contact between modern and premodern sediments cannot be defined precisely by these criteria. At places where dark horizons occur, concretions may be present in the darker zone or at various depths below that zone. In other valleys where apparently little or no modern sediment accumulation has occurred and where no dark surface soil has developed, concretions, if present, may be at the surface or at various depths below the surface. Bleached colors may also underlie the dark horizons at various depths or may occur at the surface where there has been no modern flood-plain aggradation. Thus, in a vertical flood-plain sequence, the sediment in which concretions or bleached colors are present is premodern, but not all the overlying material is thereby proved to be

[14] In a few places hard concretions were found in modern sand, but their presence was apparently due to redeposition rather than formation in place.

modern. Therefore, these two criteria indicate the maximum possible depth but not the exact amount of modern sediment at the place of observation. Furthermore, their presence below the flood-plain surface does not necessarily indicate that modern flood-plain aggradation has occurred. The value of these two criteria lies chiefly (1) in supplementing the criterion of dark horizons and (2) in marking the maximum possible depth of modern sediment accumulation that may have occurred at places where the exact depth cannot be determined.

3. A pronounced color change, commonly from brownish to grayish, has usually occurred in the modern deposits where they are below the ground-water level, and in such places the contact between the brownish and grayish sediment marks the approximate level of the ground-water table, not the contact between the modern and premodern deposits.

Evidence has been presented (pp. 39–40) that in the Tobitubby and Hurricane Valleys a change from brownish to grayish color has taken place in the modern sediments subsequent to their deposition and that this change has taken place at and below the ground-water level. Similar changes in color have taken place in Piedmont valleys. For example, in Ferguson Creek Valley at United States Highway 221, near Spartanburg, S. C., the contact between gray and brown sediment occurred at the ground-water level, 12 inches below the ground surface. A buried old soil horizon, which at this place was a very dark gray silt, indicated that the thickness of modern sediment was 52 inches. In another boring about 2 miles above the junction of Ferguson Creek and the South Tyger River, the contact between brown and gray sediment was at 51 inches, the ground-water level was at 53 inches, and a fairly dark, slightly bluish, gray silt or silty clay old soil underlain by light steel gray (bleached) sand was found at 95 inches. These and other borings indicate that in the Ferguson Creek Valley, as in Tobitubby and Hurricane Valleys, some of the sediment changed color after it was deposited and that the contact between brownish and grayish sediment is at or close to the level of the ground-water table. In both the South Carolina and Mississippi areas the ground-water level, and consequently the brown-gray contact, is not a horizontal plane across the valleys but varies in elevation, partly because of variation in the texture of the deposits.

That there is such a relationship between soil drainage and soil color has been noted in many soil survey reports of the Bureau of Chemistry and Soils. Spaeth and Diebold (*71, p. 72*), on the basis of 14,000 measurements of the elevation of ground water at 50 stations in Schuyler County, N. Y., have concluded that for upland soils "the presence of a mottled layer is a reliable indicator that water tables occur at that depth for a considerable part of the year."

Investigation of this color change has thus developed two significant points, namely, (1) that in places where such a change has taken place the contact between the brownish and grayish sediment marks the approximate level of the ground-water table, not the contact between the modern and underlying older sediments, and (2) that changes in color subsequent to deposition of alluvial sediments are comparatively rapid.

When the criterion of dark horizons is used, the dark color of the old soil must be distinguished from the grayish color common in the modern deposits wherever they lie below the ground-water table. The grayish modern sediment may appear rather dark when compared with the overlying brownish sediment, and consequently, unless care is taken, the contact between them may be erroneously interpreted to be the contact between the modern and underlying older sediments. Such misinterpretation would have caused an error of perhaps 40 percent in measurement of the volume of modern fill in the Tobitubby and Hurricane Valleys.

It has been recognized for many years that differences in color between the several horizons of alluvial soil profiles have resulted from modification of the material subsequent to its deposition, but there has been little available evidence as to the length of time required for such changes to take place. The investigations in Tobitubby and Hurricane Valleys have furnished evidence of the rapidity with which such color changes take place and have shown that changes

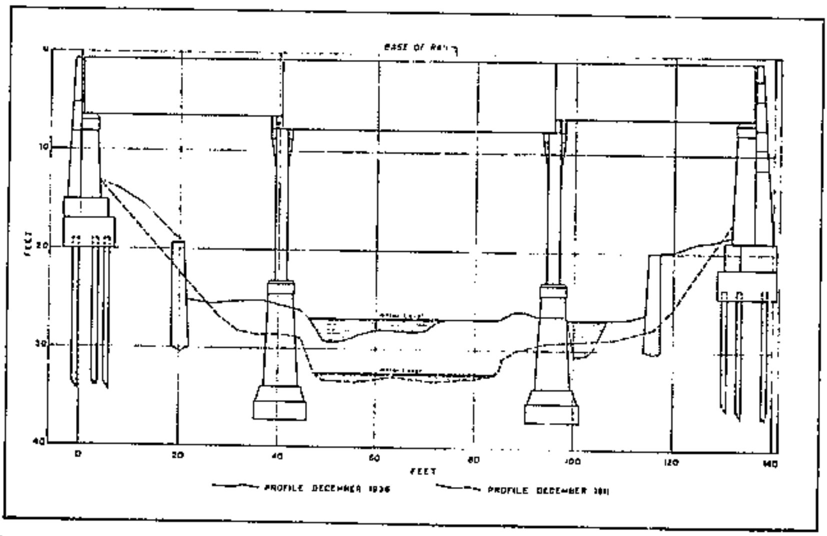


FIGURE 19.—Cross section beneath Illinois Central Railway bridge No. 565 56 across Hurricane Creek, showing extent of aggradation between 1911 and 1936. Two retaining walls at 20 and 116 feet, which cause some of the discrepancy between the profiles near the bridge ends, are piers of an earlier bridge but were not shown on the 1911 profile.

in color may be caused by rise of the ground-water level. Vertical differences in color have been observed in the modern deposits in a large proportion of the test borings made in both Tobitubby and Hurricane Valleys. Inasmuch as the modern deposits have all accumulated within 100 years, the time required for such changes must be less than that period. That the time required is probably considerably less is suggested by the fact that in some test borings more than half of the modern sediment was gray.

At the railroad bridge over Hurricane Creek the change in color has taken place in much less than 100 years. The level of the ground surface beneath this bridge was determined by an Illinois Central Railway survey in December 1911. In December 1936 the profile of the ground surface beneath the bridge was measured again, the same datum (base of rail) being used. These two profiles are shown in figure 19. Test borings beneath the bridge showed that the contact between brown and gray sediment occurs more than 1 foot above the 1911 ground surface. Thus at this place the color change must have occurred within 25 years and may have taken place in a much shorter time.

TYPES, CHARACTER, AND DISTRIBUTION OF MODERN VALLEY SEDIMENTS

4. It is practicable to divide valley deposits into six or more distinct genetic types, and into four or more distinct associations of types.

One of the principal results so far achieved in the valley studies is the establishment of a genetic system of classification of modern valley sediments. On the basis of field observations and theoretical consideration, six genetic types have been recognized as previously described in this bulletin (pp. 22–25). These six types are:

Colluvial deposits.
Vertical accretion deposits.
Lateral accretion deposits.
Flood-plain splay deposits.
Channel-fill deposits.
Channel lag deposits.

These six genetic types of deposits have been found to occur in four distinct associations, which have also been previously described (pp. 26–31) as follows:

Normal flood-plain, or valley-flat, association.
Alluvial-fan, or alluvial-cone, association.
Valley-plug association.
Delta association.

This classification may prove to be incomplete, but its basis is believed sound and hence suitable for such expansion as may become necessary with the development of further knowledge of valley sediments. No attempt has been made to include the various types of ephemeral stream-channel deposits, such as crossing bars, which usually do not become part of the more permanent complex of comparatively stable flood-plain sediments. Neither has any attempt been made to subdivide the colluvial deposits as the fluvial deposits have been subdivided. Deposits resulting from mass movements, other than those included in the colluvium, have not been listed because they have not been recognized as a distinct part of the sedimentary complex in any of the valleys that have been investigated.

The genetic classification differs in two principal respects from other methods of classification previously used. (1) It is not based on texture, although in any particular restricted area the various genetic types are commonly marked by rather persistent textural characteristics, which are of great assistance in the identification and tracing of the different genetic types. (2) The system here proposed is believed to be more practicable for detailed field classification of the modern valley sediments than that of Twenhofel (*77, pp. 806–811*), who identified the various types of deposits according to the environmental conditions at their places of accumulation. Thus, for example, all the genetic types here recognized would be part of the valley-flat environment of Twenhofel, but the flood-plain deposits of vertical accretion might include both deposits of flood-plain lakes and flood-plain swamps, as well as other flood-plain deposits of vertical accretion not accumulated in either swamps or lakes. In field practice, however, the flood-plain cover of relatively fine sediment, the deposit of vertical accretion, is found to be widely developed in many places as a distinct unit in the flood-plain complex, although its separation into lake, swamp, or other deposits does not usually appear to be possible on a practical scale.

5. Recognition of genetic types makes possible interpretation of horizontal and vertical variations in the distribution and texture of valley sediments.

It is widely accepted that the textural aspect of valley sediments is commonly one of irregular heterogeneity. It is possible, however, to distinguish some regularity of sequence in the valley sediments when they are interpreted in the light of the genetic system of classification. Relatively coarse sediment, representing lateral accretion or channel filling, characteristically occurs beneath the relatively fine flood-plain cover of vertical accretion, and apparent inversions of this vertical textural sequence are commonly due to colluvial or flood-plain splay deposits overlying deposits of vertical accretion.

With the recognition of an orderly sequence of flood-plain sediments, the interpretation of the history of flood-plain growth and development becomes possible. Thus it has been possible to distinguish the modern sediments accumulated during the period of culturally accelerated erosion and to interpret some of the conditions of their accumulation as recorded in their textures and structures. By this approach some progress has been made toward both a reliable evaluation of the effects of culturally accelerated soil erosion on valley sedimentation and development of a sound basis for prediction of future trends in the relation between soil erosion and valley sedimentation.

Of significance is the increased prominence of flood-plain splays among the modern, as contrasted with the premodern sediments. Such splays, by covering finer-grained deposits of vertical accretion, cause a very large part of the serious damage to valley lands by sanding. Modern channel-fill deposits have also been important in causing much damage to valley lands. They have not only increased flood heights and swamped valley lands by raising the ground-water table or obstructing drainage, but have also caused sand to be carried out upon the adjacent flood plain more frequently and in greater quantities. Both splay and channel-fill deposits are composed dominantly of relatively coarse bed-load sediment, and the prominence of these deposits in modern sediments indicates an increasing quantity and importance of bed-load sediment in the flood-plain accumulations.

The accelerated rate of flood-plain aggradation by accumulation of modern deposits of vertical accretion may be due to one or more of three possible causes: (1) More frequent or deeper overflows; (2) heavier loads of suspended sediment in the overflow floodwaters; or (3) decrease in the relative rate of lateral channel migration, by which deposits of vertical accretion ordinarily are periodically swept away and a balance maintained between accumulation of the deposits of vertical accretion and removal by the lateral swinging of the stream. Very probably all these factors have contributed, although the third probably has been of only local importance except where streams have been artificially prevented from cutting laterally. In many places, especially where stream banks have been cleared, lateral stream erosion obviously has been greatly accelerated during the period of modern influence.

It is of interest that no consistent marked difference in texture has been found between modern and older sediments where these are deposited in approximately the same location and are of the same genetic type. For example, modern deposits of vertical accretion have not been found to be consistently coarser than the older deposits of vertical accretion underlying them, although this might have been expected to result from the enormous increase in the rates of upland erosion. Where modern sediments are notably coarser than underlying older sediments, the modern deposit is usually of a different genetic type, as for example, a flood-plain sand splay overlying older silt deposits of vertical accretion.

6. Modern sedimentation tends to build up or aggrade channels and bordering natural levees, thereby obstructing surface and subsurface drainage of the adjacent bottom lands.

In many areas of accelerated stream and valley sedimentation, channel aggradation appears to have been more rapid than aggradation of the flood-plain surface. In most places this is due to an excessive contribution of sand, gravel, or boulders, which are carried largely as bed load and hence are not distributed upon the flood-plain surface except where splays are formed. More and coarser sediment has been carried from the channel as suspended load and dropped where the velocity is checked by shallowing of the water and by the resistance offered by vegetation along the banks. A greater part of the sediment has been deposited near the channels and thus the natural levees have been built up more rapidly than the rest of the flood plain.

The damages due to sedimentation have been greatly increased because of channel and natural-levee aggradation. Surface drainage of the bottom lands has been obstructed or impaired where the rapidly growing natural levees prevent both overflow waters and local run-off from getting into the stream channel. The interference with drainage is especially serious where the stream swings so close to the valley side that the natural levee is built up against the valley side or the colluvial slope in front of it, or where the natural levee connects with an alluvial fan built into the main valley by a tributary (fig. 6). Under such circumstances normal down-valley surface drainage of the flood plain is prevented, and a swamp or pond forms.

The aggradation of channels not only reduces their capacity for discharging floodwaters, thus increasing the frequency and severity of overbank floods, but it also further aggravates the drainage problem by causing the ground-water table, which is adjusted to the level of permanent flow in the channel, to rise and thus reduce the available capacity for subsurface drainage of the valley lands. In some places the stream beds have been built up above the level of parts of the adjacent flood-plain surface and permanent ponds have been formed where the water table has been brought to the surface. Much larger areas of bottom lands have been damaged seriously by swamping at places where the water table has been raised so much that adequate drainage for agriculture is impossible or impractical. Such rise in the ground-water level is especially serious in the middle Rio Grande Valley of central New Mexico, where it is complicated by the fact that the water carries a high percentage of alkaline salts in solution. These salts become concentrated in the soil by evaporation of the water, in some places to the extent that the land becomes valueless for crop production. To reclaim such land an artificial drainage system must be installed and the alkali leached out by repeated applications of irrigating water. In many locations, however, the difficulty of draining the water into the aggraded river channel makes reclamation impossible or impracticable.

7. Sediment tends to accumulate in alluvial fans at the confluence of tributaries with the master valleys, being deposited at some places in sufficient quantity to impede drainage and thus increase deposition both in the main valley and in the valley of the tributary.

Wherever there is a marked decrease in gradient of a stream, sediment tends to be deposited, and commonly, especially where a tributary enters the valley of its master stream, an alluvial fan, or alluvial cone, is formed. All the recognized genetic types of valley sediments may be present in such fan deposits, but in characteristically different association than that of the normal flood-plain association. Splays and channel deposits are especially prominent. The channel of the tributary shifts frequently, and consequently radiating ridges, marking abandoned filled channels and their natural levees, are common. These fan deposits correspond essentially to those of the piedmont environment as defined by Twenhofel (*77, p. 800*).

The growth of alluvial fans has been one of the important phases of harmful modern valley sedimentation. Fans built in valleys by debris from tributaries and from minor gullies and washes trenching the valley sides have caused considerable damage in many places. In the Tobitubby-Hurricane area such damage has been due chiefly to obstruction of the natural down-valley surface drainage of the flood plain. Thus formerly usable valley lands have become swampy and useless. An example of such drainage obstruction is shown in figure 5. The fan deposits are dominantly sandy, and where they have been spread upon cultivated bottom lands, the productivity of the land has usually been reduced.

In other areas accelerated modern fan growth has been the cause of much more severe damage to valley lands, as well as to highways and other improvements. On some highways in the Driftless Area of the upper Mississippi Valley, for example, a major part of the costs of maintenance is devoted to cleaning away sediment deposited on highways and in roadside ditches at places where they cross alluvial fans that are subject to excessive modern deposition.

Fans are areas of channel aggradation, and as they are built up there is a tendency for backfilling up the channel of the fan-building stream. Where such a stream is itself flowing through a valley of sufficient width to be valuable for agricultural use, damage may result not only from excessive deposition, often of coarse material, on the flood plain adjacent to the backfilled channel but also from the rise in the ground-water table and the more frequent overflows caused by the channel filling.

8. Sand or coarser sediment may accumulate locally in channels to such an extent as to plug them, and thus cause more rapid sediment deposition on the adjacent flood plain and, by backfilling of the channel, cause the locus of deposition to move progressively upstream. The plug deposits are, however, subject to dissection and further downstream transportation.

Stream channels may become locally constricted by any of several types of channel obstructions, and at such places rapid deposition commonly results. Such channel plugs have not yet been studied while in the early stages of growth, but the method of formation has been inferred from study of plugs in more advanced stages. The channel obstruction may be accidental, as by lodgment of fallen trees or other debris, or may be caused by delivery of sediment by a tributary faster than the master stream is able to remove it. Similar effects may result from inadequate channel capacity below sections of streams that have been artificially enlarged or straightened. After the channel becomes completely plugged, all water is turned out onto the flood plain. Overbank deposition is thus greatly accelerated, both by increased vertical accretion from the deeper and more frequent overflows and by formation of splays where part of the bed load is carried out of the main channel. The rest of the bed load, as well as part of the suspended load, is deposited as channel fill. As channel filling proceeds, more of the water goes overbank farther upstream and the velocity and carrying power of the stream is reduced. This results in further channel filling. The channel is thus progressively backfilled from the original plug, the final deposit at each point usually being an accumulation of driftwood. The photograph (pl. 8, *B*) of the head of the West Goose Creek plug shows the sand-filled channel in the foreground and the driftwood cover in the background, where there is no longer any channel capacity. The upstream migration of the head of the plug may be very rapid. During heavy rains of December 1936 and January 1937 the head of the East Goose Creek plug moved upstream about 1,600 feet and the head of the West Goose Creek plug moved 575 feet. Plate 9, *A* shows the point at which the last water left the West Goose channel in February 1937.

Valley-plug associations are somewhat similar to alluvial fans, but differ in three respects: (1) They often do not develop a fan form because of the lateral constriction imposed by the valley configuration. (2) Channel-fill and vertical accretion deposits are more important than in typical alluvial fans, and colluvial and lateral accretion deposits are less important. (3) They may form where there is no break in the stream gradient, whereas alluvial fans typically form where a stream enters a low area of gentler slope. The valley-plug association also is somewhat similar to the upstream part of the delta association but differs in the primary causes of origin and in being less stable and less permanent than most deltas.

Sanding and swamping of valley lands are common in plug areas, and the resulting damages may be severe. As the stream is forced from its aggrading channel, it tends to concentrate its flow through the back-swamp sections of the flood plain, there to cut new channels. Thus erosion of cleared and cultivable land is added to the damage by sedimentation, for the back-swamp areas, wherever they can be adequately drained, are commonly desirable parts of the valley bottom for agricultural use.

As the plugged channel is filled progressively upstream, the locus of most active overbank deposition also moves in that direction. In this way the area of damage may be extended for miles up a valley. The plug deposits are, however, subject to dissection after the overflow waters have collected and cut a new channel. Very commonly this channel is cut back headward by upstream migration of an overfall or rapid at its head. Thus, the plug deposit cannot be considered as a stable element in the valley accumulation. At the same time that the area of damage to valley lands is being extended progressively upstream the lower part of the plug may be undergoing dissection and contributing sediment that is carried on downstream and may cause further damage there. Such conditions have been observed both on Tobitubby Creek and in the Piedmont of South Carolina, on Ferguson Creek, Spartanburg County. McGee (*51, pp. 261–273*) has described similar local aggradation in very small valleys of the Driftless Area of northeastern Iowa.

9. Sediment from tributaries may be delivered to the main stream channels more rapidly than it can be transported downstream. In such places deltas may be built, which tend to reduce the flood-discharge capacity of the master channel and to promote increased erosion of the opposite bank by causing the migration of the channel across the flood plain away from the delta.

Where a tributary brings more sediment to the channel of its master stream than can be carried away promptly, deposits are formed that are in part deltaic. If the master stream is at high stage, the deposition of material is controlled by the water level of the master stream; if the master stream is at low stage, the change in stream gradient at the confluence may be the cause of deposition. Thus these deposits are genetically related to both deltas and alluvial fans and are typically composed of both kinds of deposits. In many places their differentiation as either deltas or alluvial fans is arbitrary.

Where such valley deposits are mainly deltaic they may be differentiated from alluvial fans, as a special type of the delta association, on the basis of (1) place of occurrence, (2) relation to the stream gradient, and (3) relative importance of the various types of deposits of which they are composed. These deposits are built largely within the channel of the master stream, whereas alluvial fans are built largely on a flood plain, terrace, or other surface outside the channel; hence typical fans are dry surfaces most of the time. Fans characteristically form at places where the velocity of the water is decreased by flattening of the stream gradient, whereas accumulation of these delta deposits, by contrast, is controlled by the water level of the master stream. The fluctuation of the water level in the main stream, however, allows alternate periods of dissection and aggradation of the delta. As contrasted with alluvial fans, the delta association typically shows a greater proportion of channel-fill deposits, an equal or smaller proportion of deposits of vertical and lateral accretion, and a smaller proportion of splays and colluvium.

This type of the delta association appears to be of little importance in the modern deposits in Tobitubby and Hurricane Valleys, except that such deltas or deltaic alluvial fans, formed as a result of contribution of large quantities of sand from tributaries, appear to have caused the initial plugging of stream channels at some places. Locally such accumulations in the stream channels have decreased the discharge capacity, and thus have increased the frequency of flooding. In other parts of the country, as in the upper Mississippi Valley, deltas or deltaic alluvial fans have been a factor both in decreasing the discharge capacity of the master stream and increasing bank erosion by directing the water against the opposite bank. Plate 9, *B* and *C* shows a delta built into the Upper Iowa River in Allamakee County, Iowa.

About 5 acres of valuable bottom land has been destroyed by lateral migration of the river away from this delta. As a general rule, however, deltas are not important as causes of valley damage.

10. Modern valley sediments tend to be concentrated largely in the upper or minor valleys, near the head of flood-plain development.

In Tobitubby and Hurricane Valleys, and generally throughout similar parts of northern Mississippi as found by brief reconnaissance, the modern valley sediments are concentrated in the minor, headwater parts of the drainage systems. This distribution appears to be due chiefly to (1) the coarse sandy texture of part of the sediment and (2) the short period during which the modern erosional debris has been in transportation. The modern period of accelerated erosion has been relatively short, and consequently there has not been time for many cycles of the normal process of intermittent transportation, deposition, and reentrainment of the sediments. This is particularly important because a large part of the modern erosional debris is sand or coarser material and does not ordinarily move far in suspension during any one period of transportation.

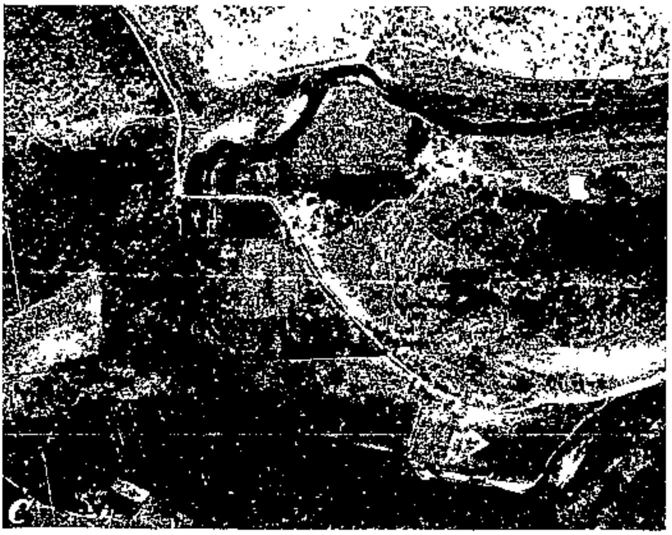
Notable accumulations of modern sediment are known, from reconnaissance, to occur in the headwater parts of many valleys in the South Carolina Piedmont, in parts of the Texas Coastal Plain, and in parts of western Wisconsin. Whether they represent equally large parts of the total quantity of modern erosional debris produced in their respective watersheds is not definitely known.

In other areas where stream gradients are steeper or the modern erosional debris is finer-grained the sediment may be deposited farther downstream. In the valleys tributary to the middle Rio Grande of central New Mexico, for example, the modern erosional debris contains much sand or coarser material, yet most of this has been carried down arroyos, which trench the tributary valleys, directly to the main valley of the Rio Grande. High gradients and the flumelike arroyo channels, themselves developed during the past century, have more than counterbalanced any tendency of the sediment to concentrate in the headwaters.

11. Modern valley sediments are as well sorted, within individual beds, as older valley deposits, but as a whole the modern sediments show more frequent and more irregular vertical and lateral changes in texture.

Samples from corresponding parts of the modern and premodern valley deposits in the Tobitubby and Hurricane Valleys are about equally well sorted texturally. The upper 4-inch layer of the present surface deposits are less well sorted than the premodern surface deposits, but this difference appears to be due largely to difference in genetic type and to more intimate interbedding of sand and silt in the modern deposits. Thus the modern streams appear to be just about as effective as the premodern streams in sorting sediment into various grain sizes. Analyses of samples from Ferguson Creek Valley, Spartanburg County, S. C., show a similar relationship.

In the aggregate, however, the modern deposits show more interbedding of sand and silt layers and greater lateral variations in texture than the premodern deposits. The lack of stratification in the premodern deposits may be due in part to diagenetic changes during the soil-forming period. At the present time, however, there is a marked difference in the degree of stratification in the modern and premodern deposits at many places (pl. 4, *B*). This may prove to be a criterion



A, Complete diversion of ordinary flow from the filled West Goose ditch, at the head of the plug 500 feet above range WG 6. *B*, Delta built into stream channel, forcing lateral migration of the stream and consequent destruction of valley land, Upper Iowa River, Allamakee County, Iowa. *C*, An aerial view of the delta in *B*. The delta, which is shown in the upper left-hand quadrant of the photograph, is forcing the river toward the center of the view.

by which the two age classes of sediment can be differentiated. The frequent formation of sand splays and the greatly accelerated growth of alluvial fans have contributed much to the lateral and vertical variability of the modern sediments. The increased variability of sedimentation rates and processes appears to reflect a marked disturbance of the normal stream and sedimentation regimen.

12. In a large proportion of the areas affected by accelerated sedimentation, the modern valley deposits are of such texture and composition as to be suitable for agricultural use when they are, or can be, adequately drained.

A significant result of the present studies is the conclusion that only a small part of the area affected by accelerated sedimentation appears to be permanently destroyed, or even excessively damaged, for agricultural use. Some areas of sanded flood plains are receiving additional deposits of silt at such rates that in the near future they will be converted again into loams suitable for cultivation. The rapid natural recovery of apparently severely damaged bottom land has been noted in many places. The two photographs of a part of Ferguson Creek Valley, Spartanburg County, S. C. (pl. 10), although taken at different seasons, indicate how extensive the natural recovery may be in as short a time as 15 months. But unless effective control and remedial measures are applied, future sedimentation may be expected to become more harmful because the sediment will be derived in greater amounts from infertile upland subsoils and parent geological materials.

Swamping caused by obstructed drainage or rise in the ground-water table has caused a large part of the sediment damage. The sediment deposited in these swamped areas appears to be similar in all respects to the sediment deposited in adjacent areas that are being successfully cultivated, which indicates that the damage is primarily due to the swamping rather than to inherent infertility of the sediment. In many places the obstructed drainage will be a serious and difficult problem to solve, but at least the situation is much less serious than it would be if the sediment were itself inherently unsuitable for crop production.

Even in areas where relatively infertile sand makes a large part of the modern sediment, as in Tobitubby and Hurricane Valleys, it is encouraging to find that this sand tends to be concentrated in certain parts of the valleys. In other large areas in these valleys the modern accumulation is dominantly silt that, judging by growth of native vegetation and some small cultivated plots, will make a high-quality alluvial soil. Not only does this indicate that a large part of the valleys might be profitably reclaimed if the flood and drainage problems can be solved, but it also suggests that much good might be accomplished by building up parts of the flood plain through artificially controlled deposition of this better type of sediment.

EROSIONAL PROCESSES AS FACTORS IN EXCESSIVE SEDIMENTATION

13. Gullying is more important than sheet erosion as a cause of harmful stream and valley sedimentation.

Although more spectacular and obvious, gullying is usually considered to be less serious than sheet erosion as judged by total resulting damage to uplands, partly because gullying is less widespread, is more commonly confined to land of low agricultural value, and is susceptible to more concentrated and therefore often simpler, cheaper, and more convenient control measures. As a source of harmful sediment, however, gullying is more serious than sheet erosion.

There are several reasons for this difference. (1) A smaller part of the erosional debris derived from the uplands by sheet erosion probably reaches the valleys, for much of this debris lodges on lower slopes. In contrast, the concentrated run-off from gullies usually delivers its sediment load directly to the valley bottoms, or directly to the stream channels. (2) Sheet erosion affects only the surficial material, which in many places is markedly finer in texture than the underlying materials exposed by gullying. Consequently, the effects of gullying and sheet erosion on downstream sedimentation are markedly different. In the Tobitubby-Hurricane area, for example, the sediment derived from the surficial loess is fine-grained and when delivered to the valleys is harmful only insofar as it contributes to the growth of natural levees and alluvial fans or to the filling of channels, requires replacement of fences and elevation of road grades and bridges, and raises flood heights above the terrace levels, thus subjecting more land to flooding. The fine-grained sediment makes a fertile soil where it is well drained, or can be drained. Gullying, on the other hand, is the main source of the sand that causes most of the damage in the valleys.

This principle may have wide application in the United States, especially where fine debris is produced by sheet erosion and coarse debris by gullying. It may be particularly applicable in the region of loessial soils in the central United States, in those large parts of the Coastal Plain underlain by unconsolidated sandy deposits, and in those parts of the southeastern Piedmont underlain by deeply weathered granitic rocks. It also applies where old sandy alluvial deposits now form high valley terraces that are subject to gully erosion, as is common in the glaciated and neighboring regions in the northern United States.

In drainage basins or regions where any of these conditions prevail, the particular nature and extent of stream and valley damages should be considered in planning an erosion-control program, for measures best adapted to reducing erosional damages on the uplands are not always the most effective in reducing the sediment damage in the valleys. The humus-rich, dominantly silty topsoils, which it is most desirable to protect from erosion on the uplands, may not be the major source of harmful stream and valley sediment. But after the topsoils are removed and sheet erosion begins to deliver mainly subsoil materials which may be coarser or less fertile, a larger share of the sediment damage may be caused by sheet erosion. Adequate protection of valley resources may also call for special attention to gullied areas of such low agricultural value that control measures would not be justified solely for prevention of erosional damage to the uplands.

14. Stream-bank erosion is an important factor in stream and valley sedimentation, for the alluvial land that is eroded usually is replaced by less productive deposits and the debris produced by the erosion may cause damage where it is deposited farther downstream.

Although stream-bank erosion is not now a serious form of damage in Tobitubby and Hurricane Valleys, it does occur on a sufficient scale to illustrate a principle of wide application. Lateral cutting is always most active on the outside of a stream bend, and thus causes the channel to migrate away and downstream from the inside bank

Natural recovery of bottom land after damage by accelerated sedimentation, illustrated by two photographs of same locality in Ferguson Creek Valley, Spartanburg County, S. C., (*A*) March 17, 1937, and (*B*) June 20, 1938. The camera was slightly closer to group of three small trees in the center of *A* than to same trees in left center of *B*.

A, Bank erosion in a small valley tributary to the Whitewater River, Winona County, Minn., has removed a large part of the premodern alluvial deposits. The new land built on the inside of the bends is sandy and boulder-strewn and is more frequently flooded than the land being removed. *B*, Trenching of sandy Pleistocene valley fill in east branch of Dumfries Valley, Wabasha County, Minn.

of the bend. As this occurs, a bar is built out from the inside bank. The process involves progressive destruction of the flood plain on one side of the stream and building of a new segment of flood plain on the other. At first the constructional or building process is chiefly by lateral accretion, the bar deposits of lateral accretion being composed dominantly of coarse debris derived from the bed load. After the bar is built up sufficiently to check the velocity of overflow water by shallowing, or by the retarding effect of vegetation established when the bar is exposed, finer deposits, derived largely from suspended load, accumulate by vertical accretion.

In time, if the stream continues to flow at the same level and other conditions remain essentially unchanged, the new flood-plain surface may be built up to the level of the older surface that was destroyed. If this happens, the area of land destroyed may be equaled by the area of new alluvial land built on the opposite side of the stream, and no net loss of land occurs. Individual landowners may suffer much inconvenience and extensive losses, however, and highways, railroads, and other improved properties may be severely damaged as the stream migrates across its flood plain. Commonly, however, there is a time lag between the erosion of the old flood plain and the development of the new one, and, as a result, the area of land available for cultivation is reduced.

Under modern conditions, and especially in areas of severe soil erosion and rapid sedimentation, the new land built in connection with the bank-erosion process is commonly inferior in texture and fertility to the older alluvial land being destroyed. In addition to change in character of the alluvium, the new flood plain may be built at a lower level, and hence may be subject to more frequent and more violent overflows than the older, higher flood plain that is undergoing destruction. This type of damage has been observed widely in the upper Mississippi Valley, where in some headwater tributaries half of the former alluvial land has been removed for distances of a mile or more. This land has been replaced by a valueless, bouldery, or sandy torrent plain, or lower flood plain, which is overflowed after almost every storm. Such a low, sandy torrent plain on a tributary of the Whitewater River in Winona County, Minn., is shown in plate 11, *A*.

Of major significance is the fact that removal of the natural vegetation from the stream banks greatly facilitates bank erosion. This is not by any means a new observation, for an established practice in drainage ditching has been to dig ditches narrower than desired and rely on bank erosion, and perhaps channel deepening, to attain the necessary size and discharge capacity (*61, p. 1*). To promote the desired widening, clearing of the banks is common practice.

The same principle has also been applied in the clearing or brushing-out of natural stream banks for flood control, the decrease in frictional resistance to flow produced by clearing the banks commonly resulting in channel enlargement by lateral bank cutting (*66, p. 224*). In this regard, however, it should be noted that many progressive landowners make a practice of cutting large trees that have begun to be undercut by lateral bank erosion in order to minimize the rate and amount of damage. Cutting the trees removes the factor of tree weight, which tends to cause the undercut bank to cave, slump, or slide into the stream, and reduces the area of surface and volume of material that would be removed from the bank if the tree toppled into the stream and tore out its roots and a large mass of earth. After the tree is cut, the root system continues to provide bank protection for several years, and a new growth can be established before the old roots have rotted away. Such selective bank clearing may prove to be an effective measure for combating bank erosion.

In the northern part of the United States the action of ice is an important factor in bank erosion. Both the abrasive and battering effect of ice carried by spring freshets and the tearing out of vegetation and earth when the ice is lifted and floated away by the rising stream in the spring are involved in such bank erosion.

The texture of the flood-plain alluvium is also an important factor in stream-bank erosion. Where the streams are flowing between banks composed dominantly of silt or clay, lateral cutting is minimized by the resistance of such material to abrasion and slumping. Where the flood plain is dominantly sandy or where a sandy layer of considerable thickness is exposed to the action of the water, bank cutting is greatly facilitated, for sandy materials are less resistant to such erosion. In sandy alluvium, especially, channels are apt to increase in width, as the result of erosion of the outer bank of a bend at a more rapid rate than the inner bank is built forward, and produce what Melton (*54, p. 599*) has aptly termed "meanders of advance cut."

15. Valley trenching is an important factor in accelerated stream and valley sedimentation, both as a source of sediment and because the resulting flumelike channels expedite the delivery of sediment to the major streams and lower valleys.

The trenching of headwater valleys has occurred widely throughout the southwestern, southern, and midwestern parts of the United States, and perhaps elsewhere, during the period of culturally accelerated erosion. In the Southwest this phenomenon has been recognized as the "arroyo cycle" and, in at least some places, the present trenches have developed within the last 60 years (*13*). In the Southern and Midwestern States valley trenching has not been generally recognized as a distinct physiographic process or condition, being commonly included as part of the gully problem.

Valley trenching, of course, produces sediment that contributes to sedimentation farther downstream. In many, and probably most, places this effect is more important than would be indicated solely by the percentage of the erosional debris derived from trenching, because a large part of the older valley fill, which is removed in the process of trenching, may be sand or gravel. This is especially true in parts of the Northern States where the material of the older valley fill dates from the widespread aggradation of valleys during and following the Pleistocene glaciation. Many of the smaller valleys in these areas were graded to the level of what are now high terraces along the master valleys. Many such tributary valleys are now being deeply trenched as the modern stream, in the process of readjusting itself to the present lower level of the master stream, cuts into the unstable sandy alluvium. Plate 11, *B* is from a photograph of a minor valley tributary to the Zumbro River in southeastern Minnesota, which is now being trenched to a depth of about 25 feet. The sand derived from this trenching is causing considerable damage where it is deposited on a fan built upon the flood plain of the river.

The effect of valley trenching on excessive sedimentation is not confined to the production of harmful types of sediment. In Tobitubby

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and Hurricane Valleys, and commonly elsewhere as indicated by many observations, an important result of the valley trenching has been the development of flumelike channels through which sand or gravel, derived from upland gullies as well as from headward extension and lateral widening of the trenches, is carried down to the wider and more valuable parts of the valleys and to the larger streams. The trenches also facilitate the downstream transportation of fine-grained sediment and thus may increase damage to valley resources, such as reservoirs, where the bulk rather than the character of the sediment determines the extent of damage.

In their action as flumes the valley trenches serve to upset one of the natural physiographic balances that play such a large role in fashioning the surface of the earth into forms suitable for agriculture. The headwater parts of most valleys, where the streams are intermittent or ephemeral and lack extensive replenishment between periods of surface run-off, are areas of alternate erosion and sedimentation. The longitudinal profiles of such headwater valleys are relatively steep, yet much erosional debris collects because of the intermittent character of transportation and because of colluvial deposition caused by lessening of the slope at the base of the valley sides. These small headwater alluvial areas are less subject to prolonged flood overflows than the valley bottoms farther downstream, where gradients are lower and where subdrainage is commonly slower because the texture of the alluvium is finer. The headwater valleys are therefore almost always desirable agricultural lands and are extensively used for crop production or for pasture if too narrow or too frequently overflowed for safe cultivation.

When the headwater valleys are trenched, however, the locus of sedimentation shifts down valley, and coarse sediment may be delivered from the mouths of the valley trenches to stream channels that have a lower gradient and are not able to transport large quantities of such coarse debris; hence the sediment tends to accumulate in the channel. As the channel is partly or wholly choked, the main stream is forced overbank and distributes on the adjacent flood plain the coarse sediment that is normally moved chiefly as bed load and would otherwise not be so widely distributed on the flood-plain surface. The resulting damages may be much greater than those directly and obviously due to the erosion of the valley trench itself.

One of the most serious known instances of such valley trenching, which serves to illustrate the dual nature of the resulting damages, is that of the Rio Puerco, a tributary of the Rio Grande in central New Mexico. Bryan [15] has reported convincing evidence that the present Rio Puerco has trenched its valley for a distance of approximately 140 miles since about 1885. He has estimated that 40 percent of the heavy annual sediment loads delivered to the Elephant Butte Reservoir are being derived from the extension and widening of this arroyo system. In addition, the trench now serves as a great flume to carry sediment directly to the main valley. At and below the mouth of the Rio Puerco trench, the Rio Grande itself is aggrading at an alarmingly rapid rate, undoubtedly, in large part, because of the sediment from the Rio Puerco.

[15] BRYAN, KIRK, and POST, GEORGE M. EROSION AND CONTROL OF SILT ON THE RIO PUERCO, NEW MEXICO. Report to the chief engineer, Middle Rio Grande Conservancy District. October 1927. [Unpublished.]

VALLEY SEDIMENTATION AS A MEASURE OF UPLAND EROSION

16. Part of the debris produced by soil erosion accumulates in valley deposits, and thus the volume of these modern valley sediments provides a minimum measure of erosion in the drainage basin during the contemporary period.

The importance of gully and sheet erosion in damaging the soils on sloping lands is well established and has become a matter of increasingly wide concern during the past few years. That all the soil material washed from upland slopes by these processes must be deposited at some lower elevation is equally certain, although less commonly appreciated. Some of the debris may move only a short distance down the slope before it is redeposited; some may accumulate near the base of the slopes as colluvial deposits or, if there has been some concentration of the run-off, as alluvial fans; the rest will be carried into the stream systems. Once it is in the streams, the material derived directly from upland slopes, augmented by debris from valley trenches and eroding stream banks, may be deposited in one of the several types of valley deposits, may come to rest in the quiet waters of a reservoir or lake, or may, either at once or after a number of cycles of transportation, deposition, erosion, and further transportation, be carried to the sea. Except for the trapping of sediment in man-made reservoirs, this disposal of eroded material is similar to that which has taken place throughout geologic time.

Since some debris is deposited on slopes, some in lakes or reservoirs, and some is carried to the sea, the valley deposits contain only a part of the debris that has been eroded from the uplands. The volume of the modern deposits therefore is a minimum measure of the combined normal and accelerated erosion that has taken place in the tributary drainage area during the contemporary period. A greater part of the erosional debris will be deposited in some valleys than in others, and hence the disparity between actual and measured erosional output will vary in different drainage areas.

17. Rates of valley deposition, together with the measurements of suspended load of streams, indicate rates of erosion of the same order of magnitude as those computed from erosion surveys, erosion-plot measurements, and reservoir-sedimentation surveys.

Erosional debris is in part deposited above the alluvial valley and in part carried on downstream; therefore, the volume of valley sediments represents only a minimum measure of the amount of erosion in the tributary drainage basins. It is possible, however, to supplement measurement of the volume of modern valley sediments by suspended-load sampling of the water discharged from the area of survey and thus to secure a more accurate, although still minimum, measure of the average rate of erosion in the drainage basin.

In areas in which the sediment is predominantly fine-grained this method may be fairly accurate, but in areas where a large proportion of the erosional debris is coarse-textured and is carried mainly as bed load the resulting estimates may be much too low, because satisfactory methods of determining the amount of material carried from the areas as bed load have not yet been developed. The measurement of the amount of debris deposited above the alluvial valley is also difficult and costly. Not only are the colluvial deposits usually distributed widely throughout the upland portion of a drainage area, the cumulative linear extent being many miles, but they may be difficult to distinguish from the premodern deposits. This difficulty is especially troublesome where the colluvium lies on slopes from which the topsoil had been removed by accelerated erosion before the colluvial accumulation, and where the colluvium is similar in physical character to the underlying material.

From measured and estimated volumes of valley deposits, plus measurements of suspended load transported past Greenwood, Miss., average depths of upland surface erosion of 5.5, 5.1, and 5.4 inches, and average rates of erosion of 1 inch in 18.2, 19.6, and 18.5 years in the Tobitubby, Hurricane, and the combined drainage areas, respectively, have been computed (table 7). Comparison of these average depths and rates of erosion with the results of similar computations based on (1) erosion surveys, (2) erosion-plot measurements, and (3) rates of sedimentation in reservoirs, shows that all four methods yield results of the same order of magnitude.

(1) The amount of erosion during the period of agricultural occupation of the land has been mapped in some localities as a part of the conservation-survey program of the Soil Conservation Service. Mapping is the only direct method of complete measurement of upland surface erosion, but in many places other methods of obtaining reasonably accurate estimates at less expense and more quickly may be adequate for many purposes. Sedimentation data are often used as a measurement of erosion, for such data are already available for some drainage basins in which it is unlikely that adequate erosion surveys will be made for many years.

The average depth of erosion in drainage areas for which conservation survey data are available may be calculated by multiplying (1) the number of acres from which designated percentages (less than 25 percent, 25 to 75 percent, etc.) of the topsoil have been removed by (2) the average depth of soil represented by such removal, and (3) dividing this product by the number of acres in the watershed. The average rate of erosion, in terms of years to erode 1 inch, may be calculated by dividing (4) the period of land use by (5) the average depth of soil eroded. The results, although based on preliminary and incomplete data, are thought to be of the correct order of magnitude, and probably conservative.

Such data are available for the Scantic drainage basin in Connecticut, the Reedy Fork drainage basin in North Carolina, the Lake Crook drainage basin in Texas, and the West Tarkio drainage basin in Iowa. Table 8 presents the preliminary basic data and the calculated average depths and rates of erosion. The average rate of erosion in the Tobitubby-Hurricane area, exclusive of first bottoms, is 1 inch in 18.5 years; if the bottom land is included, the average rate is 1 inch in 21 years. The latter rate is comparable with the rates derived for entire drainage areas from erosion surveys. It is about 50 percent lower than in the Iowa area, nearly twice as high as in the North Carolina area, 50 percent higher than in the Texas area, and eight times as high as in the Connecticut area. Because of the difference in the length of the period of agricultural use, however, the average depth of erosion in the North Carolina area is about the same as that in the Tobitubby-Hurricane area; in Texas and Connecticut, respectively, it is roughly 60 and 40 percent as much, and in Iowa it is about one-third higher. Considering that the depths and rates of erosion computed for the Tobitubby and Hurricane areas are minimum figures, whereas the depths and rates measured by erosion surveys should approximate the true values, the results of the two types of surveys serve to support each other, and thus to indicate that the figures for rates of erosion as determined by erosion surveys are of the right order of magnitude, although they are much higher than most earlier estimates based on geological concepts and data.

TABLE 8.—*Erosion rates computed from results of conservation surveys* [1]

Drainage basin	Symbol of erosion class [2]	Area	Estimated average soil loss	Soil lost	Average surface reduction	Approximate period of agricultural use	Average annual surface reduction	Time required for erosion of 1 inch of soil
		Acres	*Inches*	*Acre-inches*	*Inches*	*Years*	*Inch*	*Years*
Scantic River, Conn.	1	5,654.9	0	0	2.02	297	0.00680	147
	+	2,377.7	0	0				
	2, 27	46,300.1	2	92,600.2				
	37, 38	14,142.0	3	42,426.0				
	33, 337, 338	557.5	5	2,787.5				
	4, 46, 48	17.1	8	136.8				
	5	20.0	30	600.0				
	9	36.8	36	1,324.8				
	Wind	93.8		0				
Total		69,199.9		139,875.3				
Reedy Fork, N. C.	1	1,946	0	0	5.69	200	.0284	35
	+	3,914	0	0				
	2, 27, 28	7,048	2	14,096.0				
	3, 37, 38	28,845	6	173,070.0				
	4, 47, 48	4,428	10	44,280.0				
	5, 57, 58	274	36	9,864.0				
	9	539	48–60	25,872.0				
Total		46,994.0		267,182.0				
Lake Creek, Tex.	1	5,054.4	0	0	3.37	112	.0301	33
	+	3,561.6	0	0				
	2	14,578.4	2	29,156.8				
	27, 28, 3, 37	8,744.0	6	52,464.0				
	38, 4, 47	1,402.8	10	14,028.0				
	48, 557, 58, 9	508.0	36	18,288.0				
Total		33,849.2		113,936.8				
West Tarkio, Iowa	1	31,454	0	0	7.26	87	.08345	12
	2	5,108	3	15,324.0				
	3	10,032	6	60,192.0				
	33	25,710	10	257,100.0				
	4	28,561	14	399,854.0				
	5	4	30	120.0				
Total		100,869.0		732,590.0				

[1] Data from the files of Physical Surveys Division, Soil Conservation Service.

[2] Figures indicate type and degree of erosion as follows: 1. No apparent accelerated erosion. 2. Less than 25 percent of topsoil removed by sheet erosion. 3. 25 to 75 percent of topsoil removed by sheet erosion; when subdivided 3 indicates 25- to 50-percent removal, 33 indicates 50- to 75-percent removal. 4. Over 75 percent or all of A horizon, or the upper part of B horizon, removed by sheet erosion. 5. Sheet erosion of lower B and C horizon. 6. Landslides or slips. 7. Occasional gullies. 8. Frequent gullies. 9. Very frequent or distinctively large gullies. +. Recent alluvial and colluvial deposition. Combinations of sheet erosion and gullying or slips are indicated by combining the respective symbols; thus the symbol 38 indicates 25 to 75 percent of topsoil removed by sheet erosion plus frequent gullies.

(2) Erosion-plot studies have been carried on at more than 15 localities in the United States, on a variety of soil types under various conditions of climate, slope, plant cover, and land use. The plots used in these studies are commonly about one-hundredth of an acre in area; are rectangular in shape, with the long dimension paralleling

the direction of maximum slope; and are enclosed on three sides by metal strips, which exclude run-off from adjacent areas. Soil and water losses are measured by means of collection tanks at the lower end of the plots.

At most of the sites the period of operation has been too short to eliminate entirely the effects of short-term variations in weather. Studies have been continued for a period of 14 years at Columbia, Mo., however, and practically the same annual losses were recorded for the first 6 years as for the entire duration of the investigation (*55, p. 17*).

At 10 soil and water conservation experiment stations operated by the Soil Conservation Service, the rates of erosion for fallow and clean cultivated plots ranged from 1 inch in 1½ years to 1 inch in 12 years (*48, 59*) and averaged 1 inch in about 5 years. By contrast, the most rapid rate of erosion from grass or forest plots was 1 inch in 83 years and the average from grass and forest plots, where run-off had occurred, 1 inch in about 16,000 years. At the Southern Forest Experiment Station, at Holly Springs, Miss., erosion on plots of smaller size (12 feet long) varied from 1 inch in about 2 years to 1 inch in 4⅔ years from clean-cultivated and barren abandoned land, and erosion from forest and pasture land ranged from 1 inch in 320 years to 1 inch in 6,700 years (*53*). By application of the Holly Springs data it has been estimated that the average sheet erosion from the Tobitubby-Hurricane area during the period of culturally accelerated soil erosion has been between 0.4 and 10.2 inches (p. 62). It has been estimated that an average of 3.2 inches must have been removed from the uplands by sheet erosion in order to account for the volume of sediment that has accumulated in the valleys (p. 62). The fact that the average surface erosion as calculated from sedimentation data falls within the range indicated by application of plot-study data to the entire drainage basins tends to support the validity of both methods.

(3) The rates of sedimentation in reservoirs also may be used as a measure of the average rate of erosion in the tributary drainage basins. The rates so derived are based only on the fraction of the total erosional debris deposited in the reservoir basins, and consequently are minimum figures. In this respect, reservoir and valley sedimentation results are similar. Where the volume of both reservoir and valley deposits can be measured, a closer approach to the actual erosion rates may be secured.

Of 96 reservoirs of various sizes in the United States on which sedimentation surveys have been made by the Sedimentation Division of the Soil Conservation Service, by the Reclamation Service, or by other Government and private agencies, 21 show rates of erosion in their tributary drainage areas of 1 inch in less than 50 years; 13, 1 inch in 50 to 100 years; 21, 1 inch in 100 to 200 years; 8, 1 inch in 200 to 300 years; and 33, 1 inch in more than 300 years. These rates were calculated by using an average porosity of 63.6 percent (weight about 60 pounds per cubic foot) for the reservoir sediment and 48.5 percent (about 85 pounds per cubic foot) for the eroded soils. Table 9 shows the location, drainage area, age, and rate of sedimentation in those reservoirs whose tributary drainage areas are being eroded at a rate of 1 inch in less than 50 years. Only in the small drainage basins of

Rogers Municipal, Greenbelt, and Live Oak Reservoirs has the rate of erosion been greater than in the Tobitubby-Hurricane area, even though most of the reservoir drainage areas are smaller than that of Hurricane Creek and might for this reason be expected to show higher erosion rates.

TABLE 9.—*Reservoir drainage basins in which sedimentation data indicate erosion rates of more than 1 inch per 50 years*

Reservoir	River or creek	Locality	Drainage area [1]	Age	Accumulation per year per acre of drainage area	Time required for erosion of 1 inch of soil from drainage area
			Square miles	*Years*	*Cubic feet*	*Years*
Greenbelt Lake	Unnamed creek	Greenbelt, Md	0.65	1.6	[2] 624.4	8
Lake Concord	Coldwater Creek	Kannapolis, N. C	3.6	10.17	[2] 144.8	36
Ocoee No. 1	Ocoee River	Parksville, Tenn	600	18.75	[3] 125.9	41
Lake Bracken	Brush Creek	Galesburg, Ill	8.6	12.7	[2] 137.5	37
West Frankfort	Tilley Creek	West Frankfort, Ill	3.5	10	[2] 182.5	28
Pine Lake	Pine Creek	Eldora, Iowa	15.34	8	[4] 103.0	50
Lake Bennett	East Fork Creek	Conway, Ark	4.1	.37	[2] 179.5	29
Mission Lake	Mission Creek	Horton, Kans	11.1	13	[2] 135.9	[5] 30
Lake Olathe	Cedar Creek	Olathe, Kans	6.1	4.9	[2] 125.0	[6] 40
Ardmore Club Lake	Unnamed creek	Ardmore, Okla	3.9	15.5	[2] 171.7	30
Boomer Lake	Boomer Creek	Stillwater, Okla	9.9	10.25	[2] 130.9	39
Guthrie	Cottonwood Creek	Guthrie, Okla	12.9	14.5	[2] 164.7	31
Lake Gibbons	Pine Creek	Paris, Tex	1.90	36	[2] 117.2	44
Rogers Municipal	Little River	Rogers, Tex	.51	12	[2] 413.8	12
White Rock Lake	White Rock Creek	Dallas, Tex	112	25	[2] 108.8	47
Baker	Sandstone Creek	Baker, Mont	5	20.1	[2] 118.6	43
Lake Chabot	San Leandro Creek	Oakland, Calif	42	48	[3] 118.2	43
Live Oak	Live Oak Creek	Los Angeles County, Calif.	2.32	2.2	[2] 381.0	13
Morena	Cottonwood Creek	San Diego County, Calif.	109.4	25.67	[2] 173.9	30
Santa Anita	Big Santa Anita Creek.	Los Angeles County, Calif.	10.8	10.2	[3] 222.3	23
Upper Crystal Springs.	Laguna Creek	San Francisco, Calif	7.8	57.83	[2] 147.8	35

[1] Area of reservoir basin excluded except for Ocoee No. 1, Pine Lake, and Lake Chabot.
[2] (*22*.)
[3] (*68, p. 210*.)
[4] MARSTON, G. A. SEDIMENTATION IN SOUTHERN IOWA RESERVOIRS. Thesis, University of Iowa. 1933. [Unpublished.]
[5] Based on determinations of volume-weight of reservoir sediment and upland soils. See the following: JONES, VICTOR H. ADVANCE REPORT ON THE SEDIMENTATION SURVEY OF MISSION LAKE, HORTON, KANS. APRIL 15 TO MAY 6, 1937. U. S. Soil Conserv. Serv. SS-22, 15 pp., illus. 1938. [Mimeographed.]
[6] Based on determinations of volume-weight of reservoir sediment and upland soils. See the following: JONES, VICTOR H. ADVANCE REPORT ON THE SEDIMENTATION SURVEY OF LAKE OLATHE, OLATHE, KANS., MAY 26 TO JUNE 4, 1937. U. S. Soil Conserv. Serv. SS-24, 14 pp., illus. 1938. [Mimeographed.]

18. Suspended-load sampling alone, especially on major streams, fails not only to measure the total erosion in a drainage basin but also to afford a reliable basis for the comparison of the relative severity of erosion in two drainage basins that are widely different geologically.

It has been emphasized, in the discussion of the two preceding principles and in other parts of this bulletin, that part of the debris produced by erosion is deposited as colluvium, alluvium, or lacustrine or reservoir sediment. Obviously, none of the material accumulated in such semipermanent deposits above a suspended-load measuring station will be measured by sampling the river water. According to the computations reported in this bulletin (pp. 60–61), for example, only 6 percent of the erosional debris from the uplands of the Tobitubby-Hurricane area has been carried past Greenwood, Miss., the only place below this area at which suspended load has been systematically measured. Therefore, estimates of the total erosion in the drainage areas tributary to measuring stations, based on suspended-load measurements alone, will be below the true values in direct ratio to the proportion of erosional debris deposited upstream or carried past the measuring point as bed load.

The present studies indicate that in some valleys the deposits tend to be concentrated toward the headwaters of the streams. In general, it is also true that the rate of sedimentation per unit of drainage area is higher in reservoirs near the headwaters than in those farther downstream. Thus, as the distance of the sampling stations from the headwaters increases, the suspended-load sampling may be expected to measure a smaller proportion of the total erosional debris being produced in the drainage basin.

The character of the erosional debris is of major importance in determining the effectiveness of suspended-load sampling in measuring the total or gross erosion in a drainage area. If the material is relatively coarse in texture, a larger part of the total debris ordinarily will be deposited upstream than if it is fine-grained and can easily be carried in suspension. If the sediment carried by a stream is coarse the proportion of material carried past the measuring station as bed load will also be greater. Thus in two drainage areas that are underlain by different types of bedrock but have the same (total) erosion rates, suspended-load measurements may give an entirely erroneous impression of the relative severity of erosion.

The shortcomings of suspended-load sampling as a means of comparing the relative severity of erosion in two drainage areas that are widely different geologically do not invalidate in any way the use of the method, with proper caution, for such purposes as estimating the probable rate of sedimentation in reservoirs to be located near the sampling station or for comparing rates of sediment output from drainage basins producing similar kinds of erosional debris.

DAMAGES RESULTING FROM CULTURALLY ACCELERATED VALLEY SEDIMENTATION

19. Accelerated stream and valley sedimentation has already caused serious damage in various parts of the United States by impairment or destruction of the agricultural productivity of valuable valley lands.

The agricultural value of a large part of the bottom lands in Tobitubby and Hurricane Valleys has been seriously impaired by sanding and swamping caused by excessive sedimentation during the modern period of accelerated soil erosion. A large part of these bottom lands was formerly valuable for agriculture, and more might be reclaimed for agricultural use if it were not for the conditions now prevailing as a result of the excessive sediment accumulation. The value of these bottom lands increases as the adjacent uplands continue to be eroded and thus become less adequate to maintain a prosperous agriculture. As erosion continues and increased use of the valleys is prevented by sediment damage, there is a constant pressure toward greater cultivation of sloping lands that are subject to excessive erosion and therefore, in the interests of agricultural conservation, should not be plowed.

Similar valley damage is known, from reconnaissance, to occur generally throughout the Central Hills section of the Coastal Plain of northern Mississippi and is reported to be common also in western Tennessee. In the South Carolina Piedmont much of the bottom land that was once cultivated has already been abandoned, owing to a combination of sediment and flood damage. In the rugged Driftless Area of the upper Mississippi Valley thousands of acres of bottomland pastures and cultivated fields have been severely damaged by sand and boulders deposited during the period of cultivation. Sanding (pl. 12, *A*) was locally severe as a result of the Ohio River floods of 1937. Sedimentation in the middle Rio Grande Valley of New Mexico is also known to have caused or aggravated swamping and flood damages to such an extent that hundreds of acres of formerly irrigated valley lands have been abandoned. Less fully verified reports testify to similar damage in other widely scattered parts of the country.

In most, if not all, of these areas of sediment damage to valley agricultural lands, the lands are valuable not only because of their own productive capacity and sale value to the owners, but also because they offer the only available area for possible expansion of cultivation of level, relatively nonerodible areas as an alternative to continued or expanded use of steeper sloping lands that are subject to serious soil erosion. In the Southwest, where irrigation is necessary for crop production, the valley lands are commonly the only areas available for cultivation, and consequently there is no possibility of replacing those lands that cannot be economically utilized because of sediment damage.

The agricultural use of bottom lands not only has the advantage of requiring less use of artificial plant-food fertilizers, but also offers the most practicable method of obtaining some return from the large volumes of plant-food material annually washed from upland fields and started on its way to the sea. With respect to a permanent national well-being, the valley lands thus assume an importance far in excess of what would be indicated solely by the ratio of such valley lands to the total land area of the United States. Their greater utilization constitutes, in effect, an important means of conserving the plant-food constituents that are removed by erosion from upland soils.

20. Sand or coarser sediment causes most of the sediment damage to valley agricultural land.

A measurable thickness of modern sediment is already known to have accumulated on a large percentage of the valley flood plains of the Southern and Midwestern States and also in some valleys in other parts of the United States. A large number of the areas of this modern flood-plain aggradation, perhaps the largest number, show sediment dominantly of silt size at the surface. In such silt-covered areas little sediment damage is known to occur except where flood damage or drainage obstruction results from stream-channel filling or flood-plain aggradation. But where the flood-plain deposit is dominantly sand or coarser sediment, the damage is almost always severe. The channel deposition that contributes to flooding or swamping of areas of silt deposition on the flood plains is also chiefly the result of accumulation of sand or coarser material. Thus most of the sediment damage can be charged to accumulation of sand or gravel or, in extreme cases, even boulders, although the individual boulder

A, Several feet of sand deposited on a flood-plain field in Daviess County, Ky., by the Ohio Valley flood of 1937. *B*, Boulders accumulated in channel of small stream 3 miles southeast of Elba, Winona County, Minn. Black soil horizon representing premodern flood-plain surface averages about 1 foot below present channel bed. Notable channel aggradation is indicated.

accumulations are seldom of large areal extent. Plate 12, *B* shows such a local boulder accumulation in southeastern Minnesota.

As accelerated erosion progresses on upland soils, removing more and more topsoil and exposing subsoils to erosion, greater quantities of subsoil material will be contributed to the valley deposits. It is reasonable to expect that this will reduce the productivity of valley fields, because of the relative infertility of a covering of sediment derived largely from upland subsoils. Such observations as have been made, however, suggest that the present damages may be due chiefly to the effects of overflow waters or obstructed drainage rather than to a change in the inherent fertility of the sediment. More detailed studies, including laboratory and experimental field tests, will be required to evaluate the factor of inherent fertility of the modern deposits, and such investigations may support the assignment of greater importance to this factor. At present, however, no conclusive evidence is at hand which indicates that modern flood-plain silt deposits, where adequately drained and reasonably protected from excessive flooding, are as a rule less productive than the older flood-plain silts.

Since the damages resulting from accelerated sedimentation are caused chiefly by sand or coarser sediment, those erosional processes responsible for the production of the larger parts of such coarse sediment are especially important as causes of valley damage. In the Tobitubby-Hurricane area, gullying of the uplands is the principal source of sand, the coarsest sediment produced in the area. Some sand is also produced by the incision of headwater valley trenches and by stream-bank erosion, but, compared with the amount derived from gullying, the sand contributed by these processes appears to be small and therefore probably has caused only a small part of the sediment damage. Conditions appear to be generally similar in the South Carolina Piedmont. In other areas, however, other processes may be much more important. In the area tributary to the middle Rio Grande in New Mexico, for example, valley trenching by arroyo incision and arroyo widening by bank erosion are dominant factors in production of sediment that is causing damage to the valley lands. In parts of the Driftless Area of the upper Mississippi Valley, stream-bank erosion and gullying of sandy terraces are probably the most important sources of coarse debris.

The coarseness of the sediment deposited in any particular part of a stream or valley does not depend solely on the texture of the erosional debris being produced in the contributing drainage area; it depends also on the competency of the surface run-off and the stream flow to transport coarse sediment to or beyond the particular depositional area. Thus, insofar as the extent of damage depends on the texture of the deposits, the problem of sediment damage is affected to a large degree by the carrying capacity of the stream bringing the sediment to a given area. It seems probable that in some places the transporting capacity of a stream may be a limiting factor in determining the areal extent of sediment damage and in others a factor in causing especially harmful localized concentrations of sediment. In some localities, possibly including Tobitubby and Hurricane Valleys, damage to valley lands by excessive sand accumulation may be localized in the headwater areas because stream gradients are too low and channel capacities too limited to permit transportation of the sand down the streams as rapidly as it is brought to them. In this way much sediment may be prevented, temporarily at least, from being transported to the valley lands farther down the drainage system.

A very important question that has not yet received adequate attention is: Are the incompetent channels below areas of excessive sedimentation the result of a progressive channel filling that represents an early stage in geomorphic readjustment to the modern accelerated run-off and erosion regimen, or was the incompetence, together with the low gradient, inherited from an earlier premodern stream regimen in which the channels, now too small, were adequate to transport the available sediment load? Channel filling is definitely known to have taken place during the modern period within the areas of present accelerated sedimentation, but whether the same process is under way farther downstream, where no such accelerated sediment damage has been recognized, is still unknown.

A large part of the sand and nearly all the gravel and boulders transported by streams in alluvial valleys are carried as bed load rather than in suspension. In the consideration of processes of transportation and deposition and possible corrective measures it is therefore of prime importance to take cognizance of the greater damage caused by the bed-load material. Observation of stream action, as well as consideration of the magnitude of the deposits composed largely of sediments brought into place as bed load, is sufficient to show that bed-load transportation is very active not only in the Tobitubby and Hurricane Valleys but generally throughout most of the other known areas of severe sedimentation. Present knowledge of bed-load transportation of sediment is so extremely limited that this may be considered one of the notably unexplored fields of the natural and hydraulic sciences.[17] Hence, no adequate basis exists for more precise evaluation of this factor in the processes of stream and valley sedimentation damage. Thorough studies, including hydraulic experiment beyond the scope of the present investigation, are urgently needed in this field.

21. Much of the valley land that has been directly damaged by deposition of infertile modern sediment has also been affected by increased flooding and drainage obstruction caused by the deposition of sediment in stream channels, on alluvial fans, and on natural levees.

A very large part of the valley areas now covered with comparatively infertile sandy modern sediment is swampy, because surface water has been ponded behind natural levees and alluvial fans composed of modern sediment, and is subject to frequent flooding because the stream channels have been completely or partly filled with sand, so that even minor floods are diverted over the flood-plain surface. These areas are not known to have been well drained or immune to floods under premodern conditions, but they would be much less affected by flooding and swamping if modern sediments had not accumulated in the channels and on the fans and levees. Consequently, in these areas the accurate assignment of the degree of present damage caused by sanding as contrasted with that caused by swamping and flooding is impossible. Much of the sandy land would

[17] An investigation of the fundamental principles of bed-load transportation is being conducted at field stations near Greenville, S. C., Dadeville, Ala., and Statesville, N. C. as part of the research program of the Sedimentation Division. These field studies will be supplemented by investigations at the cooperative hydraulic laboratory of the Soil Conservation Service and the California Institute of Technology, at Pasadena, Calif.

now be valueless for agriculture because of swamping and flooding even if the surface material were not infertile. On the other hand, much of this swamped and flooded land is now too sandy to justify the expense of reclamation by drainage and flood-protection works, which might otherwise be feasible.

A considerable part of the modern valley sediment accumulation has occurred in areas that were naturally swampy and frequently overflowed under primeval conditions. In such places no damage has resulted except where deposition in low areas has reduced the capacity for storage of floodwater in the upper valleys or for the discharge of floodwaters in trunk valleys, thereby tending to increase the frequency and height of flooding of higher valley lands more suitable for agriculture.

In some areas of swamping and excessive flooding, sand accumulation may prove beneficial if the land surface is built up until it can be more easily drained and protected from floods. This beneficial effect is reported by local residents to have occurred in an area of several hundred acres on the alluvial fan built on the flood plain of the Mississippi by the Buffalo River, a tributary in western Wisconsin. Similar beneficial results of sedimentation on fans in Mississippi have been reported by Lowe (*49, p. 10*). Such benefits can be expected, of course, only if channel filling does not exceed flood-plain aggradation.

22. Sedimentation is an important factor in the cause or perpetuation of the swamp conditions that contribute to the problem of malaria control and eradication.

Malaria is recognized as a major hazard to the public health and prosperity of large sections of the United States. Wherever feasible, eradication of breeding places of the malaria-carrying mosquitoes is now recognized as the most satisfactory method of controlling or eradicating the disease. In the eastern United States malaria is transmitted by *Anopheles quadrimaculatus*, which breeds in stagnant water and only where there is some protection from direct sunlight. In the western United States malaria is transmitted by *A. maculipennis*, which breeds in quiet water but requires a slow replenishment, such as commonly occurs in pools fed by seepage, rather than stagnant conditions.

The ponding of drainage and swamping of bottom lands, which characteristically occur in areas of excessive stream and valley sedimentation, produce in each of the above-mentioned sections of the country the conditions most conducive to free breeding of the malaria carriers in that section. In the East, ponding of surface water behind natural levees and alluvial fans and swamping of the lower parts of flood plains by rising ground-water levels controlled by aggrading stream beds are common in areas of accelerated sedimentation. Filling of drainage ditches and frequent channel shifts resulting from development of sand plugs are particularly important factors in producing pools in which mosquitoes may breed. Much of the surface ponding occurs in wooded areas, or where a growth of vegetation sufficient to protect the *Anopheles quadrimaculatus* larvae soon develops. The frequent appearance of new ponds also favors rapid breeding of the mosquitoes; for new ponds, during the first 3 to 5 years of their existence and before the natural enemies of the mosquito larvae become sufficiently numerous to exert a natural control, are especially prolific sources of mosquitoes.

In the middle Rio Grande Valley of New Mexico, which is one of the malarious areas in the *Anopheles maculipennis* zone, modern sedimentation has caused a rapid rise in the elevation of the bed of parts of the Rio Grande. Numerous areas of ponded water, occupying closed flood-plain depressions below the level of the river, occur in these sections of the valleys (pl. 13, *A*). These ponds are maintained by seepage from the river or by ground water and consequently do not disappear by evaporation or infiltration. Probably not all these ponded seepage areas are due to modern sedimentation, but their abundance and persistence certainly is favored by rapid channel aggradation.

Although no specific data are at hand, and no special study has been made of the relation between malaria incidence and the effects of excessive modern sedimentation in streams and valleys, accelerated sedimentation must be considered to be one of the potential causes of the persistence of malaria in various parts of the country. As one of the border-line subjects of scientific knowledge, this problem needs careful investigation from more than one line of approach.

23. Much of the damage to bottom lands by modern sedimentation is, or may be, temporary.

One of the most encouraging points brought out by the study of modern stream and valley sedimentation is the considerable extent to which the sediment damage may prove to be only temporary or at least susceptible to natural or comparatively easy artificial amelioration. Areas where the modern surface deposits are too coarse or too sterile to be restored to crop production by practical farming methods are comparatively small. If adequate erosion-control or other protective measures are established, drainage ditches may provide satisfactory relief for a large percentage of the area that has been affected by the swamping and excessive flooding resulting from sediment accumulation in stream channels and on natural levees and alluvial fans. Of course, such reclamation measures will be costly, and they will not restore the past economic losses. But at least they do offer a means of reducing the amount of future, recurrent annual losses that otherwise will result if present conditions due to modern sedimentation are not corrected.

Areas damaged by valley swamping and flooding also may tend to be improved by natural processes. Many swamped areas have already become areas of particularly rapid sediment accumulation, and in consequence tend to be built up above the water level. More frequent overflows increase the rate of sediment accumulation and thus facilitate both the filling of swamps and the aggradation of the flood plain in general. If the stream channel is not filled with equal or greater rapidity, the general aggradation of the flood plain will reduce the frequency and depth of overbank flooding except where terrace lands may become subject to more frequent and deeper flooding as a result of decreased discharge capacity below the terrace level.

Swamping and flood damage in localized areas of channel plugging may also be naturally relieved by the development of a new channel through the plug deposits. After the main channel in these plug areas has been largely or completely abandoned, the stream flow drains down valley for some distance through the back-swamp area of the flood plain and becomes concentrated in a new channel. These new channels grow headward up valley by migration of an overfall at their heads, and thus trench and drain sections of flood plain that were swamped by filling of the former main channel.

Areas of flood-plain sanding are ordinarily also subject to natural reclamation. Flood-plain splays, which are most numerous along the natural levees and in plug and fan areas, usually cause most of the flood-plain sanding. Such deposits are of local extent, however, and characteristically are later covered by the finer-grained deposits of vertical accretion, which improve the texture of the sandy sediment. Hence the presence of coarse, infertile sand on the flood-plain surface at any particular place does not mean that the surface will always remain sandy or that the extent of surface sanding is necessarily progressively increasing. It is true that a progressive increase in the total areas of valley sanding is taking place in some parts of the country, but this is due in large part to the development of a greater number of sand splays rather than to progressive growth of existing splays. The indications are that the aggregate areas of sand damage will continue to increase for many years, but probably many of the individual sanded areas will remain unproductive for only a limited time.

Over a considerable part of the total affected area flood-plain sanding is associated with stream-bank erosion. As a stream migrates laterally, cutting on one bank and filling on the other, the slip-off or depositional surface built behind it is first composed largely of the deposits of lateral accretion. These are usually sand or gravel, being composed largely of material sorted out of the bed load of the stream.

In some sections of the country and especially in the upper Mississippi Valley, stream-bank erosion has been very rapid during the modern period, and, following removal of a former flood-plain or terrace, large aggregate areas of flood plain have been formed at lower levels. These areas of new flood plain are characteristically sandy or bouldery and are overflowed frequently, but they also receive deposits of vertical accretion except where they are subject to such violent overflows that little deposition of fine material can take place. The progressive addition of vertical accretion deposits, however, tends to build up these low areas and cover them with fine sediment that is more suitable for agricultural use. In this way much of the land now too sandy and too frequently flooded for agricultural use may in a few years become valuable for cultivation or pasture. If this occurs, the damage due to the combined bank erosion and modern sand deposition is temporary, for the land destroyed by bank cutting will eventually be replaced by an equivalent area of new flood plain on the opposite side of the stream. This, of course, does not eliminate the damages resulting from loss of crops, bridges, roads, fences, or buildings, or the loss to individual farm owners where land destroyed on one farm is replaced by new land built on another farm on the opposite side of the stream. Neither does it eliminate the reduction in values that results if the new flood plain is surfaced with less productive soil material or if it is not built up to the same level as the old flood plain and hence is subject to greater flood damage. These various types of partial but essentially permanent damages are very common. It must also be borne in mind that all land removed by bank erosion may not be replaced by new flood plain, for channels may be widened.

INDICATIONS OF FUTURE TRENDS IN STREAM AND VALLEY SEDIMENTATION

24. The present tendency of sediment to accumulate most rapidly in upper valleys will continue if present run-off and erosion rates continue essentially unchanged.

The detailed studies in Tobitubby and Hurricane Valleys and numerous observations in scattered areas in other parts of the United States show that a considerable part of the sediment produced by accelerated erosion is being deposited in upper valleys. This sediment accumulation involves aggradation of the channels and flood plains and the resultant steepening of the longitudinal gradient for some distance downstream. Such steepened gradients are essentially unstable; for the normal tendency of all stream action is to flatten the longitudinal gradient, although locally sediment accumulation may counterbalance this tendency for some period of time. These modern sediment accumulations in the upper valleys must therefore be considered unstable.

At the present time there is no apparent general tendency for these deposits to be destroyed by erosion, unstable though they must be. They are usually covered with a fairly dense stand of vegetation, which protects the surface from flood scour and retards lateral stream-bank erosion. In some places knickpoints or overfalls have worked back from straightened or improved channels into or through the areas of upper valley accumulation, and in these places lateral stream-bank cutting may also be accelerated. Such erosional activity has, however, been local. On the whole, sedimentation is still most rapid in the areas where the thickest deposits have accumulated during the modern period, which indicates that aggradation has not reached the maximum that can be attained without upsetting the existing physiographic balance.

Since the present stream and valley gradients apparently are not too steep to be temporarily stable in areas of sediment accumulation in the upper valleys, the factors that will control the immediate future history of these deposits probably are erosion rates and run-off regimens. These two factors are directly affected by erosion-control operations, and their modification as a result of these operations is discussed under principle 45.

25. Valley deposits will shift down valley, but the locus of most active deposition may move alternately up valley and down valley.

From the time of its initial entrainment, a sediment particle is in process of down-valley transportation. This process is commonly intermittent, the times of active transportation being separated by long periods during which the sediment particle forms part of the valley accumulations. After each period of transportation, however, the particle is farther from its source. The valley deposits as a whole, being composed of sediment particles that have found temporary lodgment, are also in process of moving down the valleys.

By contrast, the locus of most active sediment deposition may, for short periods, progress either up valley or down valley. Thus in the Tobitubby and Hurricane Valleys backfilling in channels above valley plugs and alluvial fans has caused headward migration of the locus of most active sediment deposition on the adjacent flood plains. Similar conditions have also been observed above both plugs and alluvial fans in the southeastern Piedmont and above alluvial fans in the upper Mississippi Valley. If such a phenomenon is common above alluvial fans, it may be expected to occur widely and perhaps in the aggregate affect a large area in the United States.

Such valley-plug and fan deposits are unstable, perhaps more so than other types of alluvial deposits, because their deposition commonly involves a more radical and localized modification of the stream gradients. After deposition of a large part of its sediment load, the water that leaves the channel above the filled section flows down through the back swamps until it is concentrated again below the plug or fan. The point at which this comparatively clear water returns to the stream channel becomes a critical point, from which the dissection of the unstable deposits may start by headward migration of an overfall. In easily eroded sediment that is unprotected by vegetation this dissection may be rapid; in compacted, fine sediments that are well protected by vegetation it may be slow. In either, the sediment so eroded is carried farther downstream to a new place of deposition.

The development of a channel around a plug either by headward migration of an overfall or by other means may move the locus of most active sediment accumulation downstream. Figure 5 shows that such a change has taken place in the East Goose Creek Valley. Here the drainage ditch below the old Batesville Road was completely plugged with sand, and the sediment is now carried past the plug through a reoccupied natural channel to a new place of deposition farther downstream.

Trenched sections of the upper Tobitubby and Hurricane Valleys and of many other valleys in the southern and midwestern part of the United States, also commonly show evidence of a down-valley shift in the locus of deposition. In these places a modern deposit several feet in thickness commonly overlies a dark-colored old soil, indicating that active modern deposition on the flood plains has occurred. Now, however, the valleys are trenched to depths that eliminate the possibility of overbank deposition. Sediment that would otherwise be deposited, as well as sediment previously deposited but now being eroded as the trenches form and widen, is being carried farther downstream.

26. Sand accumulation in channels leads to increased percolation and underground flow, thereby tending to cause downstream migration of the head of permanent surface flow and further channel deposition because of loss of surface water for sediment transportation.

The present surface flow in most of the stream channels in the upper parts of the Tobitubby and Hurricane Valleys is intermittent, taking place only after fairly heavy rains. It is not known definitely whether these streams were intermittent before accelerated sedimentation began in the channels, although it seems probable that the permanent streams extended farther up the valleys. Certainly the present conditions in these upper valleys suggest that channel aggradation has caused the position of the head of permanent surface flow to shift downstream.

As sand is deposited in a stream channel a progressively greater part of the normal stream flow moves downstream as seepage through the porous sand deposit. If aggradation continues at any one place, a time may come when all the flow at ordinary stages passes through the sand. Consequently the position of the head of permanent stream flow must then be farther downstream. At least two additional factors may affect this migration. Aggradation of the stream channels tends to raise the ground-water level, and this tends to counteract the effect of channel aggradation. On the other hand, clearing and cultivation of the uplands increase the immediate surface run-off after storms and thereby decrease the amount of water available for ground-water maintenance of the permanent stream flow. This would tend to supplement channel filling in causing downstream migration of the head of permanent stream flow.

In the upper parts of valleys where the streams are intermittent, the sandy channel fill above the seep-water level acts as a reservoir into which some of the early run-off after storms will percolate. The loss of surface flow in this manner results in a decreased capacity for sediment transportation, and a self-perpetuating process is instituted by which channel aggradation tends to cause additional channel sedimentation, which in turn further decreases the capacity for sediment transportation. During many light rains or during rains that follow a long period of dry weather, the entire run-off may percolate into the channel fill and the entire sediment load be deposited in the channel. Such deposits are unstable and subject to further downstream transportation by later freshets, but they furnish an additional sediment load for the later run-off and consequently tend to accelerate the channel aggradation.

27. Channel filling may precede and cause increased overbank deposition.

Aggradation of stream channels, unless accompanied by equal or higher rates of flood-plain aggradation or by lateral widening sufficient to increase the cross-sectional area, reduces the discharge capacity and thereby causes more frequent and more prolonged overbank flooding. This in turn commonly causes increased overbank deposition. Not only may the total amount and rate of overbank deposition be increased, but there may also be a marked increase in the proportion of coarser debris, usually transported as bed load in the channel, that is carried out upon the flood plain. Because of this greater proportion of coarse sediment, the resulting injury may be much greater than the increased rate of sedimentation alone would indicate. A close relationship between channel filling and the most severe flood-plain damage has been found in the Tobitubby and Hurricane Valleys and is believed to be common elsewhere.

Erosional debris sufficiently coarse to collect in channels is being delivered to many streams in the United States. If the delivery of such coarse debris to the streams continues unchecked, channel aggradation will continue and the amount and severity of overbank deposition may be expected to increase. Even if further production of coarse erosional debris is prevented, the debris already in process of transportation is very likely to be carried on downstream and to accumulate in the channels where the gradients are lower and cause damage there. As the channel filling becomes more pronounced and extends farther downstream, overbank deposition will probably also become more rapid and more injurious progressively downstream.

28. The sediment already accumulated in the upper valleys is a potential threat to valley improvements and soils downstream.

Where modern erosional debris contains a large percentage of sand or coarser material, there is apparently a strong tendency for the sediment to accumulate in the upper valleys. These accumulations also include much silt and clay, which, because of the increased overbank flooding caused by channel filling or plugging, are deposited in larger quantities than would otherwise be the case. This concentration of sediment in the upper valleys has modified the longitudinal gradient of the streams, flattening it above the point of maximum deposition and steepening it downstream. The deposition in the upper valleys also decreases the sediment load of the streams farther down and in this way may facilitate erosion by the clearer water. In the areas that have been investigated little downstream movement of the modern deposits has occurred except in the headwater valleys that have been trenched. Nevertheless, these deposits are potentially unstable and are subject to dissection and further downstream transportation. As sediment accumulation continues in the upper valleys and the modification of the longitudinal gradient of the stream becomes more pronounced, the instability of the deposits will become a more active threat to downstream resources.

Sediment now stored temporarily in the upper valleys, if carried downstream, will do as much damage to downstream resources as sediment derived in equal amounts from the uplands. The sand or coarser debris will be just as effective in filling ditches or stream channels or in lowering the productivity of the alluvial soils, and the fine material will be just as effective in reducing the capacity of reservoirs. Consequently the upper valley accumulations must be considered as an important potential source of injurious sediment, and particular attention should be devoted to their stabilization in order to protect downstream resources. A complete soil conservation program should include specific attention to the valley deposits, for upland erosion-control measures will not necessarily stabilize the valley deposits and may even tend to hasten their dissection and downstream transportation.

29. If upland erosion continues at the present accelerated rate the resulting valley sediments will be composed of a progressively greater proportion of debris from upland subsoils and underlying geological materials. The result will be increased damages to the agricultural productivity of valley lands.

Under normal geological conditions the rate of soil formation in general was more rapid than the rate of surface erosion. Consequently, in most places a distinct soil profile developed. At the present rates of accelerated erosion, however, the ratio of formation to removal has been modified and surface soils are being eroded faster than they are formed. Thus progressively lower horizons of the soil profile are being exposed at the surface. Where gullies develop, the subsoil and underlying geological materials may be exposed in a very short time. Where the dominant process is sheet erosion the period required for exposure of the subsoil and underlying geological material may be much longer. As this process continues, the erosional debris delivered to the valleys will become progressively poorer for agricultural use, and the damage to valley lands will be correspondingly greater.

30. Severe sediment damage has affected only a small part of the valley land potentially subject to such damage, and it may be expected that a progressively larger area will be affected in the future.

The productivity of much valley land in different parts of the United States has been impaired or destroyed as a result of accelerated stream and valley sedimentation, but these seriously damaged areas constitute only a small percentage of the valley land potentially subject to such sediment damage.

The areas that have already been seriously damaged are largely in the upper parts of the valley systems. Inasmuch as the sediment is in process of intermittent, progressive, down-valley movement, in the future it will reach areas farther downstream in progressively greater amounts. The area of severe sediment damage will not necessarily increase only by downstream growth from headwater tributaries, for the locus of excessive accumulation will also move up valley as a result of backfilling from the heads of alluvial fans, channel plugs, and reservoir deltas. Hence sedimentation damages have not by any means reached a maximum but may continue and progressively increase in areal extent and importance for many years to come.

In many places in the United States the subsoil and underlying geological material have already been exposed by erosion, although in most places erosion has not yet reached this stage. Consequently, the debris now being delivered to the streams in most areas is derived mainly from the topsoil and, when deposited on the valley bottoms, may provide a fertile soil material. If erosion continues at its present accelerated rate, however, progressively larger upland areas will be completely denuded of topsoil and progressively larger amounts and proportions of subsoil and underlying geological material will be fed into the stream systems and deposited in the valleys.

The debris from these lower horizons may not in all places cause more damage than equal quantities of topsoil. For example, if such debris is calcareous and is deposited on acidic alluvial soils, definite improvement may result. If the material is poorer than the topsoil in plant-food elements or in texture, however, increased damage to valley resources may result. In Tobitubby and Hurricane Valleys, for example, the productivity of the land has been seriously impaired wherever sand, derived from the Holly Springs formation which underlies the surficial loess cover, has been deposited in large amounts on the bottom lands or has filled stream channels and otherwise obstructed valley drainage. In areas having clay subsoils, excessive accumulation of this fine subsoil debris may also reduce the productivity of the bottom-land soils. Thus, even if the rates of accumulation remain constant and even if the subsoil debris in some places is no more injurious than that derived from the topsoil, the damage to valley resources resulting from increased erosion of subsoils and underlying geological materials may be expected to increase as a whole.

RELATION OF STREAM AND VALLEY SEDIMENTATION TO FLOOD-CONTROL PROBLEMS

31. Reduction of downstream sedimentation rates may prove to be one of the most valuable ways in which upstream engineering and upland-conservation measures can contribute to flood control.

In the vast and complex problem of flood control, two major methods of approach have been widely advocated. In one, which may be called the downstream-engineering approach, detention reservoirs, levees, floodways, and straightened channels are used to control the flow in the stream so as to minimize or prevent damage by overbank flooding. In the other, which may be called the upstream-engineering approach, increased or improved vegetal cover, improved tillage practices, and small-scale detention structures are used to reduce the surface run-off and thereby reduce the frequency and extent of overbank flows in the main streams. There is much variance of opinion as to the relative effectiveness of these two methods. There seems, however, to be a growing acceptance of the general principle that the two types of measures should be used to supplement each other rather than that either should be regarded as solely and universally adequate.

From the standpoint of the soil conservationist, upstream engineering is of extreme importance, because the methods of upstream engineering are, to a large extent, identical with the best-known methods of soil conservation. Hence any upstream engineering for flood control will almost certainly also effect some degree of soil-erosion control, and vice versa. By contrast, downstream engineering for flood control seldom if ever has any important bearing on upland-soil conservation, because it is primarily concerned with controlling water after it has run off the soil.

These are, of course, well-known facts. Another important factor also deserves mention. Upland surface run-off nearly always causes some surface erosion, and consequently floodwaters almost invariably carry some sediment load, and often a heavy one. This sediment load is an important factor in flood problems and in flood damages, although it has never yet been satisfactorily evaluated. In regard to sediment, however, the upstream- and downstream-engineering approaches are diametrically different. Upstream engineering reduces the sediment load by reducing the rate of sediment production at its source. Increasingly abundant data from controlled experiments in various parts of the country consistently show that the usual practices of upstream engineering are more effective in reducing erosion (which is sediment production) than in reducing surface run-off.

It is true, of course, that sedimentation is a problem of direct concern in upstream engineering and upland-conservation practices. Sedimentation in detention basins behind small control structures may be very rapid, and may quickly reduce the capacity of such structures for storing water. Sedimentation in terrace channels and outlets may reduce their discharge capacity to the extent that overflow and trenching across the terraces will occur and will temporarily destroy their value and necessitate repairs. Accumulation of fine sediment may choke the pore space of the soil in water-spreading areas and thus reduce the rates of infiltration. The value of sediment accumulation behind check dams in gully-control work is only a partial compensation for these various types of sedimentation damage. As contrasted with downstream sedimentation, however, the upstream and upland deposits are comparatively innocuous, for the structures impaired may be comparatively easily and cheaply replaced, and the sediment is seldom sorted to the extent that it is either too coarse or too infertile for agricultural use.

In the practice of downstream engineering, on the other hand, sediment is a factor, and in some places an important one, in the

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maintenance of reservoirs, improved channels, and floodways, and the disposition of sediment is an important part of the problem that must be solved. Thus one of the most important effects of upstream engineering may be in the reduction of sedimentation rates in downstream reservoirs, channels, and confined floodways. In downstream-engineering practice, such sedimentation is an added problem, which may require added expense and trouble and which, if not given adequate attention, may threaten the continued effectiveness of the control measures. In upstream engineering for flood control, sediment production is reduced without additional cost or trouble. Hence, wherever sedimentation is an important factor in the maintenance or effectiveness of downstream flood-control works, there is a twofold reason for considering upstream engineering as a supplementary control measure.

32. Sediment damage to floodways and improved channels may be due chiefly to accumulation of bed load rather than suspended load, but in reservoir sedimentation suspended load is a serious factor and perhaps usually the major factor.

In floodways and channels improved for flood control the effect of the control structures or improvements is to confine the floodwaters, and hence to increase the discharge velocity. Under such circumstances sedimentation is generally slow, except where unusually large quantities of coarse sediment are being contributed. Such coarse sediment is commonly moved largely as bed load, and hence bed load rather than suspended load is the main source of harmful sedimentation in floodways and improved channels. Exceptions to this rule may occur, for example, where the channel gradient of a tributary flattens markedly near the junction of the tributary and its master stream, but, in general, excessive sedimentation in floodways or improved channels may be charged to the accumulation of bed-load sediment. Hence sedimentation will be a serious threat to such improvements chiefly in areas of rapid production of sediment of sand, gravel, or boulder size, and will be of comparatively little importance if the erosional debris from the contributing drainage basin is mostly of fine size, silt and clay, which can be transported in suspension.

In the problem of reservoir sedimentation, on the other hand, suspended-load sediment must be reckoned a major factor of potential damage, for in the stilled water of the reservoir basin much or most of the suspended load may be deposited. In consequence, reservoir sedimentation may be expected to be considerably more rapid, other conditions being equal, than channel or floodway sedimentation. Hence in areas where production of bed-load sediment is low and a flood-control program involving improved channels and floodways would therefore have only a slight sediment problem, the effectiveness of a flood-control program based on detention reservoirs might be seriously endangered by deposition of suspended load. It is true that some allowance for excess storage capacity can usually be made in the design of detention reservoirs to offset storage loss due to silting, but the significant point is that quantity and texture of sediment deserve consideration in the selection of the best flood-control program for a given drainage basin.

The Sardis Reservoir on the Little Tallahatchie River, which will include the lower parts of Tobitubby and Hurricane Valleys within its basin, serves to illustrate the relation of sediment size to the type of sediment damage. In the past, sediment damage in the area has been almost entirely due to sand accumulation in the channels and on the flood plains. So far as is known, the large quantities of finer sediment carried by the streams as suspended load have caused comparatively little damage. When water is impounded in the reservoir, however, a large part of the suspended load probably will be deposited, for much of this suspended load is coarse silt derived from the loess on the uplands. The rate of filling of the reservoir may be slow because the impounding basin is very large relative to the catchment area and because the erosional debris will to a great extent continue to be trapped in the headwater valleys above the reservoir. But even a small loss of total capacity may affect the adequacy of the reservoir to provide the degree of flood protection for which it is intended, and hence may be of importance in the success or failure of the flood-control program for the Yazoo Basin, of which this reservoir is a part. Thus the sedimentation problem may be vastly changed, and the major concern shifted to the need for reservoir protection by reduction of suspended load in the contributing streams. Although there are insufficient data to justify definite conclusions regarding the Sardis Reservoir problem, the obvious possibilities are evidence of the importance of the principle involved.

33. Sedimentation may be more rapid in headwater reservoirs than in reservoirs of equal capacity-inflow ratio farther downstream and more rapid than would be indicated solely by suspended-load measurements on the main streams.

The tendency of sediment to be concentrated in the upper parts of the valleys, as shown by the results of the Tobitubby and Hurricane investigations, points to another principle worthy of consideration in flood-control planning. In designing reservoirs primarily for flood control it is often desirable to locate them as near as possible to the head of the stream system in order to provide protection for the largest possible part of the valley areas. But in drainage basins, like Tobitubby and Hurricane, where a large part of the erosional debris is deposited in the upper valleys, sedimentation will be more serious in headwater reservoirs than in reservoirs of similar capacity-inflow ratio farther downstream. Also in such drainage basins the sediment load of the main streams cannot be considered an adequate indication of the sediment load that may be delivered to headwater reservoirs, for the sediment load indicated by these main-stream measurements will not include the amount of material that is deposited above the measuring station.

34. Local accumulations of sediment are important factors in aggravating flood damage.

In addition to the widespread effects of excessive sedimentation throughout a stream system, such as channel aggradation and flood-plain sanding, an important factor in flood damage in some areas is the local, and in some places temporary, accumulation of sediment. These local accumulations may take the form of (1) deltas built at the confluence of tributary and master-stream channels, (2) alluvial fans at the mouths of tributaries debouching upon a flood plain, (3) channel plugs, or (4) temporary accumulations of sediment and trash lodged behind bridge piers or other obstructions during a flood.

The importance of such local concentrations of sediment and the extent and significance of their influence on stream activity is seldom appreciated.

Deltas built in main stream channels by tributaries may cause several types of damage. The deposits reduce the cross-sectional area of the main channel and in this way tend to reduce its discharge capacity. By directing the current against the opposite bank of the stream, bank erosion is increased and migration of the stream channel across the valley is accelerated. If the contribution of sediment is sufficient, the main channel may be entirely blocked and all water forced onto the flood plain. Obstruction of channels of Tobitubby and Hurricane Creeks by such delta accumulations may have been the primary cause of several of the plugs in these streams. The genesis and effect of channel deltas have been described in more detail under principle 9 (pp. 73–74), and their effect in causing lateral migration of the channel is illustrated by a photograph (pl. 9, *B*) of a delta built into the Upper Iowa River by a small tributary in Allamakee County, Iowa.

The growth of alluvial fans not only causes direct damage by burial of productive soil beneath unproductive sand and gravel, but also increases the flood damage. As a result of channel filling in areas of active fan growth, there is a loss of capacity for discharging floodwater without overflow. Consequently a larger percentage of the floodwater may become overbank flow. This increased overbank flow is not necessarily confined to the surface of the fan but may extend a considerable distance up the fan-building stream as a result of backfilling of its channel. The growth of alluvial fans may also increase the height of floods in the trunk valley, for the sediment deposited on the fan below flood level reduces the overbank-discharge capacity on the flood plain. This is a factor of particular importance in those floodways where a single levee is used to confine the water against one side of the valley. In such places the tributary streams may build their fans directly into the floodway.

Channel plugs are more effective than either deltas or alluvial fans in causing local modifications of stream activity. When the channel is completely plugged all the water in the channel is forced overbank and must work its way down valley through the back swamps. In addition, the low sandy ridges that result from the abandonment of plugged channels effectively divide the flood plain into two or more parts insofar as surface flow is concerned. Separation of the water into two parts and the increased frictional resistance to flow in the poorly defined channels retard delivery of floodwater to the valley below the plugs. The effect on the downstream-flood problem of this retarded, and perhaps decreased, delivery is not known, but the effect is detrimental in and above the plug areas, where flooding becomes both more frequent and prolonged.

Temporary accumulations of sediment and trash deposited behind bridge piers or other obstructions during a flood may also modify the stream activity. If the channel is partly obstructed, the water may be directed against the bank and cause damage by eroding valley land or undermining the obstruction. If the water is ponded, both sediment and floodwater damage to the adjacent flood plain and lower terrace lands may be increased, and road fills may be breached by overflows. If the ponded water is released suddenly by development of a new channel or failure of the temporary accumulation, the resulting concentrated flow down the valley may cause much more damage than if the water had been discharged more uniformly.

35. Clearing of stream banks to expedite flood discharge tends to increase bank erosion, and the consequent channel enlargement or lateral migration may destroy valley lands and increase the sediment load of the streams.

It is a common and widespread practice to clear vegetation from stream banks in order to reduce the frictional resistance to flow and thus increase the capacity of the channel to discharge floodwaters without serious overflow of the banks. The efficacy of the practice is well established, and unquestionably it is a valuable auxiliary measure for use in flood-control engineering. In areas of potentially severe bank erosion, however, and especially where accelerated sediment production is known to be an important factor in the aggravation of flood damages farther downstream, such bank clearing or brushing-out measures should not be instituted without consideration of possible harmful effects resulting from an increased rate of bank erosion. Discrimination in the removal of different types and sizes of living vegetation, and possibly the use of supplemental measures for stabilizing the cleared banks, may be profitable.

Bank erosion is not generally serious in the Tobitubby-Hurricane area, as has been noted on page 53, but the striking instance of accelerated ditch widening caused by bank clearing in West Goose Valley, shown graphically in figure 17, illustrates this principle. It seems probable that the principle will prove to be most applicable to areas in which the stream banks are dominantly sandy and therefore particularly susceptible to lateral erosion or where the flood plain is underlain by gravel and boulders at such shallow depth that lateral cutting adds large quantities of coarse and comparatively injurious sediment to the stream load. Where the quantity of sediment is a major factor in the damage caused by floods, bank erosion may be especially serious if it affects high terraces that are largely composed of sandy material and are therefore eroded rapidly when subject to lateral stream cutting. In such places the quantity of debris delivered to areas of deposition farther downstream may be greatly increased even if a new flood plain is built on the opposite side of the stream, for the new flood plain is built at a lower level and does not represent accumulation of as much sediment as is produced by bank erosion of the older, higher terrace. This is illustrated by plate 11, *A*.

36. The ratio of channel deposition to overbank flood-plain deposition is a major factor in determining the effect of stream and valley sedimentation on flood problems.

If sedimentation results in a decrease in the cross-sectional area of a stream channel, it will increase the flood hazard and flood damages by increasing the frequency, height, and duration of overbank floods. Such reduction in channel capacity by sedimentation will occur whenever and wherever the ratio between the rates of channel and overbank deposition is such that the channel bed is built up more rapidly than the surface of the adjacent flood plain and widening by bank erosion does not compensate for the capacity lost by aggradation. If the rate of vertical accretion of the flood plain exceeds the rate of channel aggradation, however, the net effect may be to increase the available depth of channel (by increasing the height of the banks) and thus to increase the capacity for discharging storm waters without overbank flooding. For any given stream gradient and discharge regimen, texture and quantity of sediment appear to be the controlling factors in determining which of these effects will be dominant.

It does not follow, however, that wherever flood-plain aggradation exceeds channel aggradation stream and valley sedimentation will necessarily reduce flood danger and flood damage. One important complicating factor is the effect of flood-plain aggradation in raising flood levels until terrace lands previously above the flood level are inundated. Under such circumstances, flood damages may become more severe regardless of whether or not flood discharges become greater or more frequent. This has happened in Tobitubby Valley and probably in Hurricane Valley. (See pp. 48–50.)

Recent preliminary investigations in Coon Creek Valley, Vernon County, Wis., have brought to attention an even more striking example. The premodern alluvial soils in Coon Creek Valley have a thick black surface horizon and consequently may be traced laterally with great detail, which permits restoration of the surface as it existed before the inception of accelerated sedimentation. From such evidence, supported by the testimony of old residents, it is known that in certain places there was a flood plain several hundred feet wide, with bordering terraces ranging generally from 5 to 10 feet higher. During the period of modern sedimentation, the flood plain has been built up an average of 5 feet or more, and in many places a few inches or a few feet of modern sediment has been deposited on what formerly was a low terrace above flood level. In at least one place the present flood-plain surface extends laterally, without break in elevation, across a former terrace that the landowner regarded as safe from flood overflow. Although the ratio of channel to flood-plain aggradation has not yet been investigated thoroughly, it appears that the rate of flood-plain aggradation may have exceeded channel aggradation. Even though the capacity of the channel to discharge storm waters without overbank flooding may have been increased and though the depth of ordinary flood-plain overflows has probably been decreased because of the increased width of the first bottom, the area of valley agricultural land subject to overflow and flood damage has been greatly increased by the aggradation of the flood plain up to the terrace level. It is believed that such extension of flood levels across terrace lands, due to aggradation of the first bottoms, may be a factor of major importance in the flood problems of many valleys.

RELATION OF SEDIMENTATION CONTROL TO SOIL CONSERVATION

37. Erosion-control practices are generally preferable to other methods of reducing sediment damage because they remove the basic cause of the damage and benefit both the areas of erosion and the areas of sedimentation.

Four types of measures have been used with some success to control harmful stream and valley sedimentation or ameliorate the resulting damage.

(1) Water and its sediment load may be passed around the area to be improved or through a restricted part of it, by ditching, protective levees and jetties, or channel straightening.

(2) The sediment-laden water may be directed onto the area to be improved in order to build it up by sedimentation. Land building

(colmatage or warping in European terminology), for example, raises the surface above ground-water level or above the height of frequent flooding or may improve the land by covering relatively infertile material with deposits of more favorable texture or more fertile composition.

(3) The sediment-laden water may be prevented from reaching the area of improvement by diverting it onto less valuable lands or restricted areas farther upstream, as in desilting basins and water-spreading structures.

(4) Sediment production may be reduced by upland or up-valley erosion-control measures, such as terracing, contour cultivation, strip cropping, retirement of eroding lands to pasture and forest, improvement of grazing lands and forest cover, check dams and other gully-control devices, and stream-bank protection. In general, these correspond to the erosion-control and soil conservation practices developed by the Department of Agriculture and other agencies and individuals concerned with the problem of soil erosion in the United States.

The first three types of control measures listed above differ fundamentally from the fourth in that they are designed only to handle excessive quantities of sediment after they have reached the valleys. The fourth type, by contrast, is designed to prevent the harmful effects by eliminating the cause. For this reason, erosion control is the only method that, as a general rule, offers promise of future reduction in the cost and extent of necessary sediment-control works. Furthermore, the same types of erosion-control measures needed for sediment reduction are expected to be beneficial in reducing surface run-off, in establishing a more uniform regimen of stream flow, and in preserving and improving the value of uplands that are subject to excessive erosion. In many places these incidental benefits will exceed the direct benefits of relief from sediment damage. Thus, where they are applicable and not unduly costly, erosion-control measures are to be preferred to other methods of controlling sediment damage.

In many special cases supplementary measures will be needed in the valleys to control or prevent sedimentation at critical places or on especially valuable lands. Even if a complete erosion-control program is adopted, supplementary measures may be needed for a number of years in order to prevent excessive damage by the sediment now temporarily lodged in headwater areas but subject to further down-valley transportation.

38. The value of valley resources subject to sediment damage justifies greater expenditures for erosion-control measures than are justified solely by the value of the land subject to erosion.

In the uplands of Tobitubby and Hurricane drainage basins both gullying and sheet erosion have been widespread and serious. If the productive capacity of the upland fields is to be maintained or improved, most of the upland agricultural lands in the two drainage areas must soon be placed under an adequate erosion-control program. Inasmuch as the area is almost entirely agricultural, the preservation of the soil and maintenance of its productivity are essential to the social well-being and economic stability of the community.

The sediment derived from the eroding upland fields has rendered about 28 percent of the bottom lands unfit for agricultural use (table 6) by decreasing their fertility or obstructing drainage. By reducing the amount of sediment delivered to the valleys, erosion-control measures on the uplands will tend to prevent further increase in the area of sediment damage and, in some places, will alleviate the present conditions. Consequently, anticipated benefits to the valleys should properly be included in any determination of the amount of erosion-control work that can be economically justified on the uplands.

Where the land has been so intricately and deeply dissected by gullies that erosion control will be unduly expensive, consideration of valley benefits will be particularly important. Where such eroded areas are essentially destroyed for agricultural purposes, erosion-control measures may not be justified by the benefits to the lands to be treated. But the sand from these gullied areas causes much of the valley damage, and, consequently, in a program of erosion control planned primarily for protection of the bottom lands from sediment damage, the gullied areas would deserve particular attention. Thus, for a complete soil conservation program, including attention to all parts of the drainage basins and planned for the greatest ultimate public benefit, consideration should be given to the extent to which otherwise unjustified gully-control work may be justified by valley benefits. Similar consideration should be given to roadside erosion, which may contribute large quantities of harmful sediment to the valleys.

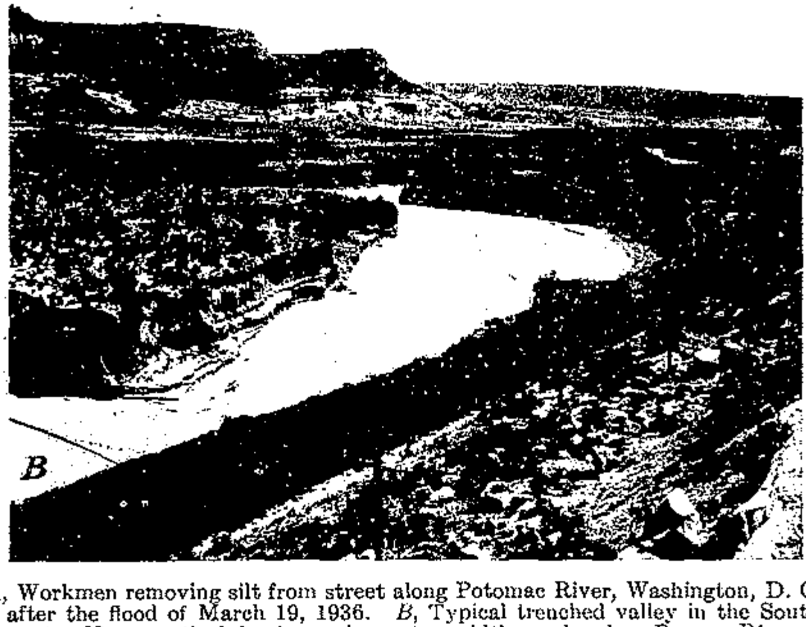
There will naturally be greater justification of upland erosion control for valley benefits in those drainage basins where the valleys are more highly improved for agricultural or industrial use, are used as the sites of cities, are traversed by railways and improved highways, or are used for water storage. In such places, the damage due to excessive sedimentation may be proportionately much greater than in Tobitubby and Hurricane Valleys, where the land is now of low sale value. For example, the United States Army Engineers (*78, p. 139*) report that in four drainage districts in the Yazoo delta, the Yocona No. 2, Big Sand, Pelucia, and Abiaca, representing a total original investment of about $550,000, the ditches have silted up in periods of 5 to 10 years to such an extent that their purpose has been entirely defeated. Minnesota State Highway No. 74, which traverses the Whitewater Valley in the southeastern part of the State, may be cited as an example of an improved highway which is frequently damaged by flooding and sedimentation. Plate 13, *B* shows one of many places where sediment frequently must be cleaned off this highway after freshets.

In the great Ohio River flood of 1937 sediment damage to buildings and the cost of sediment removal from buildings, streets, sewers, and culverts were among the major items of damage in the flooded cities and towns. In Cincinnati, Ohio, and Louisville, Ky., respectively, 612,500 tons and 563,000 tons of sediment were deposited. For all urban areas it has been estimated that the sediment totaled 3,835,200 tons.[18]

During the Ohio River flood of 1913 most of the damage, according to Horton and Jackson (*35, pp. 86–87*), was caused by the yellow, slimy, fine, penetrating mud that was deposited in the cities and towns as well as on the farms.

[18] BROWN, C. B., and BROWN, M. H. SEDIMENTATION SURVEY FOLLOWING THE OHIO RIVER FLOOD OF JANUARY 1937. Unpublished report. U. S. Soil Conserv. Serv. Washington, D. C.

A, Ponded water in a low area in the Rio Grande Valley, near Isleta, N. Mex. This is one of many formerly cultivated areas on which water has been ponded as a result of river aggradation and associated drainage obstruction. *B*, Ten inches of sediment deposited on Minnesota State Highway No. 74, about 4 miles west of Weaver, Winona County, Minn. Sediment frequently must be removed from this highway after freshets and floods, mainly because of growth of alluvial fans.



A, Workmen removing silt from street along Potomac River, Washington, D. C., after the flood of March 19, 1936. *B*, Typical trenched valley in the Southwest. Note vertical banks and greater width on bends. Puerco River, a tributary of the Little Colorado River, about 3 miles east of Arizona-New Mexico boundary.

Sedimentation was likewise a major factor in the damage caused by the 1938 floods in the Los Angeles district of California, and removal of sediment from city streets is commonly a factor in urban flood damage in many parts of the country (pl. 14, *A*).

The economic aspects of reservoir sedimentation have been discussed briefly by Eakin (*22, pp.* 3–4), who pointed out that the damage involved is by no means confined to the original cost of the reservoir. Reservoirs are constructed at the most economical and physically favorably sites, and consequently the development of additional storage to replace that lost by sedimentation is usually more costly than the original storage and, in some instances, may not be feasible because of unfavorable topography. Other developments dependent on the reservoir will also be affected as the usefulness of the reservoir is impaired. More recently, Brown (*22, pp. 124–125*) has estimated, on the basis of 98 sedimentation surveys by the Soil Conservation Service and other agencies, that of all the reservoirs in the United States, 39 percent will have a useful life of only 1 to 50 years; 25 percent, 50 to 100 years; 21 percent, 100 to 200 years; and only 15 percent, more than 200 years. There are at least 8,400 reservoirs in the United States, representing an original capital investment of at least $2,000,-000,000, and the annual loss of investment due to sedimentation is enormous. Not all reservoir sedimentation could be prevented by any practical methods of erosion retardation or sedimentation control, but a large part of it is due to accelerated soil erosion and can be greatly reduced by methods already proved by wide use to be economically feasible. As present known methods of removing sediment from reservoirs are usually ineffective and costly, an extension of erosion-control measures offers one of the most promising methods for reducing the sedimentation losses in reservoirs. As part of a complete conservation program, in many places, such erosion-control measures might profitably be supplemented by the construction of sediment-detention basins and by other methods of directing and controlling valley sedimentation above the reservoirs.

39. The improvement of valley lands for agriculture, including alleviation of sediment damage, offers a possible method of replacing those erodible sloping lands that, as a conservation measure, should not be cultivated.

Much of the land now under cultivation in the United States is subject to serious soil erosion. Part of this erodible cultivated land can, under proper handling, be protected and kept reasonably productive by economically feasible erosion-control practices. Other parts of it, however, are so steeply sloping, already so badly eroded, or otherwise so difficult to protect by economically justifiable erosion-control measures that continued cultivation can result only in the ruin of the land for agriculture within a comparatively short time. While this land is being cultivated, and after it has been abandoned, the large amounts of erosional debris derived from it will further complicate the flood and sedimentation problems in the streams and valleys. Such land should be retired from cultivation and protected from erosion by a grass or tree cover.

On some farms this retirement of certain fields to grass or trees might necessitate only a slight modification in farm practices, and the benefits might quickly exceed any temporary financial loss to the owner or farm operator. But on many other farms the retirement of even small areas from cultivation might be economically impracticable. For such farms some means will be needed to replace the acreage to be retired from cultivation. The improvement of valley lands now unused, or used only for poor pasture, offers one means by which additional cultivable land might be developed.

The productive capacity of bottom lands, when adequately drained and protected from excessive flood damage, is fully attested by the high esteem in which they are held throughout most parts of the country. Commonly they are more productive than most of the upland soils. This may be true even where the premodern bottom-land soil has been buried under a foot or more of fine-grained modern sediment. For example, in Crawford County, Wis., the old Wabash and the modern Ray silt loams, where well drained, are each given productivity ratings of 2. Some upland soils in Crawford County also have ratings of 2, but most are less productive (*24, pp. 37-38*).

If improvement of bottom lands is undertaken in order to replace erodible uplands that should be retired from cultivation, consideration should be given to protection from sediment damage as well as to the establishment of adequate drainage and protection from flood damage. Attention should be directed both to the area to be improved and to the areas where protective works will be necessary, in order that the improvement may be permanent. If upland erosion-control measures are used for protection from excessive sedimentation, the specific areas contributing harmful debris must be treated and sufficient time allowed for the control measures to become effective. In many places special attention to control of valley trenching and stream-bank erosion will be essential to an adequate program of permanent valley improvement. Even so, some bottom lands will be more suitable for improvement than others, and probably in many places valley improvement by control of sedimentation will not be economically feasible.

40. Control of valley trenching, which forms flumelike channels that carry sediment and flood run-off to the main valleys and at the same time produces additional erosional debris, offers a valuable supplementary method by which much sediment might be stabilized in the upper valleys.

Modern valley trenches occur widely in the United States, being known from various parts of the Middle West, Southwest, far West, and South. In the Tobitubby and Hurricane Valleys they have had a twofold influence on valley sedimentation, in that (1) their formation and growth furnishes sediment for deposition farther down valley and (2) they act as flumes to carry sediment and flood run-off from uplands to the main valleys. The trenches have apparently furnished only a small proportion of the total debris accumulated in Tobitubby and Hurricane Valleys, but in other places valley trenches may be of major importance as sources of sediment. This is true of the Rio Puerco, a major tributary of the Rio Grande, in New Mexico. Historical evidence collected by Bryan (*13*) indicates that previous to 1885 the Rio Puerco had a fairly shallow, discontinuous channel. Shortly after 1885 trenching began. From surveys of the valley trenches or arroyos, Bryan and Post [19] calculated that between 1885 and 1927 about 395,000 acre-feet of sediment, an average of 9,400

[19] BRYAN, KIRK, and POST, GEORGE M. See footnote 15.

acre-feet per year, was produced by the trenching of the Rio Puerco and its tributaries. This is estimated to be about one-third of the total sediment delivered to this part of the Rio Grande Valley during the 42-year period. Other streams (pl. 14,*B*) in the same general area have also developed large trenches from which vast quantities of debris have been eroded.

In places where a large quantity of erosional debris is derived from valley trenching, stabilization of the banks of the trenches may prevent further downstream transportation of a large part of the sediment that forms the valley fill in the trenched section. Stabilization of existing deposits would be beneficial not only to most headwater valleys, where the deposits are now lodged, but also to the lower valleys, which would thus be protected from damage by redeposition of the sediment.

In some places large quantities of debris are passed through the trenches to the main valleys downstream. If, in these places, measures are used that cause the trenches to fill, the trenches will cease to act as flumes to carry water and its sediment load on down to trunk valleys. Deposition of sediment in the headwater valleys both in the trenches and on the adjacent valley bottoms will be increased. Thus the lower valleys will be protected, but in the headwater valleys, where the sediment is deposited, damage may be increased. This will be especially true if the sediment is coarse and infertile and is deposited as an overwash upon the valley bottom. In such places the benefits to be derived from trench stabilization and partial protection of the lower valleys must be weighed against the damage that will be caused in headwater valleys. The control of trenching would, of course, be an important part of a complete erosion-control program, for trenches are important factors in promoting serious soil erosion, both by their own headward and lateral growth and by initiating overfalls that migrate headward up side drainageways and thus aggravate upland gullying.

41. Low valley lands that have poor drainage may be built up and improved by directed sedimentation. This might also prevent future damage by uncontrolled deposition of sediment that is in progress of intermittent down-valley transportation, but is still largely concentrated in headwater valleys and channels.

In many drainage basins large quantities of sediment, particularly sand or coarser debris, are already in process of down-valley transportation but are still largely concentrated in headwater valleys and channels. This sediment is a potential threat to drainage systems or leveed floodways, to settling basins or reservoirs, and to the productivity of agricultural lands farther downstream, and will continue to be so even if the rate of production of sediment from uplands and valley trenches is reduced by an erosion-control program. Control of debris temporarily stored in valley deposits may thus be an important factor in the prevention of future sediment damage.

In those parts of valleys where sediment damage has occurred, reclamation of the damaged bottom lands may require that reduction in sedimentation rates by erosion-control methods be supplemented by other measures. The establishment of adequate drainage will also be necessary where modern sedimentation has so modified the valley surface that the change in stream regimen resulting from an erosion-control program will not by itself remove the obstructions to drainage.

In Tobitubby Valley, for example, drainage ditches have been completely filled with sand and now form low, elongate ridges that divide the valley into several segments with independent surface drainage. This obstruction to surface drainage has been accompanied by a rise of the ground-water table and impairment of subsurface drainage. In other places in the same valley the bed of the natural channel has been built up above the surface of the adjacent flood plain and has produced the same effect. Accelerated sedimentation on natural levees, alluvial fans, and valley plugs has also obstructed drainage in many places and locally has caused surface ponding. Similar modifications of valley forms have been observed in the southeastern Piedmont. In the middle Rio Grande Valley in New Mexico the bed of the river has in some places been aggraded above the adjacent flood-plain level. Such conditions seriously aggravate the flood and drainage problems.

In improving subsurface drainage, either the ground-water level may be lowered relative to the ground surface, as by ditching, or the ground surface may be raised relative to the ground-water level by directed deposition from sediment-laden water. Where sediment in progress of intermittent downstream transportation is concentrated in channels and headwater valleys, and where there are poorly drained lands farther downstream, directed deposition might provide a feasible means of reclaiming the lowlands and at the same time protecting other valley resources from future sediment damage.

Directed sedimentation, a practice whose origin is lost in antiquity, has been used in Italy for at least seven centuries and is used in England, where it is known as warping, and in France where it is called colmatage. Directed sedimentation has also been used in India and Malaysia, and in several localities in North America. In England, tidal areas previously protected by dikes have been successfully reclaimed by diverting the river water backed up by the high tides into the diked basins, allowing the water to clear by settling, and then draining off the clear water at low tide. The rate of accumulation depends, of course, on the sediment content of the water and the depth and frequency of flooding.

In the Federated Malay States, according to Robinson (*68, pp. 76–91*), unusually heavy sedimentation in the Bentong and other rivers, caused by mining activities in tributary areas, had converted the valley bottoms into waste areas and threatened the existence of towns, roads, and railroads. In the period 1927 to 1936 experimental directed sedimentation was successful in forcing deposition of about 420 acre-feet of sediment on the sand flats and in confining the Bentong River to a definite channel with banks more than 6 feet high. Vegetation became established on the valley deposits and thereby tended to stabilize them and also to induce further sedimentation. Plate 15 shows three stages in the reclamation of this river bottom. Leete and Cheyne (*42*) have described somewhat similar reclamation measures that are used in the headwaters of the Rangoon River, Burma, where excessive aggradation of the channels has interfered with the floating of teak logs to Rangoon.

PLATE 15.—Progressive reclamation of valley by directed sedimentation: *A*, Before reclamation was started, 1930; *B*, training fences built, sand-flat levels raised, and defined river bank formed, 1931; *C*, sand-flat levels raised further, river (in foreground) flows 6 feet below flood plain, and vegetation established, 1936. Bentong River, Federated Malay States (Courtesy A. G. Robinson).

For explanatory legend see opposite page.

A, Two to four feet of sand recently deposited in first-bottom pasture, South Tyger River, Greenville County, S. C. *B*, An overfall migrating up a minor tributary of the artificially straightened and deepened Boyer River. This is typical of many such overfalls associated with trenching of minor valleys in the Missouri Valley loess belt. Crawford County, Iowa.

In North America the former abundance of cheap land available for agricultural use has been an important factor in discouraging attempts to improve bottom lands by directed sediment deposition. Warren (*81, pp. 95–96*), however, records an instance of systematic reclamation by drainage and sedimentation of 7,000 acres in the Missequash Valley of Nova Scotia and New Brunswick between 1897 and 1911 at a total cost of $14 per acre. Lindenberger (*45*) has described an attempt at land building in canyons in San Bernardino County, Calif. King (*37, pp. 264–265*) has suggested that large areas of bottom lands in the eastern United States are suitable for reclamation by this method. Wilson (*82, p. 399*) has described the use of directed sedimentation in the rugged plateau country of southern Kentucky.

In addition to raising the land surface, definite improvements in the soil are possible in some places. Because of chemical deficiencies or unfavorable texture, some bottom-land soils are of low productivity even when well drained. For these bottom-land soils, controlled deposition of sediment that is in progress of downstream transportation or that is derived directly from normal erosion of upland topsoils offers a possible alternative to drainage and application of fertilizers.

The present investigation has been directed primarily toward securing a better understanding of the principles of accelerated sedimentation and has afforded no opportunity for experimental testing of the possibilities of land building by directed sedimentation. As a possible alternative or auxiliary method of sediment control, land building seems worthy of some small-scale experimentation to further test its feasibility, the situations to which it is adapted, the best engineering methods to be used, and the approximate cost of reclamation. Directed sedimentation would have the threefold justification of improving the land upon which the sediment was deposited, recovering some value from plant-food materials that otherwise would be lost to the sea, and preventing the sediment from injuring bottom-land resources by uncontrolled deposition in other places.

Land building is, however, open to the same criticisms as all other methods by which an attempt is made to control sedimentation without reducing the rate of sediment production at its source. Erosion will continue, perhaps at an accelerating rate, and the complexity of the problem and the cost of controlling the resulting sediment will therefore continue or increase. Land building by directed sedimentation should therefore be considered as a means of supplementing an upland erosion-control program rather than as a permanent alternative method for reduction of damage to valley resources by culturally accelerated sedimentation.

42. Stream-bank stabilization in headwater valleys offers a promising method for checking both erosion of valley lands and the production of harmful sediment.

In the Tobitubby and Hurricane Valleys stream-bank erosion has not been important except in the trenched sections of the valleys and locally where vegetation has been removed from ditch banks to facilitate more rapid discharge. In western Wisconsin, in many valleys in the southern Appalachians, and in many other parts of the United States, however, bank erosion has been much more serious, both as a process of erosional destruction of valley lands and as a process of harmful sediment production. As mentioned in the discussion of principle 14 (pp. 76–78), stream-bank erosion may progressively widen the channel and thus completely destroy the flood-plain land. This is common in the headwater parts of many valleys, especially where valley trenching is taking place. In other places the channel may migrate laterally and an equivalent area of new, but usually inferior, flood plain may be built behind it to replace the older flood plain that is destroyed. The latter is the more common type of bank erosion, and is probably somewhat less serious than channel widening as a source of harmful sediment. Both types, however, produce large quantities of coarse debris, mainly from the old channel deposits that characteristically underlie the flood plains. This coarse sediment, sand, or gravel and boulders may be an important cause of sediment damage where it is redeposited farther downstream.

In many places stream banks that have been stripped of their natural plant cover by removal of trees and brush or by overgrazing are much more susceptible to bank erosion than stream banks that have a protective cover. Rapidly eroding banks usually have little or no protective cover where the active cutting takes place. Experience in artificial ditching and channel improvement verifies the conclusion that banks stripped of plant cover are usually subject to increased erosion. In fact, it is common practice to take advantage of this relation between cover and erosion rate by digging channels smaller than desired and clearing vegetation from their banks, depending on bank erosion to widen the channel and thereby increase its discharge capacity (*61, p. 1*). The fact that the desired widening does not always take place, for one reason or another, does not invalidate the observation upon which the hope is based. Thus the cultural practice of clearing natural vegetation from stream banks appears to be one of the important factors in accelerating bank erosion during the modern period. Locally, other cultural modifications such as channel straightening and building of bridge piers and other structures that deflect the current are also factors that have increased stream-bank erosion.

Accelerated bank erosion commonly follows incision of headwater channels where valley trenching occurs. It also may occur where culturally accelerated upland erosion has caused filling of stream channels with sediment so that the stream channels tend to develop a shallower and wider cross section. It is widely believed that stream-bank erosion has also been accelerated by more frequent and more severe flash floods resulting from the cultural changes that have also caused accelerated upland soil erosion. The enormous differences in surface run-off rates that numerous plot studies have shown between forested or grass-covered plots on the one hand and various cultivated, overgrazed, or denuded plots on the other indicate that the surface run-off has probably increased in volume and become more flashy. The relation between upland cultural changes and stream-bank erosion is difficult to demonstrate by clear and undisputable examples, however, because of the many complex and interacting factors that affect the relationship.

The natural tendency of a stream is to erode on the outside of bends and to build up sediment deposits in the form of bars on the inside. In many streams, and perhaps in most, the resulting migration of the channel within the valley has been a major process in the formation of the flood plain. In such valleys, at least, the complete elimination of stream-bank erosion is not only impractical but impossible. In many places where the present rate of bank erosion has been accelerated by cultural influences, however, this rate apparently could be reduced by the application of appropriate measures to modify them. As clearing of vegetation from the stream banks appears to have been one of the principal cultural influences and as accelerated upland erosion and surface run-off have also been important, a rational program for control of stream-bank erosion should include attention to these factors.

Just what effect an upland erosion-control program might have on erosion of stream banks in the valleys below is not fully known, for nowhere in the United States have erosion-control measures yet been applied to previously uncontrolled uplands to a sufficient extent and for a sufficient time to demonstrate the downstream effects on bank erosion. Bank erosion, however, probably will still be a problem even though the amount of sediment and surface run-off delivered to the streams is decreased. If this is true, upland erosion-control measures will have to be supplemented by some method or methods of stream-bank stabilization in order to check destruction of valley lands and incidental production of harmful sediment. From the observed relations between eroding banks and vegetation, establishment of vegetation on the banks appears to offer a promising method of checking bank erosion without excessive cost, especially in minor valleys where the volume of run-off and the size of the channels are small. On many banks that are undercut and essentially vertical, auxiliary methods, such as the construction of jetties, may be necessary to check active erosion until vegetation becomes established.

48. The areas of most severe erosional damage may not be the areas of most serious production of harmful sediment.

The sediment derived from some areas that are being severely damaged by erosion may cause little or no harmful sedimentation, whereas that derived from areas where erosion is less extensive or less serious may cause very serious damage. Three important factors involved are (1) the amount of erosional debris, (2) its character, and (3) the value of the areas affected by its deposition.

(1) The quantity or bulk of erosional debris rather than its character is of prime importance in several types of damage by sedimentation. Filling of reservoirs, raising flood levels by flood-plain aggradation, damages to urban areas and highways, and the filling of ditches or irrigation canals are such types of damage. Even in these types of damage the character of the sediment and especially its texture may be of great importance. If the volume of sediment were the only factor, however, the areas contributing the greatest quantities of erosional debris would be responsible for the greatest sediment damage. The areas from which the greatest quantities of debris are eroded are not necessarily areas of most severe erosional damage. Equal erosion of naturally unproductive and naturally fertile land, for example, would ordinarily result in greater erosional damage to the latter. Insofar as volume of sediment is concerned, therefore, the areas of greatest damage by erosion may not be responsible for the greatest sediment damage.

(2) The character, especially the texture, of erosional debris largely determines how far the sediment will be transported, under what conditions it will accumulate, and the nature and extent of the damage that will result from its deposition. This is well illustrated by the contrast between sand and silt as causes of sediment damage in Tobitubby and Hurricane Valleys. Sand, which is derived almost entirely from gullying of the Holly Springs formation, comprises only about 25 percent of the modern valley deposits but causes most of the sediment damage. In the Piedmont and in the upper Mississippi Valley similar association of the major sediment damage with the coarse part of the erosional debris has been observed. Coarse sand, for example, has been a major cause of damage to the South Tyger Valley in Greenville County, S. C. (pl. 16, *A*). In the Rio Grande Valley of New Mexico, sand is a major factor in causing aggradation of the river bed above the head of the Elephant Butte Reservoir, whereas sediment of silt and clay size is largely responsible for the depletion of the reservoir capacity.

Fine sediment appears to be most injurious when deposited in reservoirs or other places where the bulk rather than the character of the sediment is important. Deposition on the flood plains of unproductive fine-grained material derived from upland subsoils has damaged bottom lands in some localities, but so far as is known such deposition of fine sediment does not appear to have caused much impairment of productive capacity, although the erosion of this material may have caused severe injury to the uplands. In contrast, the production of coarse sediment, usually from gullying, valley trenching, or stream-bank erosion, in smaller amounts or from smaller areas may cause less erosional damage but much greater sediment damage. Therefore, in planning a conservation program that includes consideration of possible valley benefits the sources of the injurious sediment should receive special attention.

(3) That the damage caused by accelerated sedimentation will depend largely upon the value of the valley lands or improvements affected is, of course, obvious. Even deposition of coarse sediment may cause no damage if the coarse debris accumulates in low swamp areas or other places that cannot be improved for agriculture or for other use. The erosional damage involved in the sediment production may be severe, but as a cause of sediment damage, the area might rank far behind some other less severely eroding upland area from which sediment was being carried onto improved agricultural land or a main highway, or directly into a reservoir, drainage ditch, navigable channel, or urban area.

Sediment damage may also be particularly severe as a result of erosion in an area directly tributary to the lower part of a major stream. This is especially true if much coarse sediment is delivered directly to the major stream or valley and as a result partly blocks the stream channel or, by building a fan into the main valley, obstructs surface drainage. The effects of such obstructions may extend upstream, causing increased flood damage, drainage impairment, and harmful sedimentation. The sediment causing the damage may be derived from a very small area and, even though the erosional damage may be less severe than in many other parts of the drainage basin, such areas should receive particular attention in any plan or program for reducing sediment damage by erosion-control methods.

44. Ditching or other channel improvements for valley drainage and flood control may cause increased valley and upland erosion by headward channel incision, and the ditches or channels themselves may be damaged by accumulation of the resulting sediment.

Many valleys cannot be used effectively for agriculture or for other purposes unless ditches are dug or stream channels improved, so that better drainage and more adequate channel capacity for discharge of floodwaters are provided. Ditches and improved channels are potentially subject to damage by sediment accumulation, however, and many attempted drainage or flood-control improvements have been impaired by sedimentation. In some places these improvements may contribute to their own later impairment by causing increased erosion in the valleys and uplands farther upstream. Very commonly the ditching or channel improvement deepens the channels, either directly by artificial excavation or by scouring that results from increased velocity of flow in the ditched or improved sections. Where this occurs the gradient immediately upstream is increased. Consequently, channel incision will begin and progress headward as an overfall or a zone of rapids that migrates up the main stream and the tributaries. Plate 16, *B* shows the head of a large gully initiated by ditching of a tributary of Boyer River, Crawford County, Iowa.

The headward migration of the zone of incision may be rapid, especially if the bed material is sandy, or very slow if it is clay or consolidated rock. Where migration is rapid the production of sediment, and particularly coarse sediment, which usually forms a major part of the old channel deposits underlying the flood plain, may be so great that sediment accumulation may seriously impair the effectiveness of the ditch or improved channel. In either case, the zone of incision may work back up the minor tributaries into the uplands, there inaugurate a new epicycle of accelerated upland gullying, and thus still further increase the rate of sediment delivery to the ditch or improved channel.

In view of these mutual interrelationships, plans for reclamation or protection of valley lands by ditching or channel improvement should include the consideration not only of sedimentation to be expected as a result of the existing rate and type of debris production in the tributary drainage basin but also of the possible effects of the headward incision that may be initiated by channel deepening. Foresight and prompt remedial measures may prevent damage both by sediment accumulation in the channel and by gully rejuvenation in the tributary uplands.

45. Upland erosion-control measures that retard erosion more than run-off, unless supplemented by valley-conservation measures, may cause increased erosion and downstream transportation of deposits now lodged in headwater valleys.

Experimental and observational data indicate that upland soil conservation measures will reduce the amount of sediment and surface run-off delivered to the stream systems (*59*). The same data, however, indicate that such control measures are ordinarily more effective in reducing the amount of soil erosion than the amount of immediate surface run-off. There is a question, therefore, as to what effect this differential change of sediment and water contribution will have on the regimen of the streams. Theoretically, three possibilities exist insofar as the stream channels are concerned, namely, (1) that the decreased volume of clearer water will be unable to transport the decreased volume of sediment and, therefore, that sediment will accumulate in the stream channels, (2) that the decreased volume of clearer water will just be able to transport the decreased volume of sediment and, therefore, that the level of the stream beds will not change, or (3) that the decreased volume of clearer water will transport not only the decreased amount of sediment but also some sediment from the bed and sides of its channel. In the last case the stream channels will be deepened or widened, or both. As a result, the valleys will gradually be degraded, and part of the sediment now lodged in headwater channels and valleys will be moved on downstream and perhaps cause increased damage there.

Upland erosion-control measures have not yet been applied to any previously unprotected areas for a long enough time and over sufficiently large areas to show which of these three possibilities will be most probable throughout the United States. The effect of controlled flow of desilted water below reservoirs indicates, however, that the third possibility certainly must be considered. In the Rio Grande below the Elephant Butte Reservoir (*70, pp. 291–295*), in the Colorado River below Lake Mead (*1, pp. 539–540*), and below several other reservoirs in the United States and Europe (*68*), the desilted water from reservoirs has produced measurable scouring of the channels for miles downstream.

For alleviation of damage in valleys in which injurious sedimentation has taken place, some increase in the capacity of stream channels by scour would appear to be advantageous. After an adequate channel has been secured, however, additional scour or lateral bank erosion may cause serious damage. In addition to the modern deposits, all or a large part of the premodern sediments might be removed and transported downstream. Inasmuch as the premodern deposits in the upper parts of the many valleys constitute a much larger percentage of the total valley fill than the modern deposits, the sediment load so derived might conceivably exceed that now being delivered to the trunk streams from upland erosion. Thus the combined erosional and depositional damage to valleys might become even greater than under present conditions. Therefore in some valleys the protection of the valley resources may necessitate supplementing upland erosion-control measures with valley-conservation measures to prevent excessive stream erosion. Particular attention should be given to valleys below areas where upland erosion control is practiced in order that the downstream effects of erosion-control measures may soon be evaluated.

SUMMARY

In the preceding pages the nature and scope of the problem of culturally accelerated stream and valley sedimentation has been briefly outlined, the results of detailed studies in two representative valleys of northern Mississippi have been reported, and 45 principles have been formulated and presented with explanatory discussions of each. These principles are based chiefly on the results of the detailed studies in Tobitubby and Hurricane Valleys, but they are also supported by less comprehensive studies in several other areas where sedimentation is serious. Each principle has been presented as a

statement of fact, and the object is to call attention to general truths concerning the problem of harmful sedimentation resulting from culturally accelerated soil erosion. Because of the present imperfect state of knowledge, the principles as now presented will require revision and extension as further information becomes available.

The detailed studies of Tobitubby and Hurricane Valleys reveal that during the 100 years or so of settlement, cultivation, and accelerated soil erosion about 14,258 acre-feet, or an average thickness of 3.3 feet, of sediment has accumulated in the valleys in which boring surveys were made. An additional 5,623 acre-feet of sediment is estimated to have been deposited on the flood plains of unsurveyed tributaries. The volume of sediment accumulated in the valleys and the amount carried past Greenwood, Miss., indicate that an average depth of at least 5.4 inches has been eroded from the uplands of the Tobitubby-Hurricane area. The distribution of the sediment in the valleys, together with some scanty data on quantities of sediment carried out of them, indicates that most of the erosional debris delivered from the uplands during the past 100 years still remains within the Tobitubby and Hurricane drainage basins as valley deposits.

As a result of the accelerated sedimentation, 1,930 acres (27.7 percent) of the valley land has been damaged by sand overwash or by swamping, or both, and an additional 2,240 acres (32.1 percent) is of little value because of frequent flooding. Such flooding is also due in part to the effects of excessive sedimentation. Many stream channels, both natural and artificial, have been partly or completely filled with sediment. Deposition of sand, derived almost entirely from gullies cut through the loessial upland cover into the underlying unconsolidated Holly Springs sand, has caused most of the sediment damage.

The combined results of these detailed investigations and other more widespread reconnaissance studies point to several broad generalizations of major significance. Accelerated stream and valley sedimentation is much more widespread and progressive accumulation is taking place much more rapidly than has been commonly realized either by the general public or by specialists in allied fields of scientific inquiry. The past and prospective future damage resulting from such sedimentation is of sufficient importance to be of national concern. Damage has been of many diverse kinds, but so far as is now known the most important have been (1) impairment of the productive capacity of agricultural valley lands by changes in soil texture, composition, or drainage, (2) aggravation of flood danger and flood damage by filling of channels and aggradation of flood plains with consequent increases in height and frequency of overbank floods, and (3) impairment of the effectiveness or usefulness of artificial structures and improvements. The amount of damage varies greatly according to the area and value of the land and the size and value of structures or improvements within the areas of excessive sediment accumulation, as well as according to the rates of sedimentation.

Texture of sediment is a major factor in determining the nature of sedimentation and the extent of the damage. Largely on this account gullying, valley trenching, and stream-bank erosion are judged to be relatively more important, in comparison with sheet erosion, as sources of harmful sediment than as causes of erosional damage alone. It also appears that the erosional areas responsible for the most serious sediment damage may not be the areas that have been most seriously damaged by erosion.

In many places it has been found practicable to identify and measure with reasonable accuracy the valley sediments that have been deposited within the modern period of accelerated erosion and sedimentation. Comparison of the results of sediment measurements with the available data on volumes of erosional debris produced from uplands during the same period and with data on the suspended load carried by major streams leads to the conclusion that in some sections of the country the greatest part of the erosional debris has been, and is, accumulating in minor headwater valleys, within 10 miles or so of the place of origin. This means that the full effects of accelerated soil erosion and attendant sedimentation have not yet been felt in main trunk streams and valleys. Hence the problem of accelerated stream and valley sedimentation will become much more serious in the future unless present trends are reversed by conservation measures or by other influences not now foreseen.

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APPENDIX

As part of the Tobitubby-Hurricane investigations mechanical analyses were made of 353 selected samples of the fluvial deposits. The results of this analytical work have been used in many ways throughout the text of the bulletin. The analytical results afford a check on field determination of texture and permit more accurate calculation of the average texture of the modern and premodern deposits in various parts of the valleys and in the entire modern valley fill. Statistical values derived from the analytical results have been used in comparing the sorting of the modern and premodern deposits. Tables 3 and 11, and figures 10, 13, and 15 are based on these results.

In order to avoid excessive tabulation in the body of the bulletin, the analytical results are presented as table 10. These data, which possibly comprise the largest published series of mechanical analyses of flood-plain deposits, are presented for the information of specialists interested in stream- and valley-sedimentation problems.

Analytical work [20] was done at the sedimentation laboratory of the department of geology, University of Chicago, through the courtesy of that institution. Two methods of analysis were used. The composition of the sands was determined by sieving for 10 to 15 minutes through standard Tyler sieves in a Rotap shaker. The fine-grained sediments were analyzed by the pipette method (*38*) as modified by Rittenhouse (*62*). Samples containing both sand and silt were analyzed by a combination of the two methods, the samples being wet-sieved through a 250-mesh (1/16-mm.) sieve to separate the sand and silt. Dispersion of the samples was essentially that recommended by Krumbein (*40*). Batteries of 48 samples were analyzed simultaneously. A detailed description of the analytical technique has been prepared for publication.[21]

The analytical results were plotted as cumulative curves and the first quartile, median, and third quartile read directly from the curve. The arithmetic sorting, the geometric sorting (Trask's sorting coefficient), and the skewness were computed from the quartile and median values as recommended by Krumbein (*41*). These values have been presented in table 10 to facilitate use of the analytical data by other technical workers.

The average mechanical composition of the modern valley sediments at each boring range is presented in table 11. These values were computed from field determinations of texture at each boring hole and from the mechanical analyses of selected samples, as follows:

It was assumed that each boring on a range was representative of the modern fill half way to the adjacent borings. The cross-sectional area of fill so represented was determined by planimeter from the plotted cross sections of each boring range (figs. 8, 9, and 10). This area was multiplied by the percent of each textural class (silt, fine sandy silt, etc.) in the boring hole as determined by field examination, to give the area represented by each textural class. All mechanical analyses of each textural class were averaged to give the percent of sediment in each grade size (1/2–1/4, 1/4–1/8, 1/8–1/16 mm. etc.) in each textural class. The percent of sediment of each grade size in each textural class was multiplied by the area represented by the textural class. The areas represented by each grade size of the several textural classes at each boring were added. The result was the cross-sectional area of each grade size represented by the boring. The cross-sectional area of each size for the entire range was secured by adding the areas of each grade size from the several borings on the range, and percentages were calculated by dividing this figure by the total cross-sectional area of fill. Statistical values were derived in the same manner as for individual analyses.

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TABLE 10.—*Results of mechanical analyses of fluvial deposits from Tobitubby and Hurricane Valleys*

HURRICANE CREEK—RANGE 4

Sample No.	Hole No.	Depth	Amount in indicated grade size											Derived results					
			>1/2 mm.	1/2–1/4 mm.	1/4–1/8 mm.	1/8–1/16 mm.	>1/16 mm.	1/16–1/32 mm.	1/32–1/64 mm.	1/64–1/128 mm.	1/128–1/256 mm.	1/256–1/512 mm.	<1/512 mm.	Q_1	*Md*	Q_3	Arithmetic sorting $\frac{(Q_1-Q_3)}{2}$	Trask sorting $\sqrt{Q_1/Q_3}$	Skewness $\sqrt{\frac{Q_1 \cdot Q_3}{Md^2}}$
		Inches	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Mm.*	*Mm.*	*Mm.*			
332	1B	0– 4	1.4	2.2	3.7	8.2	15.5	18.6	25.3	16.0	6.6	3.7	14.2	0.0400	0.0206	0.0079	0.0161	2.25	0.86
334	1B	72– 76	1.0	9.1	9.5	3.2	22.8	8.4	26.2	20.5	8.8	3.6	9.7	.0450	.0184	.0087	.0182	2.27	1.08
364	2B	0– 4		1.1	7.2	4.9	13.2	6.9	17.6	17.6	14.8	7.6	22.2	.0250	.0096	.00265	.0112	3.07	.85
365	2B	4– 8	.6	3.5	4.2	2.0	10.3	9.4	24.9	18.2	11.1	5.4	20.7	.0267	.0131	.0035	.0116	2.76	.74
366	2B	8– 12	.8	5.8	2.6	1.9	11.1	9.9	27.6	19.4	9.7	4.2	18.0	.0276	.0148	.0050	.0113	2.35	.79
367	2B	12– 16	.9	3.6	2.5	2.1	9.1	13.5	29.7	18.6	9.3	3.7	16.2	.0294	.0166	.0062	.0116	2.18	.81
368	2B	16– 20	8.8	30.3	22.4	2.1	63.6	4.1	9.9	7.9	4.2	1.7	8.5	.310	.199	.0180	.1460	4.15	.38
369	2B	20– 24	2.3	8.6	8.3	2.3	21.5	5.7	24.4	20.4	10.6	3.1	14.1	.0375	.0160	.0069	.0153	2.33	1.01
370	2B	24– 28	1.0	6.3	6.7	2.1	16.1	5.9	22.7	24.8	10.5	4.9	15.1	.0272	.0141	.0057	.0108	2.18	.88
371	2B	28– 32	.6	2.9	4.2	2.8	10.5	10.4	31.2	21.7	8.0	3.7	14.8	.0270	.0162	.0072	.0099	1.94	.86
372	2B	32– 36					8.2	10.1	37.2	22.0	6.5	3.0	13.1	.0267	.0175	.0089	.0089	1.73	.88
373	2B	36– 40					3.3	29.2	28.7	20.3	5.2	1.8	11.2	.0370	.0208	.0104	.0133	1.88	.94
374	2B	40– 44					4.7	18.4	33.8	22.7	6.5	2.3	11.9	.0303	.0182	.0095	.0104	1.78	.93
375	2B	44– 48					5.5	5.9	27.0	28.0	11.6	5.9	16.2	.0172	.0090	.0046	.0063	1.93	.99
376	2B	48– 52					2.7	14.2	30.1	25.0	9.5	4.1	14.5	.0255	.0147	.0067	.0094	1.95	.89
377	2B	52– 56	.4	1.9	4.8	4.5	11.6	9.7	24.2	23.8	11.8	4.9	13.9	.0271	.0139	.0062	.0105	2.09	.93
379	2B	56– 60					8.8	6.5	23.0	23.5	11.9	5.2	21.1	.0225	.0114	.0034	.0096	2.57	.77
378	2B	60– 64					8.3	14.6	14.9	25.3	12.6	5.3	19.0	.0207	.0119	.0041	.0083	2.25	.77
380	2B	64– 68	.5	3.6	5.5	2.9	12.5	7.8	25.4	23.1	11.2	4.1	15.9	.0262	.0140	.0057	.0103	2.14	.87
335	3B	0– 4					8.8	3.4	13.2	[illegible]	16.2	11.1	27.1	.0160	.0066	.00167	.0072	3.10	.79
336	3B	48– 52					5.5	4.9	24.2	26.3	13.6	7.7	17.8	.0196	.0108	.0038	.0079	2.27	.80
337	4B	0– 4					7.9	3.3	22.1	23.2	14.8	8.8	20.3	.0193	.0096	.0030	.0082	2.53	.79
338	4B	50– 55					15.2	4.4	15.3	21.2	15.5	9.7	18.7	.0220	.0097	.0032	.0094	2.62	.86
359	6	76– 80		2.1	1.3	2.2	5.6	8.7	22.8	27.4	13.0	4.9	17.6	.0212	.0117	.0047	.0083	2.12	.85
360	7	0– 4	1.9	30.5	10.7	4.1	47.2	18.9	13.2	9.4	4.6	1.2	5.4	.310	.052	.0195	.1453	3.99	1.49
361	7	104–108		39.8	19.1	7.2	66.1	6.6	10.5	7.7	3.6	1.5	3.9	.340	.173	.0235	.1583	3.80	.52
362	8B	0– 4	13.6	39.4	14.9	3.5	71.4	5.5	7.7	5.9	2.7	1.3	5.7	.403	.259	.038	.1825	3.26	.48
363	8B	63– 68	1.8	4.7	2.7	1.1	10.3	10.6	31.6	18.4	10.2	4.5	14.3	.0280	.0165	.0063	.0109	2.11	.80
339	10	0– 4	.6	6.0	8.2	4.0	18.8	9.4	27.4	20.1	7.2	3.6	13.4	.0370	.0178	.0080	.0145	2.15	.97
340	10	4– 8	3.4	34.3	23.8	5.2	66.7	6.6	10.8	5.7	1.8	1.4	6.9	.298	.186	.028	.1350	3.26	.49
341	10	8– 12	3.0	30.1	26.0	3.9	63.0	7.7	11.8	[1] 17.4				.280	.172	.0240	.1280	3.42	.48
342	10	12– 16	6.7	35.5	27.7	6.4	76.3	3.9	7.4	3.8	1.3	.7	6.5	.324	.212	.074	.1250	2.09	.73
343	10	16– 20	4.1	24.9	25.6	7.7	62.3	9.6	12.3	5.8	1.8	1.1	7.0	.268	.147	.0275	.1203	3.12	.58
344	10	20– 24	1.5	8.8	15.4	7.3	33.0	14.6	26.2	11.6	3.6	.9	10.2	.130	.0295	.0149	.0576	2.95	1.49
345	10	24– 28	1.3	5.1	4.2	1.9	12.5	20.8	34.7	15.9	4.0	1.9	10.2	.0370	.0220	.0124	.0123	1.73	.94

346	10	28- 32	1.0	5.0	4.2	1.7	11.9	13.4	19.6	37.3	5.3	1.6	11.1	.0315	.0142	.0098	.0100	1.79	1.24
347	10	32- 36	2.1	10.6	7.9	3.2	23.8	13.5	24.4	20.3	3.9	1.4	12.8	.052	.0222	.0102	.0209	2.26	1.04
348	10	36- 40	2.0	9.7	8.5	6.0	26.2	20.7	28.3	9.7	2.7	1.0	11.2	.064	.0205	.0157	.0242	2.02	1.07
349	10	40- 44	4.2	24.7	18.9	5.0	52.8	8.0	16.6	9.4	2.9	1.5	9.0	.273	.095	.0173	.1279	3.97	.72
350	10	44- 48	1.4	4.6	7.2	5.3	18.5	13.5	30.6	18.8	4.9	2.0	11.8	.041	.0202	.0106	.0152	1.97	1.03
351	10	48- 52					7.7	11.7	29.9	21.5	8.5	3.5	17.4	.0264	.0152	.0090	.0102	2.10	.83
352	10	52- 56						[2] 19.2	31.6	24.6	7.6	2.8	14.0	.0267	.0158	.0079	.0094	1.84	.92
353	10	56- 60						[2] 25.4	37.7	19.2	5.2	1.8	10.6	.0135	.0199	.0114	.0011	1.66	.95
354	10	60- 64	1.3	2.7	2.5	2.6	9.1	15.4	40.7	17.8	4.7	2.0	10.4	.0312	.0211	.0114	.0099	1.66	.89
355	10	64- 68	2.8	9.0	6.2	3.4	21.4	16.8	35.0	13.0	3.6	.9	9.3	.0475	.0250	.0148	.0164	1.79	1.06
356	10	68- 72	2.9	13.9	14.3	6.9	38.0	15.5	24.9	9.6	2.2	1.4	8.4	.172	.0347	.0177	.0772	3.12	1.59
357	10	72- 76	4.4	16.0	10.8	6.1	37.3	21.5	20.0	7.5	2.5	.9	10.2	.193	.0397	.0184	.0873	3.24	1.50
358	10	76- 80	3.5	32.1	27.3	4.9	67.8	8.0	12.7	5.1	1.5	.6	4.4	.286	.190	.0326	.1267	2.96	.51
262	10	80- 88					10.1	10.2	33.6	20.8	7.8	4.5	13.0	.028	.0168	.00765	.0102	1.91	.87
263	10	88- 92					6.0	9.3	36.4	27.0	6.4	3.8	11.2	.0220	.0160	.0096	.0062	1.51	.91
264	10	92- 96					5.0	5.5	34.8	27.5	9.8	5.1	12.6	.0193	.0148	.0070	.0082	1.66	.79
265	10	96-100		2.2	2.2	2.0	6.4	10.0	32.2	24.9	12.6	3.4	10.5	.0247	.0151	.0073	.0087	1.84	.89
266	10	100-104					12.4	8.5	26.9	21.5	12.0	7.1	11.6	.0265	.0150	.0062	.0102	2.07	.85
267	10	104-108					7.9	10.0	25.5	19.8	10.5	6.9	19.4	.0237	.0130	.0035	.0101	2.60	.70
268	10	108-112					7.1	10.8	26.5	19.2	10.0	6.0	20.5	.0248	.0133	.0031	.0107	2.70	.69
269	10	112-116					8.1	11.8	25.0	20.0	10.4	6.1	19.0	.0256	.0137	.00402	.0108	2.52	.74
270	10	116-120					8.1	12.7	28.7	21.6	6.9	4.0	18.0	.0259	.0153	.0056	.0107	2.19	.80
271	10	120-124					7.1	16.0	29.9	19.1	7.1	3.7	17.2	.0296	.0167	.0066	.0115	2.12	.84
272	10	124-128					10.2	12.6	33.1	19.4	5.3	3.2	16.1	.0293	.0172	.0079	.0107	1.93	.88
273	10	128-132					6.9	12.4	31.2	19.2	5.0	3.4	18.9	.0263	.0164	.0062	.0101	2.05	.78
274	10	136-140					5.0	14.5	34.7	15.6	7.2	3.1	20.1	.0275	.0178	.0051	.0112	2.32	.66
275	10	140-144					6.8	13.0	33.2	16.6	5.7	3.0	21.6	.0267	.0162	.0034	.0117	2.80	.59
276	11	0- 4						2.7	21.1	30.3	16.0	7.7	22.2	.0151	.0086	.00256	.0063	2.43	.73
277	11	36- 40					3.4	17.0	41.0	17.7	5.1	2.2	13.5	.0284	.0197	.0097	.0094	1.71	.84
278	11	68- 72					4.7	10.4	36.1	23.9	8.7	4.7	11.6	.0244	.0158	.0078	.0083	1.77	.87
279	12	0- 4	2.9	8.0	6.7	2.7	20.3	13.2	30.0	17.1	4.4	3.0	12.1	.0440	.0208	.0108	.0166	2.02	1.05
280	12	8- 12					4.0	23.4	38.1	13.7	3.6	[3] 17.2		.0330	.0220	.0102	.0114	1.80	.83
281	12	20- 24					13.8	13.9	32.4	17.5	7.0	[3] 15.4		.0340	.0207	.0090	.0125	1.94	.84
281D [4]	12	20- 24	.7	4.6	5.2	3.4	13.9	16.6	31.6	16.2	7.3	4.3	10.2	.0375	.0200	.0098	.0139	1.96	.96

[1] Percent finer than 1/64 mm. [2] Percent coarser than lower limit of grade indicated. [3] Percent finer than 1/256 mm. [4] D indicates duplicate analysis.

TABLE 10.—*Results of mechanical analyses of fluvial deposits from Tobitubby and Hurricane Valleys*—Continued

HURRICANE CREEK—RANGE 7

Sample No.	Hole No.	Depth	Amount in indicated grade size											Derived results					
			>1/2 mm.	1/2–1/4 mm.	1/4–1/8 mm.	1/8–1/16 mm.	>1/16 mm.	1/16–1/32 mm.	1/32–1/64 mm.	1/64–1/128 mm.	1/128–1/256 mm.	1/256–1/512 mm.	<1/512 mm.	Q_1	Md	Q_3	Arithmetic sorting $\frac{(Q_1-Q_3)}{2}$	Trask sorting $\sqrt{Q_1/Q_3}$	Skewness $\sqrt{\frac{Q_1 \cdot Q_3}{Md^2}}$
		Inches	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Mm.*	*Mm.*	*Mm.*			
424	2	0– 4	1.6	18.3	24.0	6.5	50.4	13.6	13.4	7.5	2.5	1.1	11.4	0.218	0.065	0.0180	0.1000	3.48	0.96
425	2	108–112					9.8	14.2	38.7	17.7	6.3	3.2	10.2	.0307	.0197	.0106	.0101	1.70	.92
397	3B	0– 4	4.5	18.3	11.1	3.4	37.3	10.1	21.1	11.9	4.5	2.6	12.6	.216	.0284	.0113	.1024	4.37	1.74
398	3B	4– 8					9.9	10.1	27.3	23.1	9.0	3.0	17.4	.0262	.0149	.0060	.0101	2.09	.84
399	3B	8– 12	4.8	18.4	9.0	1.6	33.8	7.5	22.4	15.4	5.3	1.7	14.1	.227	.0225	.0100	.1085	4.77	2.12
400	3B	12– 16	14.6	49.1	19.7	2.9	86.3	2.7	3.8	1.7	.4	.4	4.4	.405	.297	.193	.1060	1.45	.94
401	3B	16– 20	10.7	40.5	20.7	5.0	76.9	7.8	6.5	2.2	.6	.5	5.6	.368	.248	.073	.1475	1.76	.66
402	3B	20– 24	9.6	48.5	22.6	3.7	84.4	4.8	4.2	1.4	.5	.3	4.5	.370	.270	.185	.0925	1.41	.97
403	3B	24– 28	3.3	12.4	6.4	2.3	24.4	12.1	27.3	16.1	4.9	1.8	13.7	.055	.0212	.0104	.0223	2.30	1.13
404	3B	28– 32	2.4	8.9	4.1	1.4	16.8	16.1	23.6	18.7	6.3	2.4	16.1	.0420	.0182	.0079	.0171	2.35	1.00
404D	3B	28– 32	2.2	8.9	3.9	1.2	16.2	12.3	30.9	17.0	5.4	2.7	15.5	.0360	.0191	.0088	.0136	2.02	.93
405	3B	32– 36					8.8	17.2	36.2	16.5	4.8	1.8	14.7	.0322	.0194	.0102	.0110	1.78	.93
406	3B	36– 40					7.6	16.2	37.6	16.8	4.9	1.9	14.8	.0302	.0197	.0098	.0102	1.75	.87
407	3B	40– 44					7.1	13.7	36.0	19.5	6.1	2.2	15.3	.0276	.0178	.0085	.0096	1.80	.86
408	3B	44– 48	1.1	3.1	2.2	3.4	9.8	24.7	34.9	12.9	4.3	1.5	11.9	.0195	.0115	.0063	.0066	1.76	.96
409	3B	48– 52					6.0	19.6	37.5	16.4	3.8	1.7	14.9	.0318	.0198	.0104	.0107	1.75	.92
410	3B	52– 56					8.0	25.1	24.4	18.4	6.2	3.1	14.5	.0382	.0194	.0083	.0150	2.15	.92
411	3B	56– 60					6.6	13.0	26.8	24.8	8.5	4.4	15.6	.0260	.0144	.0061	.0100	2.08	.87
412	3B	60– 64					8.2	7.8	29.8	24.0	10.0	5.1	15.1	.0238	.0140	.0058	.0090	2.02	.84
413	3B	64– 68					8.5	19.5	22.6	22.6	9.6	4.9	12.2	.0346	.0160	.0073	.0137	2.18	.99
414	3B	68– 72					6.9	13.3	28.1	22.8	7.3	3.2	18.4	.0272	.0150	.0061	.0106	2.11	.86
415	3B	72– 76					10.0	12.7	17.8	32.2	7.4	3.4	16.3	.0270	.0125	.0068	.0101	1.99	1.00
416	3B	76– 80	1.5	5.7	2.6	.6	10.4	18.6	24.2	22.2	6.6	[3] 17.9		.0359	.0170	.0079	.0140	2.13	.99
417	3B	80– 84	3.5	8.7	3.7	1.2	17.1	7.3	28.5	19.9	6.8	3.1	17.6	.0320	.0166	.0060	.0126	2.15	.90
418	3B	84– 88	3.5	7.8	3.5	1.2	16.0	7.9	26.2	19.6	8.3	2.3	19.3	.0303	.0156	.0055	.0124	2.35	.83
418D	3B	84– 88					17.8	8.3	25.9	19.7	7.8	3.5	17.1	.0330	.0164	.0062	.0134	2.31	.87
419	3B	88– 92	2.9	9.6	4.3	1.3	18.1	16.0	18.0	20.0	8.7	4.0	15.2	.0370	.0163	.0064	.0153	2.40	.94
419D	3B	88– 92	5.7	9.0	3.8	1.7	20.2	8.8	25.6	19.0	7.9	3.4	14.9	.047	.0178	.0072	.0199	2.55	1.03
420	3B	92– 96	3.2	9.8	4.2	1.4	18.6	10.5	25.2	19.7	7.1	3.3	15.3	.0380	.0174	.0074	.0153	2.27	.95
420D	3B	92– 96	4.0	9.7	4.3	1.4	19.4	9.3	27.6	18.4	7.8	3.4	14.1	.0370	.0182	.0077	.0147	2.19	.93
421	3B	96–100	3.7	9.0	4.1	1.2	18.0	8.8	25.5	19.8	6.9	3.2	17.7	.0340	.0165	.0062	.0139	2.34	.88
421D	3B	96–100	4.2	8.9	4.0	1.3	18.4	8.0	26.4	18.9	7.7	3.5	16.9	.0340	.0166	.0062	.0139	2.34	.88
422	3B	100–104	2.9	8.9	4.1	1.1	16.9	15.8	17.7	18.2	9.9	3.1	18.4	.0410	.0160	.0055	.0178	2.73	.94
422D	3B	100–104	3.5	8.9	4.2	1.3	17.9	8.2	25.7	19.4	7.6	3.5	17.6	.0330	.0161	.0058	.0136	2.38	.86
423	3B	104–108	3.6	9.6	4.8	1.4	19.4	15.0	16.4	19.3	7.5	3.5	19.0	.0420	.0160	.0057	.0182	2.72	.97

423D	3B	104-108	3.6	9.4	4.9	1.5	19.4	8.5	24.0	18.2	8.3	3.9	17.7	.0358	.0104	.0056	.0151	2.53	.86
426	5	0- 4	----	----	4.3	11.3	15.6	([5])	42.5	14.9	6.5	3.0	17.2	.0410	.0201	.0065	.0173	2.51	.81
427	5	32- 37	1.9	5.1	7.7	4.3	19.0	12.5	29.6	17.7	7.4	4.3	9.6	.0420	.0203	.0095	.0163	2.10	.98
428	6	0- 4	.7	7.8	24.5	20.5	53.5	16.2	10.6	5.7	1.8	[3] 12.1	----	.157	.068	.0230	.0670	2.61	.88
420	6	36- 40	----	----	----	----	9.2	6.7	28.4	24.4	9.7	5.1	16.6	.0230	.0135	.0055	.0088	2.05	.83
457	9	0- 4	1.7	7.7	13.0	10.5	32.9	24.8	15.3	9.4	3.4	2.1	12.1	.092	.0195	.0136	.0392	2.60	1.81
458	9	80- 84	----	----	----	----	6.6	3.9	18.9	27.3	15.2	8.6	19.4	.0173	.0096	.0032	.0071	2.33	.77
430	11	0- 4	----	----	15.8	24.4	40.2	19.0	13.1	7.3	3.6	1.9	14.8	.095	.046	.0138	.0406	2.62	.79
431	11	4- 8	2.5	52.8	32.6	5.4	93.3	----	----	----	----	----	----	.340	.260	.185	.0775	1.36	.96
432	11	8- 12	6.6	28.7	20.5	7.0	62.8	9.8	8.7	6.5	2.8	1.1	8.4	.303	.162	.0257	.1387	3.43	.54
433	11	12- 16	----	----	----	----	13.1	12.6	32.6	17.9	5.8	2.6	15.3	.0325	.0187	.0085	.0120	1.95	.89
434	11	16- 20	1.3	19.0	12.0	4.3	36.6	8.9	28.4	10.5	2.9	1.4	11.2	.204	.0262	.0140	.0950	3.81	2.04
435	11	20- 24	.3	4.4	4.8	4.6	14.1	15.2	27.4	17.4	6.9	2.2	16.6	.0365	.0185	.0075	.0145	2.21	.90
436	11	24- 28	.3	3.2	7.4	6.4	17.4	20.0	26.4	14.9	4.4	3.6	13.5	.043	.0232	.0101	.0165	2.06	.90
437	11	28- 32	.3	3.6	5.5	3.2	12.6	12.1	27.3	19.8	8.6	3.7	15.6	.0314	.0161	.0065	.0125	2.20	.89
438	11	32- 36	.2	6.2	20.0	9.2	35.6	12.1	21.0	13.1	4.4	1.8	11.8	.133	.0294	.0121	.0605	3.31	1.37
430	11	36- 40	.5	11.1	18.3	5.2	35.1	8.6	21.1	13.8	5.7	2.6	12.8	.157	.0248	.0100	.0735	3.96	1.60
440	1'	40- 44	.2	4.1	7.4	5.0	16.7	14.9	25.6	17.6	7.8	3.0	14.3	.0401	.0188	.0078	.0162	2.27	.94
441	11	44- 48	.3	8.2	11.7	3.7	23.9	11.7	26.6	15.6	6.9	3.1	12.2	.0530	.0203	.0092	.0219	2.40	1.09
442	11	48- 52	----	----	----	----	9.9	10.1	33.9	22.6	6.1	4.5	12.9	.0262	.0168	.0084	.0080	1.77	.88
443	11	52- 56	----	----	----	----	9.9	9.4	32.2	23.3	7.7	[3] 17.5	----	.0262	.0160	.0078	.0092	1.82	.80
444	11	56- 60	----	----	----	----	6.9	7.5	32.3	25.3	9.4	3.6	15.0	.0230	.0145	.0068	.0081	1.84	.86
445	11	60- 64	----	----	----	----	9.0	8.1	29.4	25.2	9.0	3.5	14.9	.0249	.0148	.0070	.0090	1.89	.89
446	11	64- 68	----	----	----	----	7.6	7.3	35.1	24.2	8.1	4.2	13.4	.0240	.0156	.0075	.0083	1.79	.86
447	11	68- 72	----	----	----	----	18.4	5.8	23.5	22.6	9.4	5.5	14.8	.0300	.0147	.0060	.0120	1.23	.91
448	11	72- 76	----	----	----	----	15.4	6.4	25.0	23.6	10.9	5.7	12.9	.0268	.0147	.0061	.0104	2.09	.87
449	11	80- 84	.3	2.5	5.0	4.1	11.9	15.4	25.7	24.1	11.3	5.0	6.6	.0337	.0167	.0084	.0127	2.00	1.01
450	11	84- 88	.3	2.1	6.2	4.9	13.5	17.7	23.7	21.8	9.8	5.3	8.2	.0380	.0177	.0084	.0148	2.12	1.01
451	11	88- 92	----	----	----	----	15.3	10.3	27.4	20.4	7.5	4.7	14.6	.0322	.0166	.0071	.0126	2.13	.91
452	11	92- 96	----	----	----	----	14.3	10.3	28.9	20.0	8.7	3.8	14.0	.0312	.0169	.0070	.0121	2.11	.87
453	11	96-100	----	----	----	----	14.9	11.1	30.4	21.2	7.2	3.2	12.0	.0329	.0177	.0089	.0120	1.92	.97
454	11	100-104	----	----	----	----	14.9	10.0	33.3	20.1	7.3	3.1	11.1	.0313	.0182	.0091	.0111	1.855	.93
455	11	104-108	.4	3.1	6.2	4.7	14.4	13.3	26.6	19.2	6.7	3.2	16.6	.0345	.0170	.0068	.0139	2.25	.90
456	11	108-112	----	2.4	6.7	4.6	13.7	12.0	27.8	20.2	7.3	3.9	15.1	.0320	.0170	.0072	.0124	2.11	.89
459	12B	0- 4	1.4	5.9	6.4	3.5	17.4	12.1	18.2	19.5	10.8	6.7	15.3	.0384	.0143	.0051	.0167	2.74	.98
460	12B	60- 69	1.1	4.9	6.1	3.2	15.3	11.8	22.8	20.4	10.2	7.0	12.5	.034	.0153	.0050	.0141	2.40	.93
461	13B	0- 4	6.8	20.5	13.5	4.0	53.8	13.7	13.3	7.7	3.0	2.1	6.4	.320	.100	.0215	.1493	3.86	.83
462	13B	80- 84	1.1	6.5	5.6	1.5	14.7	14.6	28.7	18.6	8.2	5.6	9.5	.0360	.0190	.0085	.0138	2.06	.92

[1]Percent finer than 1/256 mm.

[3] Included in 1/32-1/64 mm. grade.

TABLE 10.—*Results of mechanical analyses of fluvial deposits from Tobitubby and Hurricane Valleys*—Continued

TOBITUBBY CREEK—RANGE 1

Sample No.	Hole No.	Depth	Amount in indicated grade size											Derived results					
			>1/2 mm.	1/2-1/4 mm.	1/4-1/8 mm.	1/8-1/16 mm.	>1/16 mm.	1/16-1/32 mm.	1/32-1/64 mm.	1/64-1/128 mm.	1/128-1/256 mm.	1/256-1/512 mm.	<1/512 mm.	Q_1	Md	Q_3	Arithmetic sorting $\frac{(Q_1-Q_3)}{2}$	Trask sorting $\sqrt{Q_1/Q_3}$	Skewness $\sqrt{\frac{Q_1 \cdot Q_3}{Md^2}}$
		Inches	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Mm.*	*Mm.*	*Mm.*			
85	1b	0- 4	5.5	42.6	25.0	6.6	79.7	5.9	7.1	2.6	0.9	0.4	3.5	0.351	0.238	0.110	0.1205	1.78	0.83
86	1b	4- 11	5.2	44.3	25.5	5.6	80.6							.333	.244	.124	.1045	1.64	.83
87	1b	11- 15	3.9	30.9	18.3	4.7	57.8							.299	.150	.0196	.1397	3.91	.51
88	1b	15- 19					7.5	21.1	36.1	11.7	4.7	1.7	17.2	.0335	.0225	.0090	.0123	1.92	.77
89	1b	19- 23	2.8	28.2	20.9	5.0	56.9							.280	.142	.0305	.1248	3.06	.65
89D	1b	19- 23	2.2	20.4	19.6	4.6	55.8	10.0	13.9	6.5	2.0	[3] 11.6		.280	.132	.0202	.1299	3.72	.57
90	1b	23- 28	1.3	7.8	4.7	4.0	17.8	16.8	27.9	12.5	4.3	2.8	17.9	.0420	.0220	.0078	.0171	2.32	.82
91	1b	28- 33					8.4	10.2	31.2	22.3	9.2	5.3	13.4	.0263	.0155	.0064	.0100	2.03	.84
92	1b	33- 38	.7	12.0	10.9	3.2	26.8	11.9	24.8	15.4	6.2	3.6	11.0	.0900	.0231	.0096	.0402	3.06	1.27
93	1b	38- 44	1.2	28.3	26.9	5.6	62.0							.267	.161	.026	.1205	3.20	.52
93D	1b	38- 44	.9	28.5	25.7	5.3	60.4	8.5	14.3	6.6	2.4	[3] 7.9		.267	.158	.0239	.1216	3.34	.51
94	1b	44- 48	.6	23.9	30.3	7.8	62.6							.244	.147	.028	.1080	2.95	.56
95	1b	48- 55	.8	12.4	19.3	6.3	38.8	10.8	21.0	12.2	4.5	2.7	10.0	.168	.0310	.0129	.0776	3.63	1.50
96	1b	55- 57	1.5	7.3	9.5	2.9	21.2	9.8	29.6	17.3	6.3	3.2	12.5	.041	.0201	.0095	.0158	2.08	.98
97	1b	57- 63	1.6	6.0	6.7	2.1	16.4	9.9	31.7	18.2	6.3	2.4	15.5	.0334	.0188	.0084	.0125	1.99	.89
98	1b	63- 67					9.8	10.3	38.4	13.0	6.3	3.6	18.5	.0275	.0178	.0106	.0085	1.64	.96
99	1b	67- 72					8.8	8.9	31.7	21.6	6.8	4.0	18.4	.0250	.0155	.0055	.0098	2.13	.76
100	1b	72- 83	1.7	7.7	7.9	2.3	19.6	7.9	22.4	18.5	7.7	4.6	19.3	.0365	.0155	.0045	.0160	2.85	.83
101	1b	88- 92½	3.1	18.0	21.4	5.2	47.7	6.8	15.9	11.0	4.3	2.6	11.6	.225	.044	.0128	.1061	4.19	1.22
138	4b	0- 7	7.7	25.9	20.2	5.2	59.0	11.0	16.1	6.1	1.5	[3] 6.3		.296	.152	.0257	.1352	3.95	.57
139	4b	40½- 45					11.9	9.6	30.5	22.2	8.2	4.7	13.0	.0278	.0161	.0075	.0102	1.93	.90
141	6b	0- 5	2.7	15.7	21.0	7.9	47.3	11.7	20.9	9.2	2.4	[3] 8.6		.204	.0494	.0186	.0927	3.31	1.25
140	6b	38- 42					10.0	7.3	34.2	26.2	8.2	3.9	10.2	.0237	.0160	.0087	.0075	1.65	.90
142	7a	0- 5	3.3	24.3	25.8	4.8	58.2	8.3	16.1	6.9	2.0	[3] 8.3		.257	.150	.0220	.1175	3.42	.50
143	7a	46- 53					5.4	10.7	40.2	22.1	6.7	2.8	11.9	.0252	.0175	.0093	.0080	1.65	.87
41	8a	0- 7	2.2	15.0	16.9	4.9	39.0	15.5	19.0	11.8	2.9	2.1	9.7	.183	.0368	.0144	.0843	3.57	1.39
42	8a	7- 14	1.8	13.1	14.7	4.0	33.6	16.9	19.7	14.1	3.4	2.6	10.8	.170	.0340	.0137	.0782	3.52	1.42
43	8a	14- 19	1.0	5.7	4.6	1.8	13.1	15.9	32.3	18.5	4.7	3.6	12.1	.0360	.0190	.0101	.0130	1.89	1.00
44	8a	19- 25					2.1	10.8	30.0	28.4	8.8	5.9	14.1	.0220	.0137	.0064	.0078	1.85	.87
45	8a	25- 29					2.1	8.9	31.3	25.3	10.5	5.8	16.1	.0204	.0128	.0041	.0082	2.23	.72
46	8a	29- 35					2.6	17.9	38.5	19.9	5.2	3.5	12.3	.0280	.0181	.0098	.0091	1.69	.91
47	8a	35- 40					1.0	12.7	42.4	23.2	5.6	2.9	12.1	.0240	.0170	.0097	.0072	1.57	.90
48	8a	40- 47					3.2	14.5	30.6	26.5	7.9	3.9	13.4	.0247	.0152	.0077	.0085	1.79	.91
49	8a	47- 52					3.6	7.4	31.6	31.3	9.1	4.3	12.7	.0208	.0140	.0074	.0067	1.68	.89
50	8a	52- 59					4.2	7.2	29.6	31.4	10.2	5.9	11.4	.0200	.0134	.0067	.0067	1.73	.86

51	8a	59- 65					6.9	3.3	31.5	25.4	9.2	4.8	18.9	.0210	.0130	.0045	.0083	2.16	.75
52	8a	65- 74					6.2	8.5	26.8	24.2	8.1	5.1	21.0	.0222	.0127	.0035	.0094	2.52	.69
53	8a	74- 76						[2] 10.8	28.0	24.1	7.7	4.7	15.8	.0498	.0200	.0125	.0187	1.995	.86
54	8a	76- 87		3.5	2.6	1.2	7.3	9.0	30.4	26.0	8.5	4.7	14.2	.0258	.0153	.0073	.0093	1.88	.90
55	8a	87- 91		5.7	4.5	1.3	11.5	8.0	24.5	26.1	9.3	5.0	15.9	.0278	.0144	.0062	.0108	2.12	.91
56	8a	91- 95		8.7	6.8	1.7	17.2	6.4	20.9	24.9	9.2	4.8	16.6	.0351	.0144	.0059	.0146	2.44	1.00
57	8a	95-103	2.6	15.4	12.6	2.2	32.8	7.1	18.2	18.9	6.7	3.7	12.5	.203	.0202	.0094	.0968	4.65	2.16
58	8a	112½-118	5.0	40.8	31.1	2.9	79.8	.9	7.5	4.3	2.2	1.6	3.8	.331	.231	.140	.0955	1.50	.93
59	8a	122-127½	1.7	15.4	17.9	3.8	38.8	9.4	20.0	15.8	4.5	1.3	10.6	.184	.0292	.0122	.0859	3.88	1.62
145	9a	0- 6	1.1	10.5	21.1	6.1	38.8	12.0	22.5	10.9	3.0	[3] 12.7		.174	.0322	.0144	.0798	3.47	1.55
144	9a	73- 80					12.3	10.7	24.4	22.5	10.6	5.9	13.7	.0290	.0144	.0061	.0115	2.18	.92
147	10a	0- 4					5.1	9.8	32.2	23.1	7.4	4.8	17.7	.0235	.0148	.0052	.0092	2.13	.75
146	10a	78- 83					11.2	6.5	26.9	24.1	10.6	5.6	15.3	.0240	.0138	.0053	.0094	2.13	.82
150	11	0- 8	.4	6.4	24.3	16.7	47.8	19.6	14.6	6.2	2.1	[3] 9.6		.144	.054	.024	.0600	2.45	1.09
148	11	87- 90					10.4	7.8	27.5	23.5	10.0	6.3	14.4	.0250	.0142	.0057	.0097	2.09	.84
151	11c	0- 5	.9	7.4	26.5	20.0	63.8							.148	.099	.031	.0585	2.18	.68
159	11c	61- 68	1.7	11.5	11.9	2.3	27.4	12.4	25.8	14.8	6.8	4.2	9.1	.124	.0238	.0105	.0568	3.44	1.51

TOBITUBBY CREEK—RANGE 11

389	1	0- 4					4.7	2.1	13.1	24.8	18.1	8.7	28.5	0.0133	0.0068	0.00117	0.0061	3.37	0.59
390	1	30-33					7.1	1.5	20.9	26.3	16.4	7.8	17.1	.0196	.0099	.0039	.0076	2.21	.87
238	2	0- 4						[2] 7.2	18.8	26.0	15.1	7.2	25.6	.0161	.0084	.00185	.0071	2.95	.65
239	2	16-20					1.4	3.4	21.1	27.5	15.5	7.6	23.4	.0158	.0086	.0023	.0068	2.62	.70
240	2	34-36						[2] 5.3	24.6	28.0	16.8	7.9	17.4	.0172	.0096	.0038	.0067	2.13	.84
241	3	1- 6						[2] 10.2	25.6	23.3	12.9	5.5	22.6	.0211	.0100	.00265	.0092	2.82	.75
242	3	17½-20½						[2] 7.1	27.7	25.8	13.5	6.0	20.2	.0193	.0107	.0036	.0079	2.32	.78
243	3	38-41½							[2] 28.6	26.6	16.4	10.0	18.3	.0169	.0092	.00317	.0069	2.31	.80
244	4	2- 5							[2] 25.0	26.2	16.0	8.5	24.3	.0156	.0081	.0021	.0068	2.73	.71
244D	4	2- 5					4.0	3.9	19.3	25.0	16.1	7.1	24.7	.0165	.0083	.0020	.0073	2.87	.69
244DD	4	2- 5					4.3	3.7	20.1	25.3	14.3	8.6	23.9	.0170	.0087	.00225	.0074	2.75	.71
249	4	5- 8					1.6	4.1	21.8	27.4	14.8	7.0	23.4	.0165	.0089	.0024	.0071	2.62	.74
249D	4	5- 8					2.4	4.3	21.9	26.3	14.7	7.2	23.2	.0172	.0092	.0024	.0074	2.68	.70
245	4	8-11						[2] 7.7	21.2	28.0	14.6	4.0	24.7	.0175	.0095	.0023	.0076	2.76	.67
245D	4	8-11					1.6	5.1	22.5	27.8	14.6	6.7	21.8	.0171	.0096	.0030	.0071	2.39	.74
246	4	11-15					1.1	7.6	28.3	26.5	12.0	6.2	18.4	.0200	.0117	.0040	.0080	2.24	.76
246D	4	11-15					1.2	6.7	29.0	26.1	11.8	5.3	19.9	.0198	.0118	.0039	.0080	2.25	.74
247	4	15-18						[2] 6.9	30.4	26.9	11.6	[3] 24.3		.0201	.0117	.0042	.0080	2.19	.78
247D	4	15-18					1.5	8.5	29.4	25.7	11.0	4.9	19.0	.0202	.0125	.0043	.0080	2.17	.75
248	4	18-22						[2] 5.3	25.6	29.4	14.0	[3] 25.8		.0173	.0106	.0038	.0068	2.13	.77
248D	4	18-22					1.3	5.8	25.8	28.9	13.0	5.2	19.8	.0182	.0111	.0039	.0072	2.16	.76
250	4	22-25½					.5	4.4	24.5	29.3	14.1	6.4	20.7	.0170	.0099	.00325	.0069	2.29	.75
250D	4	22-25½					1.1	5.9	25.0	28.2	13.7	6.8	19.6	.0181	.0102	.0035	.0073	2.27	.78
251	4	25½-28½						[2] 2.1	18.8	29.7	18.2	[3] 31.4		.0142	.0080	.0026	.0058	2.34	.76
251D	4	25½-28½					1.6	3.5	18.6	28.0	16.8	8.4	22.1	.0148	.0084	.0026	.0061	2.39	.73
251DD	4	25½-28½					1.6	4.6	21.4	27.1	14.9	8.0	22.6	.0164	.0090	.0026	.0069	2.51	.73
252	4	28½-32						[2] 4.3	22.1	28.1	16.3	7.7	21.4	.0161	.0087	.0029	.0066	2.355	.79

[2] Percent coaser than lower limit of grade indicated.

[3] Percent finer than 1/256 mm.

TABLE 10.—*Results of mechanical analyses of fluvial deposits from Tobitubby and Hurricane Valleys*—Continued

TOBITUBBY CREEK—RANGE 11—Continued

Sample No.	Hole No.	Depth	Amount in indicated grade size											Derived results					
			>½ mm.	½–¼ mm.	¼–⅛ mm.	⅛–1/16 mm.	>1/16 mm.	1/16–1/32 mm.	1/32–1/64 mm.	1/64–1/128 mm.	1/128–1/256 mm.	1/256–1/512 mm.	<1/512 mm.	Q_1	Md	Q_3	Arithmetic sorting $\frac{(Q_1-Q_3)}{2}$	Trask sorting $\sqrt{Q_1/Q_3}$	Skewness $\sqrt{\frac{Q_1 \cdot Q_3}{Md^2}}$
		Inches	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Mm.*	*Mm.*	*Mm.*			
252D	4	28½–32					1.9	4.3	21.6	27.8	15.6	8.4	20.2	.0164	.0091	.0029	.0068	2.38	0.76
253	4	32–36						[2] 3.4	18.9	28.4	19.4	10.5	19.6	.0146	.0080	.0030	.0058	2.21	.83
253D	4	32–36					3.2	3.7	18.4	26.3	18.3	11.3	18.8	.0157	.0082	.0029	.0064	2.33	.83
255	4	36–42						[2] 7.9	25.9	28.9	14.0	8.2	15.4	.0192	.0109	.0045	.0074	2.07	.85
255D	4	36–42					2.6	5.4	26.0	27.6	14.7	6.5	17.5	.0194	.0104	.0043	.0076	2.12	.88
256	4	42–45½						[2] 7.7	27.6	29.0	13.2	5.9	16.9	.0191	.0116	.0047	.0072	2.02	.82
256D	4	42–45½					1.7	5.9	28.5	27.7	12.5	6.2	17.8	.0199	.0113	.0043	.0078	2.15	.81
257	4	45½–51						[2] 7.5	23.6	28.0	14.1	6.8	20.1	.0180	.0103	.0035	.0073	2.27	.77
257D	4	45½–51					2.5	5.5	25.0	26.4	13.5	7.0	20.1	.0183	.0105	.0033	.0075	2.355	.74
258	4	51–58					2.7	4.4	32.2	18.9	14.6	7.8	19.5	.0205	.0108	.0033	.0086	2.49	.76
258D	4	51–58						[2] 7.7	24.5	26.8	13.8	6.9	20.[illegible]	.0182	.0102	.0031	.0076	2.42	.73
259	5	3– 5					2.8	4.5	22.5	27.3	11.6	9.2	22.0	.0176	.0096	.00247	.0076	2.67	.68
260	5	15–19		2.3	7.5	5.1	14.9	14.6	31.1	16.6	6.2	3.3	13.4	.0360	.0203	.0089	.0136	2.01	.88
261	5	31–35					2.4	8.0	24.0	25.1	14.8	9.1	16.6	.0196	.0105	.0038	.0079	2.27	.82
381	6	0– 4½					4.3	3.0	15.0	26.7	17.4	7.3	26.4	.0145	.0076	.00160	.0065	3.01	.63
382	6	32½–37		.1	.6	2.7	3.4	25.4	39.2	14.8	2.8	1.1	13.2	.0335	.0223	.0129	.0103	1.61	.93
383	7	0– 4					4.6	2.1	18.1	26.9	14.4	7.7	26.5	.0155	.0082	.00150	.0070	3.22	.58
384	7	21–28	0.2	3.7	17.6	9.5	31.0	15.0	18.8	11.2	4.7	2.6	16.5	.087	.0280	.0088	.0391	3.14	.99
385	7a	0– 5					4.7	2.6	13.7	26.0	17.0	7.8	28.3	.0132	.0067	.00130	.0060	3.19	.61
386	7a	26–30					6.8	8.8	29.5	24.2	11.9	5.9	12.8	.0243	.0141	.0059	.0092	2.03	.85
387	8	0– 4					6.0	5.6	19.6	25.2	13.9	6.1	23.7	.0187	.0094	.0025	.0081	2.74	.73
388	8	37–41		2.5	11.8	11.3	25.6	20.6	24.2	11.0	3.7	2.0	12.8	.0620	.0285	.0125	.0248	2.23	.98
391	9a	0– 4					4.0	3.7	17.6	25.2	15.9	6.8	26.8	.0157	.0080	.00155	.0071	3.18	.68
392	9a	28–33					1.5	13.8	40.1	22.2	6.4	2.7	13.5	.0258	.0174	.0091	.0084	1.68	.81
1	10a	0– 4					2.0	9.9	24.7	26.6	12.1	6.8	17.9	.0200	.0118	.0039	.0081	2.265	.75
393	10a	[1] 0– 4					3.9	3.4	18.9	27.8	15.2	6.6	24.3	.0162	.0087	.00210	.0071	2.78	.67
2	10a	4– 8					2.3	8.4	28.4	28.1	11.9	6.0	14.7	.0199	.0124	.0052	.0074	1.96	.82
3	10a	8–12					2.6	7.3	25.0	28.9	13.5	6.8	15.7	.0190	.0112	.0046	.0072	2.03	.83
6	10a	12–15					3.5	9.2	26.1	26.2	13.7	6.8	14.6	.0220	.0114	.0051	.0085	2.075	.93
4	10a	15–19					2.8	10.1	27.8	28.8	13.3	5.0	13.5	.0215	.0131	.0061	.0077	1.88	.87
5	10a	19–23					4.6	10.5	31.1	26.3	11.3	4.8	11.1	.0234	.0145	.0070	.0082	1.825	.88
7	10a	23–26½	.2	3.2	12.4	6.0	21.8	11.7	24.0	19.8	8.8	6.8	7.0	.0500	.0187	.0086	.0207	2.41	1.15
394	10a	[1] 23–27		3.6	13.7	6.8	24.1	11.0	21.4	18.6	9.1	5.0	10.6	.055	.0188	.0077	.0237	2.68	1.09
8	10a	26½–34	.1	5.1	25.4	13.2	43.8	11.2	15.5	10.5	6.2	4.0	9.0	.143	.041	.0120	.0655	3.45	1.01
9	10a	34–39		4.7	25.1	13.4	43.2	12.1	14.3	9.1	5.3	3.4	12.4	.140	.0405	.0103	.0649	3.16	.94

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10	10a	39-45		4.9	24.9	14.2	44.0	11.9	14.0	9.2	5.0	3.5	12.8	.140	.043	.0108	.0646	3.60	.91
11	10a	45-51		5.1	26.4	13.1	44.6	13.4	12.5	9.1	5.0	3.5	11.9	.160	.0461	.0110	.0745	3.82	.91
12	10a	51-55		5.2	26.2	14.4	45.8	12.0	14.4	8.7	5.0	3.0	11.5	.148	.047	.0128	.0676	3.39	.93
13	10a	55-60		5.2	26.5	12.9	44.6	12.1	13.7	9.5	5.0	3.2	11.9	.153	.043	.0116	.0707	3.63	.98
395	11a	0- 5					2.9	3.1	19.9	26.6	15.4	6.5	25.3	.0160	.0084	.00185	.0071	2.94	.65
396	11a	28-32					16.3	10.1	26.4	21.4	9.1	4.6	12.0	.0333	.0167	.0077	.0128	2.08	.96
186	12a	0- 4					3.7	2.7	14.8	28.4	17.6	8.5	24.1	.0140	.0077	.0021	.0060	2.58	.70
137	12a	15½-19½					11.0	5.9	12.6	21.4	15.4	9.5	24.1	.0193	.0080	.00205	.0086	3.07	.79
127	13a	0- 4					6.8	4.1	13.2	26.0	18.0	8.3	23.5	.153	.0782	.0230	.0650	2.58	.76
187	13a	16-20					8.5	10.8	30.3	23.6	10.4	6.2	10.0	.0260	.0155	.0071	.0095	1.91	.88

TOBITUBBY CREEK—RANGE 19

149	4	0- 4					9.8	5.4	17.7	19.5	14.7	11.2	21.7	0.0205	0.0086	0.00248	0.0090	2.87	0.83
156	4	16-20	1.8	11.6	11.6	2.9	27.9	9.5	23.2	14.4	7.5	5.6	11.8	.148	.0215	.0081	.0700	4.27	1.61
14	5	0- 4						6.6	19.5	20.1	17.5	13.5	22.8	.0243	.0089	.00275	.0108	2.97	.92
15	5	4- 8					10.2	6.3	15.7	20.0	15.5	9.8	22.6	.0201	.0085	.0024	.0089	2.89	.81
16	5	8-12					11.6	8.9	18.2	21.7	13.8	8.9	17.0	.0250	.0111	.0038	.0106	2.57	.88
17	5	12-16		3.3	7.1	4.3	14.7	14.8	23.4	17.4	9.8	6.8	13.4	.0415	.0176	.0061	.0177	2.60	.90
18	5	16-20		4.7	8.0	5.0	17.7	15.4	19.6	17.1	8.5	6.4	15.3	.0455	.0173	.0049	.0203	3.06	.86
19	5	20-24		6.7	11.1	5.7	23.5	13.2	19.3	15.7	7.1	5.4	15.8	.062	.0207	.0070	.0275	2.97	1.00
20	5	24-28		11.9	10.6	4.5	27.0	12.7	17.7	15.5	6.2	4.9	15.9	.136	.0224	.0073	.0644	4.32	1.40
21	5	28-32		8.3	12.2	6.0	26.5	12.2	18.4	16.3	6.7	4.0	15.9	.091	.0211	.0073	.0419	3.53	1.22
22	5	32-36		9.1	12.6	6.5	28.2	12.4	10.5	14.4	6.4	4.1	14.9	.102	.0239	.0080	.0470	3.57	1.20
23	5	36-40		9.1	12.7	6.5	28.3	15.4	19.9	13.9	6.2	4.2	11.9	.123	.0312	.0118	.0556	3.23	1.22
24	5	40-44		9.7	13.8	6.9	30.4	14.9	17.5	14.4	6.5	4.1	12.2	.140	.0283	.0093	.0654	3.88	1.28
158	6	0- 4					7.5	4.6	15.9	21.4	16.2	10.9	23.4	.0172	.0077	.0022	.0075	2.80	.80
157	6	8-12					14.9	9.2	24.0	19.5	10.2	7.4	14.8	.0300	.0149	.0048	.0126	2.50	.81
163	7	0- 4					6.9	7.7	16.8	22.7	16.0	9.5	20.3	.0197	.0090	.0029	.0084	2.61	.84
319	13	0- 4					8.7	4.1	27.0	20.6	11.8	8.0	19.7	.0218	.0117	.0032	.0093	2.61	.72
320	13	4- 8					3.7	6.4	19.5	21.9	14.3	8.5	25.6	.0179	.0082	.00185	.0080	3.11	.70
321	13	8-12					2.3	9.0	28.1	22.5	11.1	6.1	20.7	.0209	.0119	.0032	.0089	2.55	.69
322	13	12-16					3.2	10.4	27.8	24.2	11.3	5.6	17.7	.0221	.0131	.0045	.0088	2.22	.76
323	13	16-20					6.2	11.9	27.6	21.0	10.6	6.9	15.7	.0253	.0140	.0047	.0105	2.33	.78
324	13	20-24					9.3	11.6	28.0	19.8	9.5	6.6	15.1	.0271	.0151	.0052	.0110	2.28	.78
325	13	24-28					12.8	14.4	28.8	18.8	7.1	4.4	13.6	.0340	.0180	.0077	.0132	2.10	.90
326	13	28-32					18.3	13.4	30.0	17.1	6.1	3.9	11.2	.0410	.0201	.0098	.0156	2.05	1.00
327	13	32-36					16.3	12.4	28.0	17.2	7.0	4.4	14.7	.0368	.0182	.0073	.0148	2.04	.90
328	13	36-40					13.8	11.1	26.1	19.0	7.3	4.6	17.9	.0312	.0160	.0052	.0130	2.45	.80
329	13	40-44					15.8	10.2	25.7	18.9	8.0	4.9	16.5	.0325	.0162	.0059	.0133	2.35	.86
330	13	44-48					11.4	12.5	24.8	19.2	8.5	5.3	18.1	.0306	.0153	.0046	.0130	2.58	.78
331	13	48-52					11.8	9.7	25.5	19.0	9.0	5.8	19.0	.0280	.0142	.0078	.0101	1.88	1.04
333	13	52-56					11.3	10.8	26.0	10.6	9.3	6.0	16.0	.0290	.0148	.0046	.0122	2.51	.78

[1] Percent finer than 1/64 mm.

[2] Percent coarser than lower limit of grade indicated.

[3] Percent finer than 1/256 mm.

TABLE 10.—*Results of mechanical analyses of fluvial deposits from Tobitubby and Hurricane Valleys*—Continued

WEST GOOSE CREEK—RANGE 4

Sample No.	Hole No.	Depth	Amount in indicated grade size											Derived results					
			>1/2 mm.	1/2–1/4 mm.	1/4–1/8 mm.	1/8–1/16 mm.	>1/16 mm.	1/16–1/32 mm.	1/32–1/64 mm.	1/64–1/128 mm.	1/128–1/256 mm.	1/256–1/512 mm.	<1/512 mm.	Q_1	Md	Q_3	Arithmetic sorting $\frac{(Q_1-Q_3)}{2}$	Trask sorting $\sqrt{Q_1/Q_3}$	Skewness $\sqrt{\frac{Q_1 \cdot Q_3}{Md^2}}$
		Inches	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Mm.*	*Mm.*	*Mm.*			
182	4	0–4	3.0	36.9	32.0	3.6	75.5	----	----	----	----	----	----	0.298	0.215	0.082	0.1080	1.905	0.73
180	4b	0–4	----	----	----	----	8.7	10.7	35.5	21.8	6.2	2.9	14.1	.0271	.0172	.0087	.0092	1.76	.89
196	4b	45–50	----	----	----	----	9.6	17.2	38.3	15.7	4.7	2.3	12.3	.0330	.0213	.0110	.0110	1.72	.89
181	4b	85–90	----	----	----	----	8.0	10.2	32.2	22.8	8.1	5.3	13.3	.0256	.0157	.0070	.0093	1.91	.85
25	5	0–4	.9	18.8	39.7	8.0	67.4	10.8	6.5	6.4	1.6	.7	6.2	.222	.158	.039	.0915	2.36	.59
26	5	4–8	.4	8.2	17.6	6.7	32.9	24.5	13.4	12.5	3.1	1.7	12.0	.130	.036	.0157	.0572	2.88	1.26
27	5	8–12	1.7	20.1	26.4	6.3	54.5	11.5	17.3	6.2	1.5	1.0	8.2	.228	.110	.0230	.1025	3.15	.66
28	5	12–16	7.9	42.9	36.7	4.1	91.6	----	----	----	----	----	----	.335	.247	.174	.0805	1.39	.97
29	5	16–20	5.7	37.7	43.4	6.6	93.4	----	----	----	----	----	----	.311	.230	.164	.0735	1.38	.98
30	5	20–24	13.4	49.5	28.0	4.9	95.8	----	----	----	----	----	----	.403	.287	.199	.1020	1.44	.99
31	5	24–28	16.0	56.5	22.7	2.5	97.7	----	----	----	----	----	----	.425	.320	.237	.0940	1.34	.99
32	5	28–32	37.0	47.7	13.2	1.0	98.9	----	----	----	----	----	----	.580	.413	.297	.1415	1.40	1.00
152	5	28–32	35.2	46.0	15.0	1.4	97.6	----	----	----	----	----	----	.566	.400	.275	.1455	1.435	.99
33	5	32–36	21.0	54.9	21.3	1.5	98.7	----	----	----	----	----	----	.457	.337	.248	.1045	1.36	1.00
153	5	32–36	20.4	50.6	23.2	2.2	96.4	----	----	----	----	----	----	.454	.319	.230	.1120	1.40	1.01
34	5	36–40	23.1	57.2	18.4	1.0	99.7	----	----	----	----	----	----	.438	.349	.266	.0860	1.28	.98
154	5	36–40	23.2	53.6	20.0	1.6	98.4	----	----	----	----	----	----	.480	.345	.252	.1140	1.38	1.01
35	5	40–44	26.1	58.3	14.6	.8	99.8	----	----	----	----	----	----	.501	.378	.280	.1105	1.34	.99
155	5	40–44	26.3	55.0	15.9	1.1	98.3	----	----	----	----	----	----	.505	.368	.273	.1160	1.36	1.01
36	5	44–48	25.8	39.6	9.7	1.1	76.2	2.1	6.3	3.9	1.6	[3] 9.8	----	.500	.340	.120	.1900	2.08	.72
160	5	44–48	26.3	39.3	10.7	1.5	77.8	----	----	----	----	----	----	.502	.343	.150	.1760	1.82	.80
37	5	48–52	19.0	30.2	20.2	4.7	74.1	4.9	6.9	3.5	1.4	[3] 9.3	----	.433	.237	.046	.1935	3.67	.56
161	5	48–52	20.4	29.3	20.2	5.9	75.8	----	----	----	----	----	----	.453	.244	.088	.1825	2.27	.82
38	5	52–56	9.6	22.7	47.5	8.8	88.6	----	----	----	----	----	----	.283	.185	.134	.0745	1.45	1.05
162	5	52–56	10.0	21.1	47.1	11.2	89.4	----	----	----	----	----	----	.283	.183	.131	.0760	1.47	1.05
39	5	56–60	.9	20.2	49.7	10.9	81.7	3.9	4.5	2.7	.8	.7	5.6	.230	.172	.104	.0630	1.49	.90
40	5	60–64	.4	2.6	9.7	5.5	18.2	20.0	28.9	15.7	4.1	2.7	10.7	.045	.0236	.0123	.0164	1.91	1.00
169	5	64–68	2.0	5.1	9.4	5.3	21.8	18.6	31.5	12.1	3.5	1.9	10.5	.0490	.0258	.0142	.0174	1.86	1.02
170	5	68–72	----	----	----	----	8.8	21.5	40.7	13.1	3.3	2.1	10.2	.0355	.0221	.0137	.0109	1.61	1.00
171	5	72–76	----	----	----	----	9.6	18.7	39.6	15.4	4.2	2.4	10.0	.0350	.0204	.0126	.0112	1.67	1.03
172	5	76–80	----	----	----	----	10.8	20.4	39.7	14.5	4.0	2.2	8.5	.0370	.0214	.0140	.0115	1.625	1.04
173	5	80–84	----	----	----	----	5.5	17.8	44.4	14.3	7.1	2.4	8.5	.0302	.0215	.0114	.0094	1.63	.86
183	5	84–88	----	----	----	----	5.8	13.0	40.5	21.8	6.2	3.6	9.0	.0270	.0174	.0105	.0083	1.60	.97
184	5	88–92	----	----	----	----	7.0	10.7	35.6	23.3	6.0	7.2	10.1	.0245	.0162	.0086	.0080	1.69	.90
185	5	92–96	----	----	----	----	8.6	9.6	32.8	23.1	9.6	5.9	10.5	.0250	.0160	.0075	.0088	1.825	.86

188	5	96-100						[2]20.0	32.0	23.6	8.3	4.9	10.9	.0270	.0162	.0082	.0094	1.81	.92
189	5	100-104						[2]16.9	33.8	23.7	9.2	4.7	11.5	.0261	.0157	.0074	.0094	1.88	.89
190	5	104-108						[2]14.7	33.7	20.3	11.7	5.4	14.1	.0252	.0149	.0057	.0098	2.15	.82
191	5	108-112						[2]12.3	25.8	27.0	12.9	6.4	15.4	.0200	.0121	.0049	.0076	2.02	.82
192	5	112-116					9.2	5.3	24.9	28.6	12.5	6.3	13.3	.0221	.0130	.0059	.0081	1.93	.88
179	Channel	0-4	1.5	44.1	47.2	3.4	96.2							.290	.237	.188	.0510	1.24	.99
177	6	0-4					8.3	11.6	33.6	20.0	6.8	3.6	15.9	.0277	.0170	.0076	.0101	1.91	.85
193	6	28-35	2.9	13.4	28.0	10.5	54.8	11.3	16.9	6.7	2.0	.9	7.3	.0209	.0090	.00227	.0093	3.07	.76
178	6	62-64					8.1	9.6	32.9	22.9	9.7	5.6	11.1	.0256	.0159	.0072	.0092	1.89	.85
175	6b	0-4					18.4	4.5	21.5	21.4	10.2	5.1	18.8	.0284	.0132	.0043	.0121	2.57	.54
195	6b	38-43	1.0	20.1	34.1	7.5	62.7	10.1	14.1	5.5	1.2	[3]6.4		.230	.143	.029	.1005	2.82	.57
176	6b	76-82					5.2	9.6	33.3	24.1	9.6	5.8	12.6	.0230	.0150	.0064	.0083	1.89	.81
168	7	0-4					3.5	6.1	27.6	26.0	11.0	5.2	20.5	.0196	.0117	.0036	.0080	2.33	.72
197	7	35-40	3.3	33.3	31.8	4.2	72.6	8.8	10.4	1.9	.8	[3]5.4		.280	.206	.039	.1205	2.68	.51
174	7	70-75					8.3	7.4	22.8	22.8	11.9	6.4	20.4	.0222	.0114	.0033	.0095	2.59	.75
60	8	0-4	.5	6.3	11.3	7.5	25.6	14.6	25.0	15.9	4.7	2.7	11.4	.130	.0247	.0110	.0595	3.44	1.53
61	8	4-8	.8	5.1	12.4	9.2	27.5	12.2	26.1	17.0	3.6	2.1	11.6	.0760	.0239	.0115	.0323	2.605	1.24
62	8	8-12	14.2	48.1	23.3	2.8	88.4							.400	.283	.187	.1065	1.46	.96
63	8	12-16	1.4	8.1	35.0	21.0	65.5							.167	.111	.031	.0680	2.32	.65
64	8	20-24	14.1	53.9	27.1	3.2	98.3							.402	.308	.217	.0925	1.36	.95
65	8	24-28		7.5	49.1	19.5	76.1							.183	.133	.061	.0610	1.73	.79
66	8	28-32	.3	15.5	44.3	14.6	74.7							.212	.149	.059	.0765	1.89	.75
67	8	32-36	.4	6.5	28.4	13.4	48.7	15.2	16.8	7.0	2.1	.9	9.4	.158	.0553	.0210	.0685	2.74	1.04
68	8	36-40					10.6	15.2	38.4	17.2	4.1	2.4	11.7	.033	.0195	.0115	.0108	1.69	1.00
69	8	40-44	.8	3.6	4.1	4.1	12.6	17.9	35.1	16.2	4.9	2.0	11.6	.0375	.0208	.0116	.0130	1.79	1.00
70	8	44-48					5.0	10.2	27.5	24.8	10.1	4.4	18.3	.0230	.0135	.0049	.0091	2.16	.79
71	8	48-52					8.0	11.1	32.2	20.2	9.5	1.6	14.5	.0290	.0170	.0076	.0107	1.95	.87
72	8	52-56					1.8	10.1	30.6	27.0	9.7	4.0	16.9	.0215	.0134	.0058	.0079	1.93	.83
73	8	56-60					9.4	15.5	36.0	18.1	5.0	3.0	13.0	.0313	.0193	.0100	.0107	1.77	.92
74	8	60-64					8.6	16.6	36.4	19.0	4.9	2.3	12.2	.0312	.0192	.0103	.0105	1.74	.93
75	8	64-68					11.0	12.9	15.1	21.9	26.8	2.3	10.2	.0293	.0107	.0052	.0121	2.37	1.15
76	8	68-72	1.3	10.2	14.7	4.3	30.5	11.6	28.9	15.3	4.4	1.4	8.0	.135	.0265	.0187	.0582	2.69	1.90
77	8	72-76	1.9	13.8	18.6	9.2	43.5	16.4	21.5	7.8	2.3	1.1	7.5	.187	.0445	.0205	.0833	3.04	1.39
78	8	76-80	.8	2.8	5.7	4.3	13.6	15.7	31.8	19.5	7.0	3.4	9.5	.0360	.0194	.0102	.0129	1.88	.99
79	8	80-84					11.2	10.2	27.3	22.6	12.0	7.0	10.0	.0272	.0151	.0066	.0103	2.06	.89
80	8	84-88					11.5	11.1	26.0	22.4	10.4	5.5	13.1	.0285	.0152	.0062	.0112	2.14	.88
81	8	88-92					8.8	9.2	24.1	23.3	11.8	5.9	16.9	.0242	.0128	.0046	.0098	2.29	.82
82	8	92-96					6.1	7.1	24.7	24.1	12.0	6.0	19.9	.0210	.0115	.0036	.0087	2.41	.76
83	8	96-100					5.1	9.3	25.1	18.2	16.1	4.7	21.4	.0231	.0104	.0034	.0099	2.60	.86
84	8	100-104					5.6	11.1	28.2	22.6	9.1	3.9	19.8	.0240	.0139	.0047	.0097	2.26	.75
164	9b	0-4	4.4	31.3	36.4	6.7	78.8							.284	.200	.104	.0900	1.65	.86
194	9b	32-36						[2]11.9	33.0	25.9	9.3	3.8	16.1	.0220	.0144	.0097	.0062	1.51	1.01
165	9b	72-76	.6	5.5	6.5	2.2	14.8	11.2	27.0	19.5	8.2	4.6	14.7	.033	.0168	.0067	.0132	2.22	.89
166	10	0-4	3.8	24.8	27.8	7.9	64.3	9.3	13.7	4.9	1.7	[3]6.1		.262	.160	.029	.1165	3.01	.54
198	10	26-30					3.5	11.1	20.4	16.2	7.1	4.3	28.3	.0248	.0128	.0110	.0069	1.50	1.29
167	10	54-58					6.7	11.6	33.2	18.5	6.0	3.7	20.0	.0250	.0160	.0044	.0103	2.38	.66

[2] Percent coaser than lower limit of grade indicated.

[3] Percent finer than 1/256 mm.

TABLE 11.—*Mechanical composition as computed for each range in Tobitubby and Hurricane Valleys*

Range	Amount in indicated grade sizes											Derived values					
	$>\frac{1}{2}$ mm.	$\frac{1}{2}$–$\frac{1}{4}$ mm.	$\frac{1}{4}$–$\frac{1}{8}$ mm.	$\frac{1}{8}$–$\frac{1}{16}$ mm.	$>\frac{1}{16}$ mm.	$\frac{1}{16}$–$\frac{1}{32}$ mm.	$\frac{1}{32}$–$\frac{1}{64}$ mm.	$\frac{1}{64}$–$\frac{1}{128}$ mm.	$\frac{1}{128}$–$\frac{1}{256}$ mm.	$\frac{1}{256}$–$\frac{1}{512}$ mm.	$<\frac{1}{512}$ mm.	Q_1	Md	Q_3	Arithmetic sorting $\frac{Q_1-Q_3}{2}$	Trask sorting $\sqrt{Q_1/Q_3}$	Skewness $\sqrt{\frac{Q_1 Q_3}{Md^2}}$
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Mm.*	*Mm.*	*Mm.*			
H-A	5.5	28.4	19.6	4.5	58.0	7.5	12.9	8.4	3.3	1.7	8.3	0.295	0.160	0.0190	0.138	3.94	0.40
H-B	8.3	31.2	29.3	6.9	75.6	6.2	7.7	3.8	1.3	.5	4.9	.295	.212	.065	.115	2.14	.65
H-C	7.3	30.5	20.4	4.7	62.9	7.8	11.9	6.7	2.6	1.2	7.0	.315	.188	.0245	.145	3.59	.47
H-D	4.2	22.1	19.5	6.6	52.4	10.7	15.1	8.3	3.2	1.7	8.6	.255	.083	.0184	.118	3.72	.82
H-E	4.9	22.8	15.2	3.8	46.7	8.7	16.2	11.4	4.7	2.4	9.9	.261	.046	.0137	.123	4.35	1.30
H-1	5.2	19.2	13.3	3.5	41.2	9.0	17.7	13.0	5.5	2.9	10.7	.242	.032	.0112	.115	4.65	1.63
H-2	2.8	11.6	9.4	3.0	26.8	9.8	22.1	16.9	7.4	3.7	13.3	.090	.0201	.0080	.041	3.35	1.34
H-3	2.6	9.9	7.8	2.7	23.0	10.5	23.2	17.9	7.8	4.0	13.5	.050	.0191	.0079	.021	2.59	1.04
H-4	2.1	9.9	7.9	2.7	22.6	10.1	23.6	18.0	8.0	4.0	13.8	.048	.0181	.0075	.020	2.53	1.05
H-5	2.7	12.6	10.7	3.3	29.3	9.7	21.5	16.1	7.1	3.5	12.7	.144	.0214	.0085	.068	4.12	1.63
H-6	1.9	8.5	6.7	2.6	19.7	10.4	24.1	19.0	8.3	4.2	14.3	.040	.0170	.0068	.017	2.43	.97
H-7	3.7	17.5	12.8	3.6	37.6	9.2	19.1	13.8	6.0	3.0	11.4	.217	.028	.0103	.103	4.66	1.69
H-8	1.3	6.6	5.6	2.4	15.9	10.7	25.2	19.9	8.8	4.5	15.0	.034	.0161	.0064	.014	2.30	.92
H-9	4.4	18.9	12.5	3.5	39.3	9.6	18.2	13.5	5.6	2.9	10.9	.234	.030	.0110	.111	4.56	1.69
H-10	1.0	5.8	6.2	2.8	15.8	11.4	25.2	19.9	8.4	4.3	14.8	.034	.0167	.0066	.014	2.27	.90
H-12	1.2	7.2	7.2	2.0	18.5	11.0	24.9	18.8	8.3	4.1	14.3	.038	.0178	.0070	.016	2.33	.90
H-13	1.7	7.5	6.4	2.7	18.3	10.9	24.8	19.1	8.4	4.2	14.4	.038	.0170	.0066	.016	2.40	.93
H-14	1.7	7.9	6.4	2.5	18.5	10.5	24.4	19.1	8.5	4.4	14.6	.038	.0169	.0068	.016	2.36	.95
H-15	.8	5.4	6.1	2.8	15.1	10.6	25.6	20.1	8.9	4.5	15.2	.032	.0160	.0064	.013	2.25	.90
T-1	2.4	13.6	16.2	5.5	37.7	10.4	19.7	13.1	5.5	2.6	11.0	.180	.020	.0114	.084	3.97	1.56
T-2	4.0	16.1	16.6	4.4	41.1	8.9	17.8	13.2	5.5	2.8	10.7	.217	.032	.0111	.103	4.42	1.53
T-3	6.8	32.6	21.0	4.6	65.0	6.9	10.6	6.5	2.6	1.4	7.1	.340	.128	.0126	.164	5.20	.51
T-4	4.7	17.7	14.4	4.0	40.8	9.5	18.1	13.0	5.3	2.7	10.7	.225	.032	.0114	.107	4.45	1.58
T-5	1.6	9.2	7.7	2.7	21.2	10.0	23.7	18.5	8.2	4.2	14.2	.042	.0178	.0069	.018	2.47	.96
T-6	1.9	8.9	10.6	3.3	24.7	10.3	22.9	17.4	7.4	3.7	13.5	.060	.0196	.0079	.026	2.76	1.11
T-7	2.2	10.3	9.3	3.5	25.3	10.8	23.0	16.9	7.2	3.6	13.2	.062	.0197	.0083	.027	2.73	1.15
T-8	2.2	11.2	10.6	3.5	27.5	10.5	22.2	16.5	6.7	3.4	13.0	.100	.0210	.0088	.046	3.37	1.41
T-9	.8	4.8	5.2	2.3	13.1	11.0	26.4	20.5	9.1	4.5	15.3	.031	.0158	.0061	.013	2.25	.87
T-10	.6	3.7	3.6	1.8	9.7	10.5	27.0	21.8	9.8	5.0	16.2	.027	.0145	.0051	.011	2.24	.83
T-11	.8	4.9	6.4	3.2	15.3	11.2	25.7	19.7	8.7	4.4	15.1	.033	.0164	.0065	.013	2.25	.89
T-12	1.6	7.5	5.7	2.2	17.0	10.3	24.8	19.7	8.7	4.5	14.9	.035	.0165	.0065	.014	2.32	.91
T-13	.8	5.0	5.8	2.6	14.2	10.9	26.0	20.2	8.9	4.5	15.3	.032	.0159	.0064	.013	2.24	.90
T-14	1.1	5.9	6.9	2.8	16.7	10.9	25.4	19.4	8.6	4.3	14.7	.035	.0168	.0068	.014	2.32	.92
T-15	.6	3.7	3.6	1.8	9.7	10.5	27.0	21.8	9.8	5.0	16.2	.027	.0145	.0054	.011	2.24	.83
T-16	1.1	7.7	8.9	3.3	21.0	10.4	21.0	18.4	8.0	4.0	14.2	.044	.0180	.0073	.018	2.45	1.00
T-18	.6	3.7	3.6	1.8	9.7	10.5	27.0	21.8	9.8	5.0	16.2	.027	.0145	.0054	.011	2.24	.83
EG-1	2.0	11.8	14.4	5.6	33.8	13.6	23.4	12.1	5.6	1.9	9.5	.164	.029	.0126	.071	3.61	1.57

EG-2	2.3	13.9	15.0	5.4	36.6	11.3	20.8	12.8	5.4	2.4	10.7	.178	.020	.0119	.083	3.86	1.59
EG-3	3.4	16.7	15.8	5.2	41.1	10.8	19.2	11.8	5.0	2.2	10.0	.215	.034	.0129	.101	4.08	1.55
EG-4	6.7	21.4	18.1	4.8	51.0	9.0	15.0	10.3	4.0	2.0	8.7	.270	.074	.0156	.127	4.18	.88
EG-5	3.1	15.7	11.7	4.4	33.9	9.3	20.0	14.9	6.4	3.3	12.1	.188	.0245	.0100	.089	4.34	1.46
EG-6	2.4	12.1	10.3	3.5	28.3	10.8	22.5	15.7	7.0	3.3	12.4	.124	.0224	.0089	.058	3.73	1.48
G-7	2.4	13.5	11.1	3.5	30.5	9.5	21.0	15.9	6.9	3.5	12.7	.153	.0218	.0087	.072	4.20	1.67
G-8	2.5	9.2	8.1	2.7	22.5	9.8	23.3	18.3	8.0	4.1	14.0	.048	.0179	.0071	.021	2.60	1.03
G-9	2.6	10.0	8.3	3.0	23.9	10.3	23.2	17.6	7.7	3.9	13.5	.055	.0185	.0077	.024	2.67	1.11
WG-0	9.7	32.8	20.5	4.5	67.5	6.9	10.3	5.8	2.1	1.0	6.4	.312	.219	.031	.141	3.17	.45
WG-1	3.0	16.7	18.7	5.7	44.1	11.5	18.1	11.2	3.6	1.6	9.9	.220	.040	.0141	.103	3.95	1.39
WG-2	4.9	17.7	14.3	4.1	41.0	10.1	18.4	12.6	4.9	2.4	10.6	.227	.033	.0120	.108	4.35	1.58
WG-3	1.2	8.5	12.6	5.2	27.5	13.0	23.6	14.9	6.5	2.8	11.6	.086	.0240	.0096	.038	3.99	1.20
WG-4	3.6	16.5	19.0	6.0	45.1	9.5	17.3	11.3	4.7	2.2	9.9	.215	.040	.0133	.101	4.02	1.34
WG-6	3.8	14.0	12.0	3.7	33.5	10.0	20.4	14.9	6.3	3.1	11.8	.170	.0248	.0096	.080	4.21	1.63

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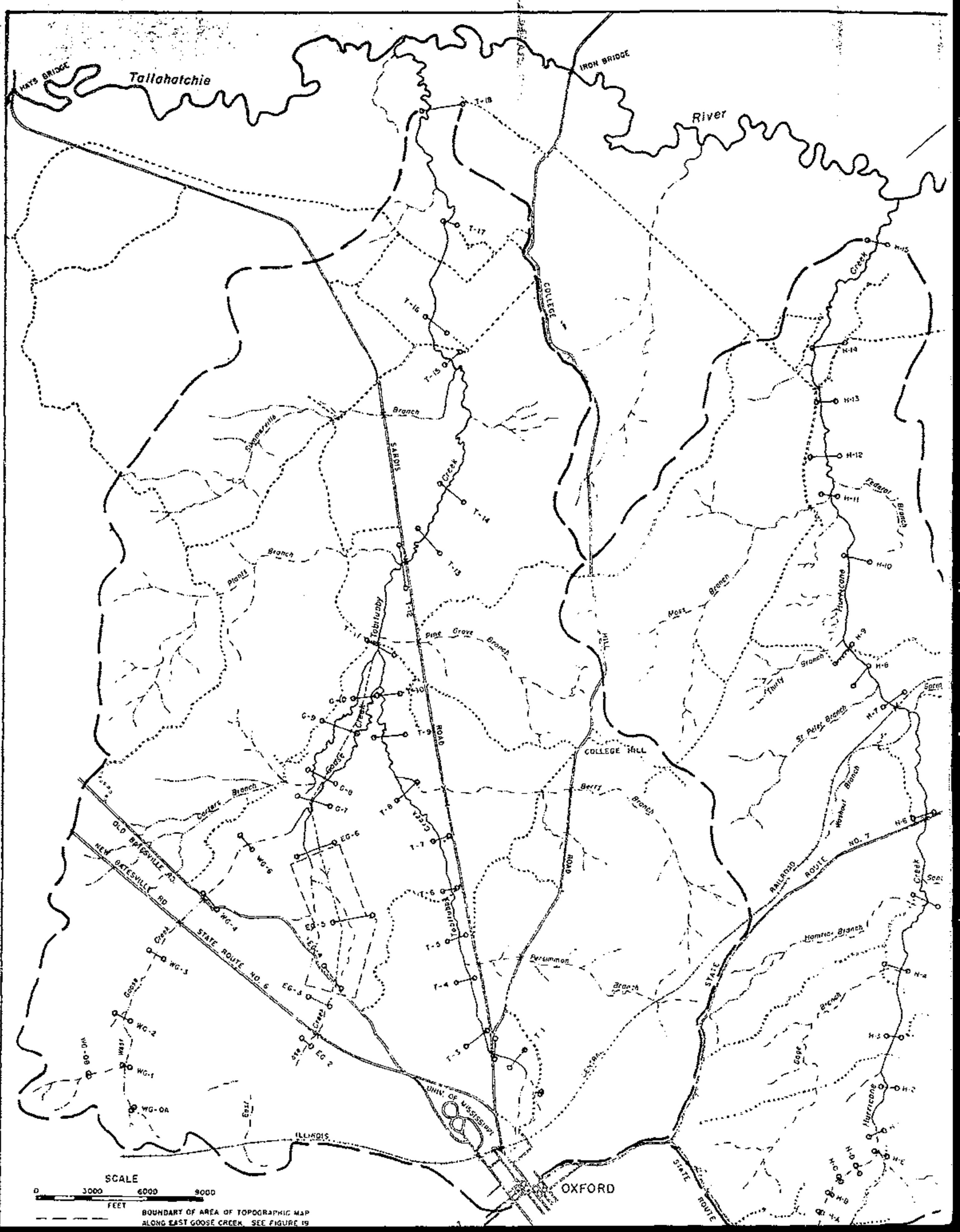
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Pine Grove Branch
Moss Branch
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Washout Branch
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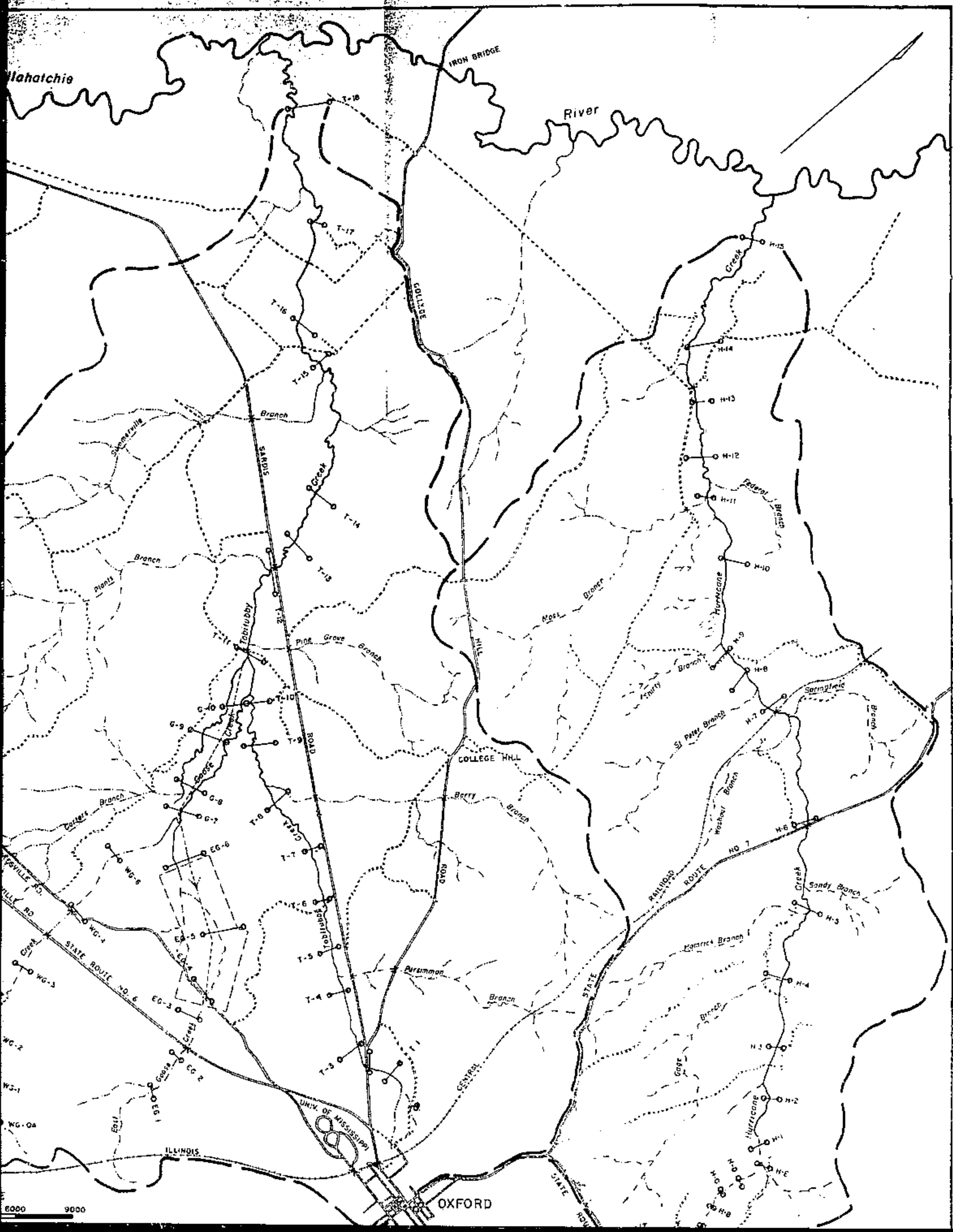
BOUNDARY OF AREA OF TOPOGRAPHIC MAP ALONG EAST GOOSE CREEK. SEE FIGURE 19



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SARDIS
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Tobitubby
Pine Grove Branch
Goose Creek
Carters Branch
Berry Branch
Tobitubby
Persimmon Branch
Hurricane
Creek
Federal Branch
Moss Branch
Thirty Branch
St Peter Branch
Springfield
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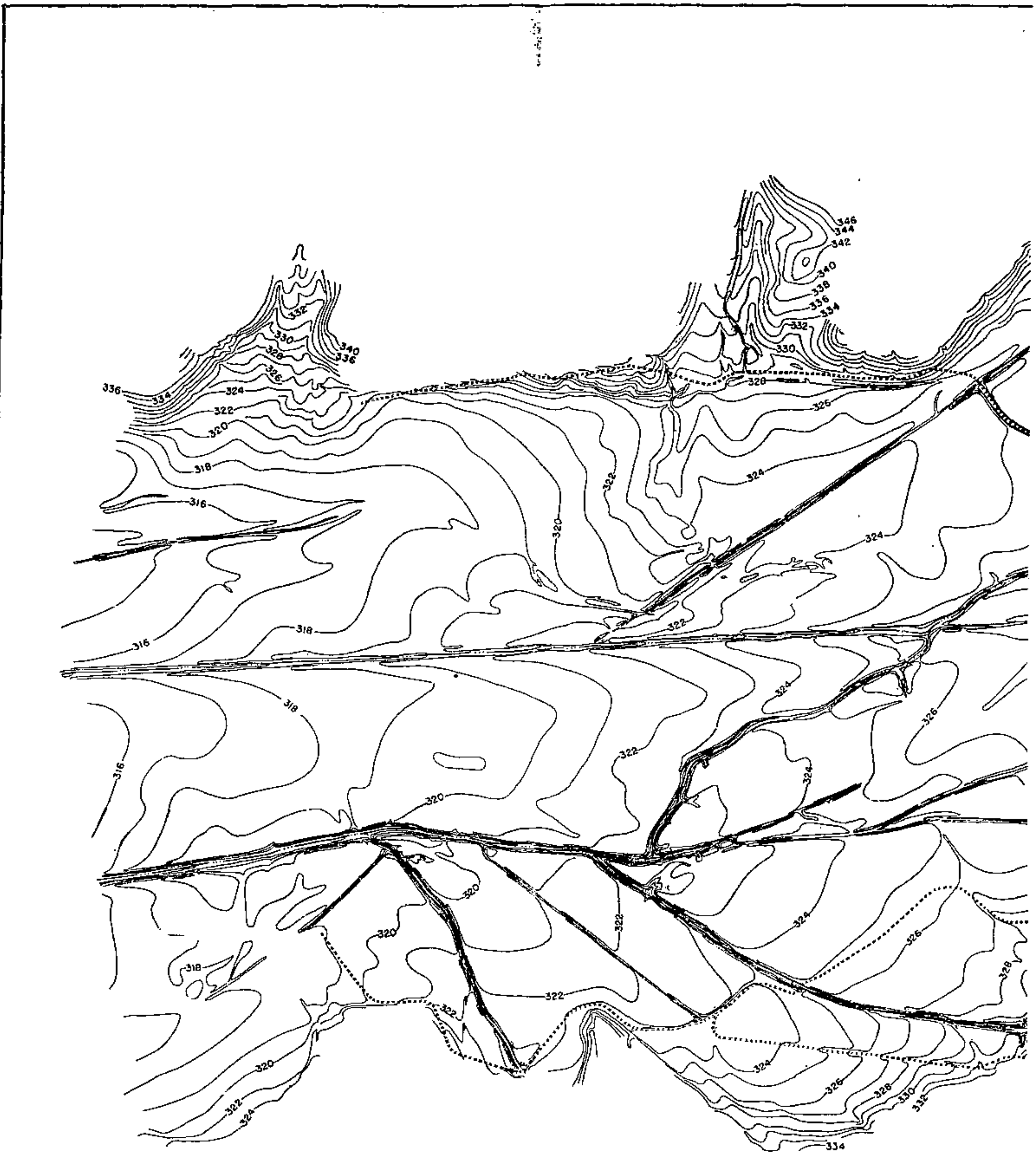
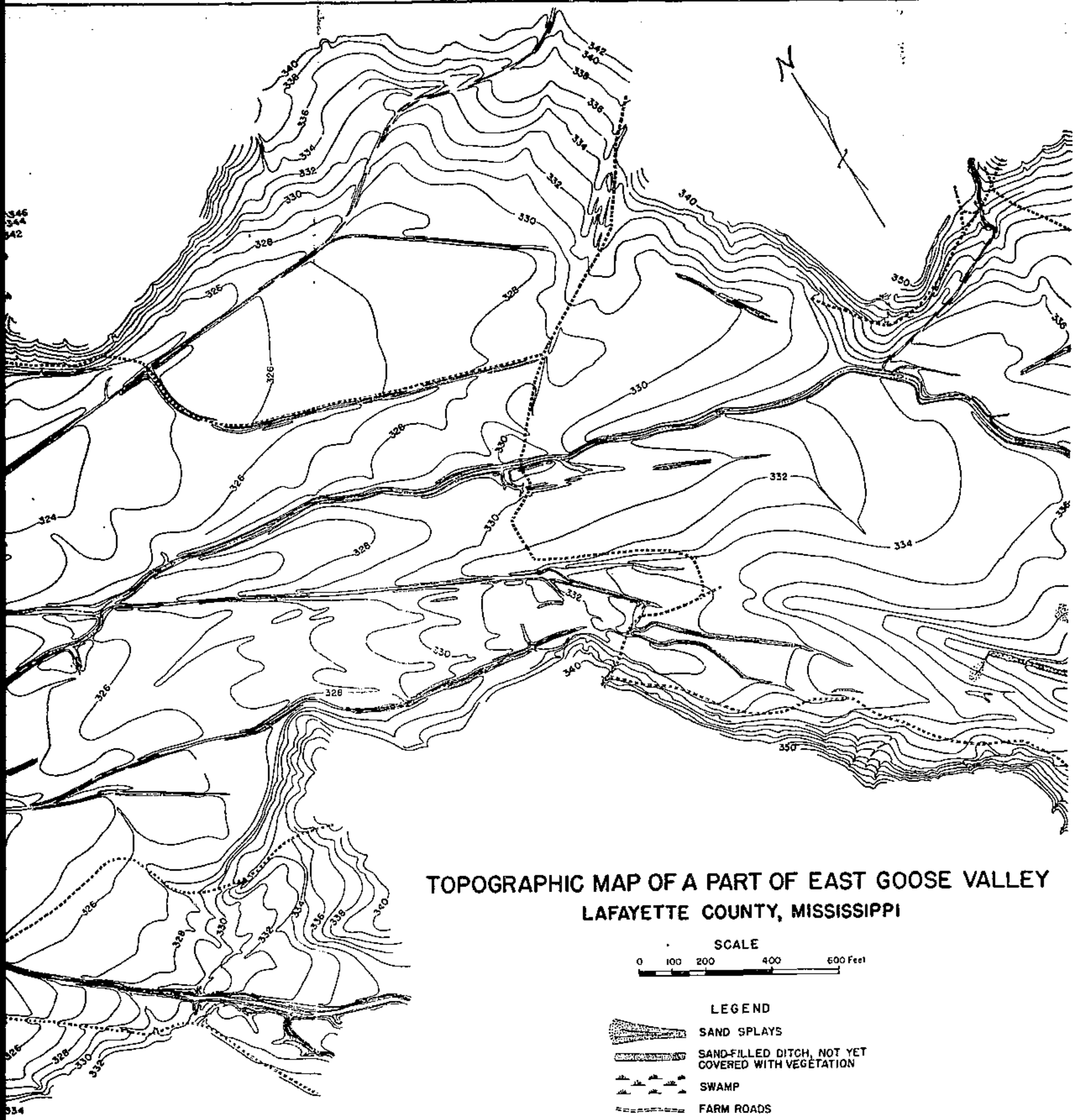


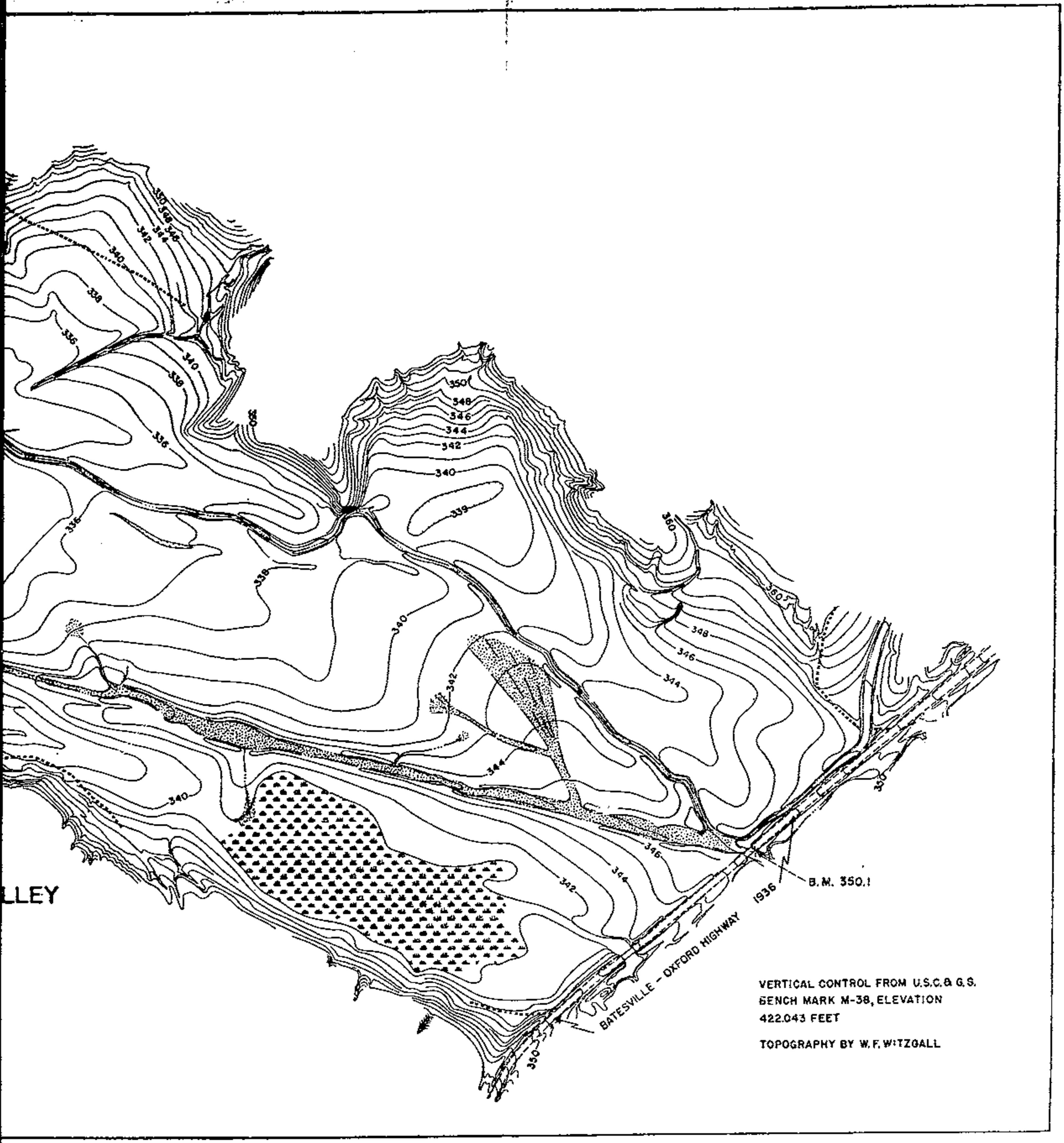
FIGURE 5.—Topographic map of a part of East Goose Valley, showing typical surface features in an area of excessive modern valley sedimentat
stream symbol) has reverted to a sinuous natural channel. Several conspicuous sand splays are shown diverging from the filled ditch, w
filled ditch and the southwest side of the valley. The stream formerly returned to the Wells ditch west of the center of the map area, belo

145619°—40 (Face p. 23)



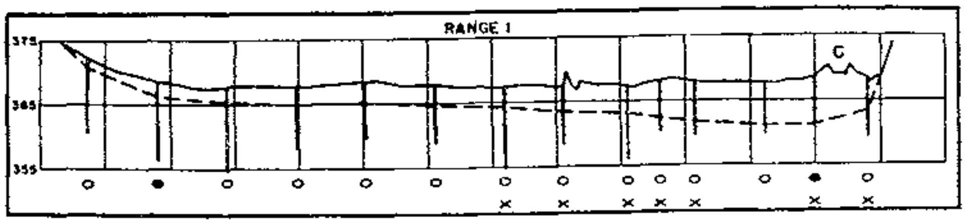
TOPOGRAPHIC MAP OF A PART OF EAST GOOSE VALLEY
LAFAYETTE COUNTY, MISSISSIPPI

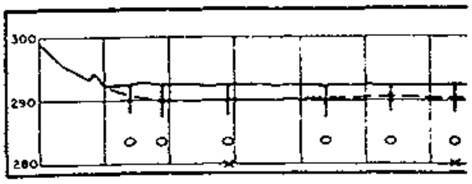
ve modern valley sedimentation. The old Oxford-Batesville highway crosses the valley at the upper end of the area (right-hand side of the map). ging from the filled ditch, which now forms a low ridge extending down the center of the valley from right to left, as shown by the contours. One of tl center of the map area, below the completely filled section of the ditch, but because of backfilling above another plug near the west edge of the area most c

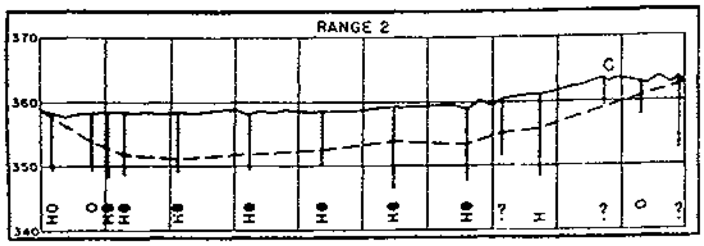


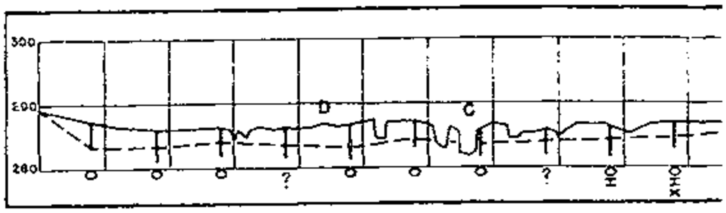
the map). Immediately below the highway bridge the Wells drainage ditch has been plugged with sand and the creek (shown by the intermittent-
One of these splays, together with an alluvial fan built out from the valley side, has obstructed the surface drainage and caused a swamp between the
area most of the water now follows the sinuous channel into what was originally a subsidiary ditch near the south side of the valley.

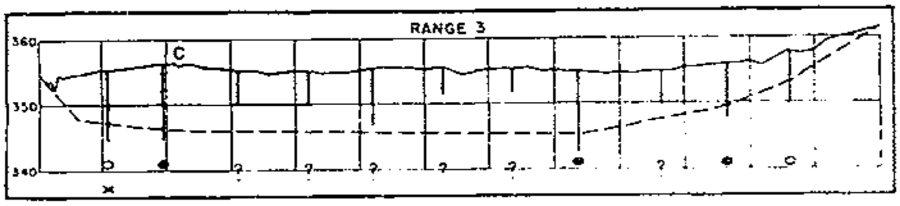
CROSS SECTIONS OF TOBITUBE

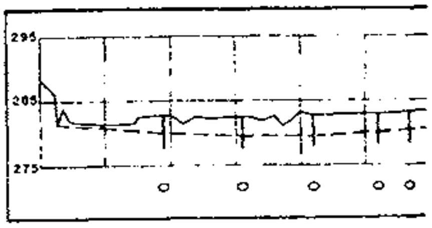


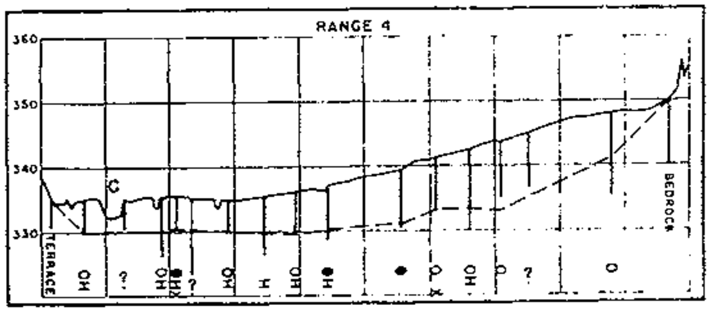


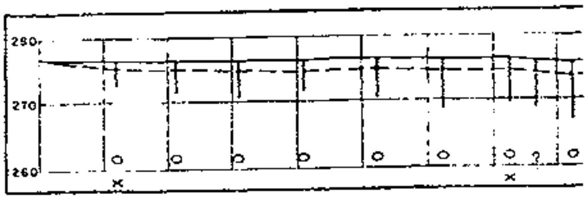


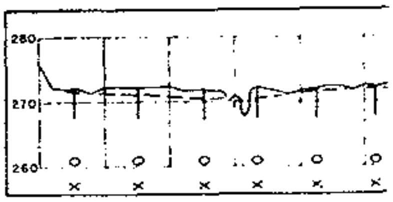


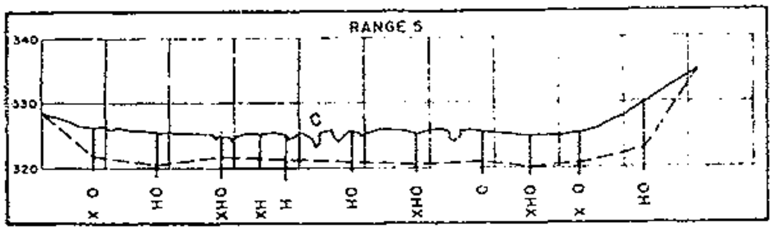


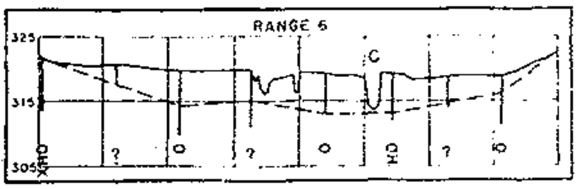


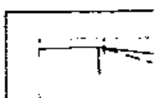




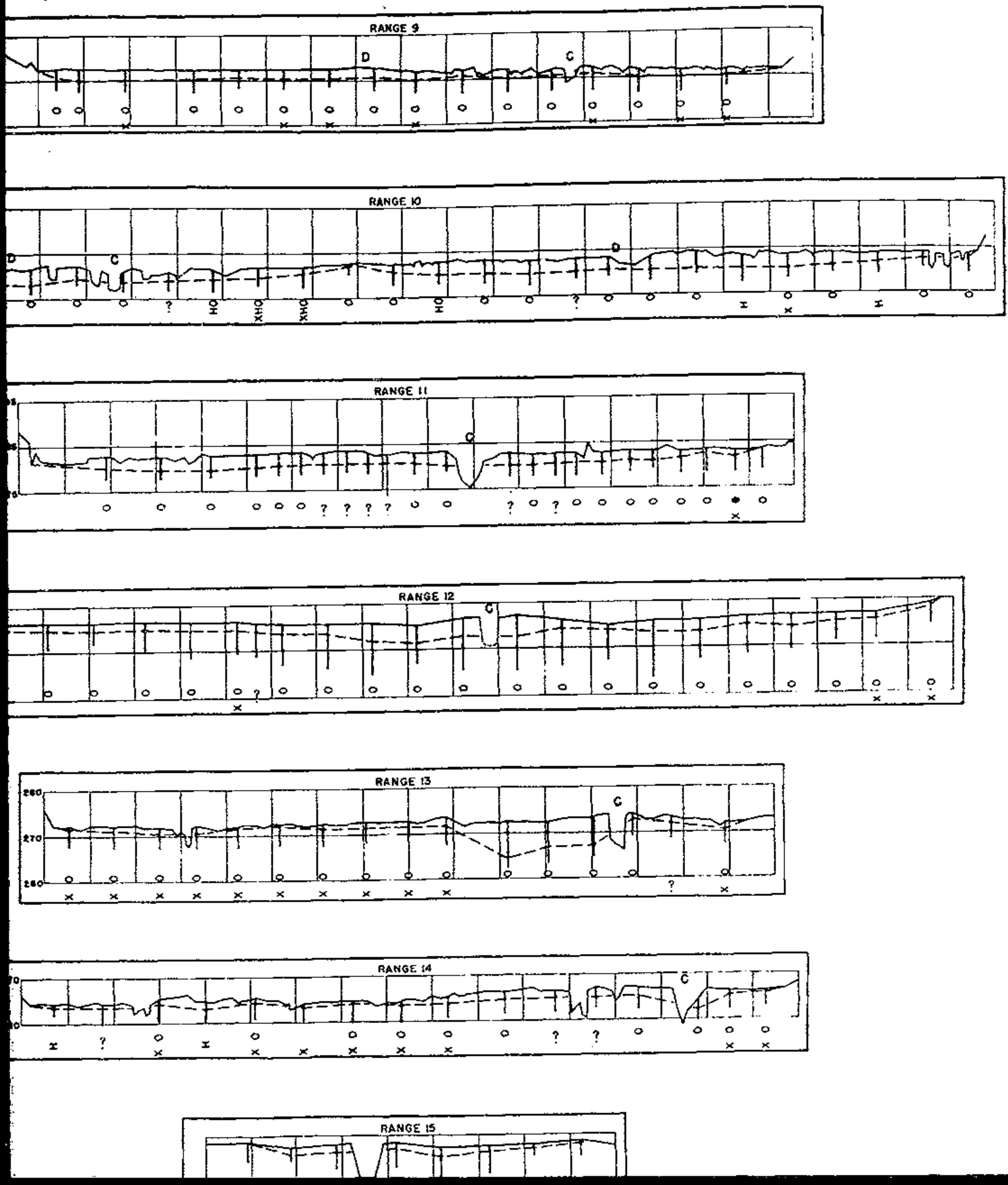




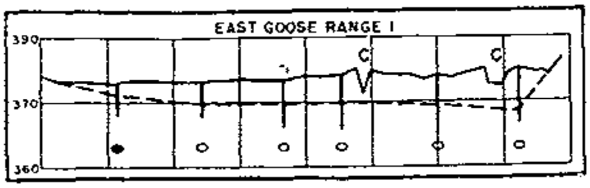


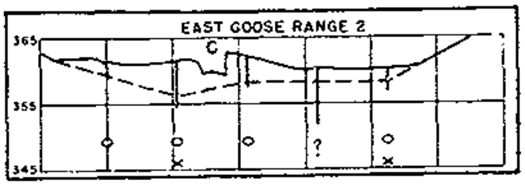


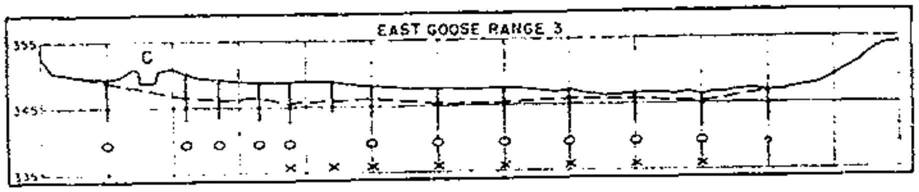
ONS OF TOBITUBBY VALLEY

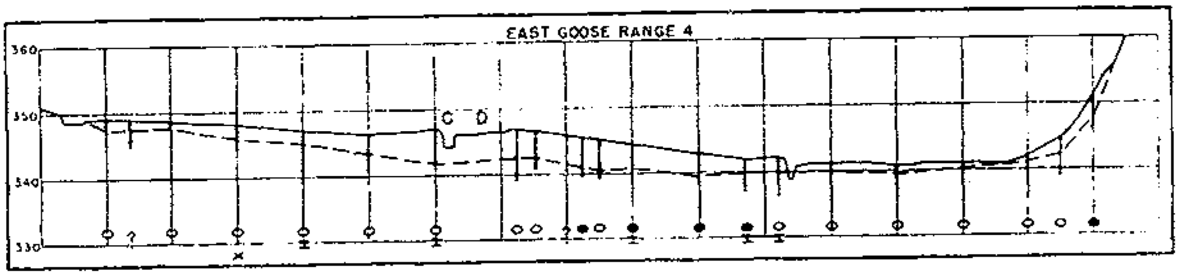


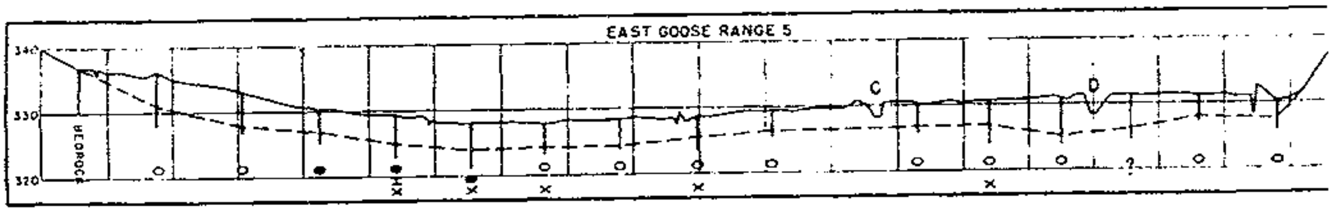
CROSS SECTIONS OF GOOSE, WEST GOOSE, AN

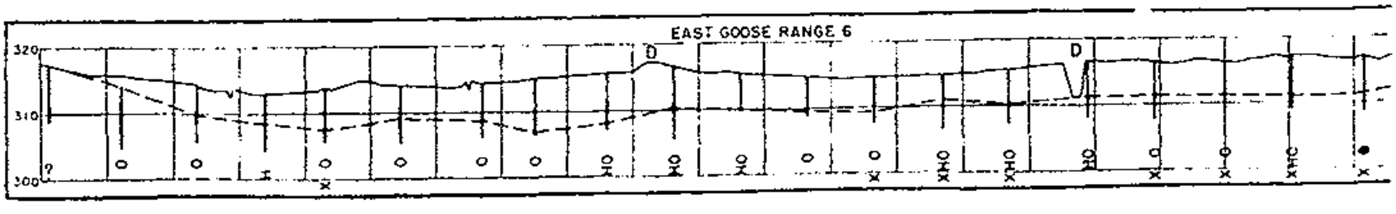




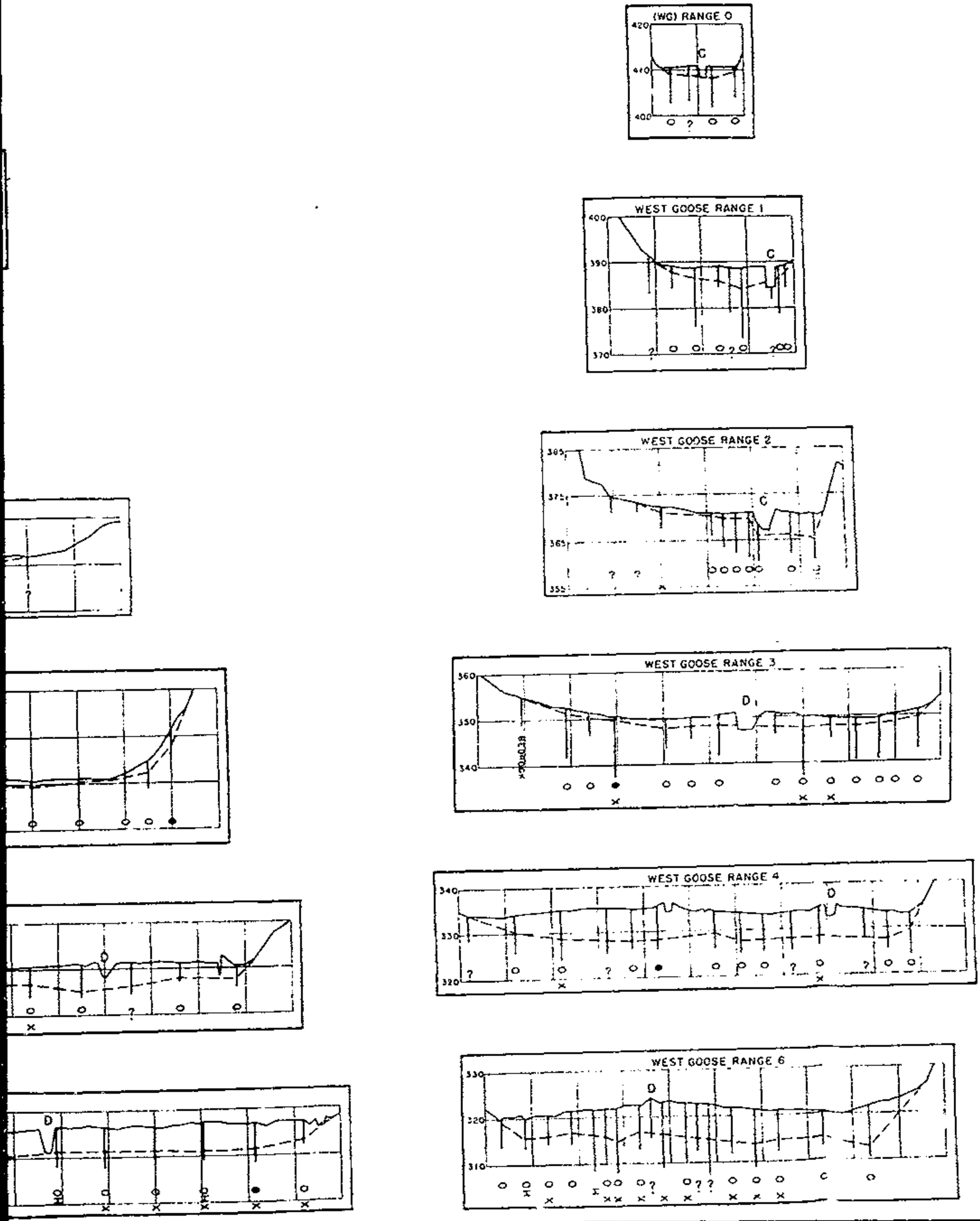








WEST GOOSE, AND EAST GOOSE VALLEYS



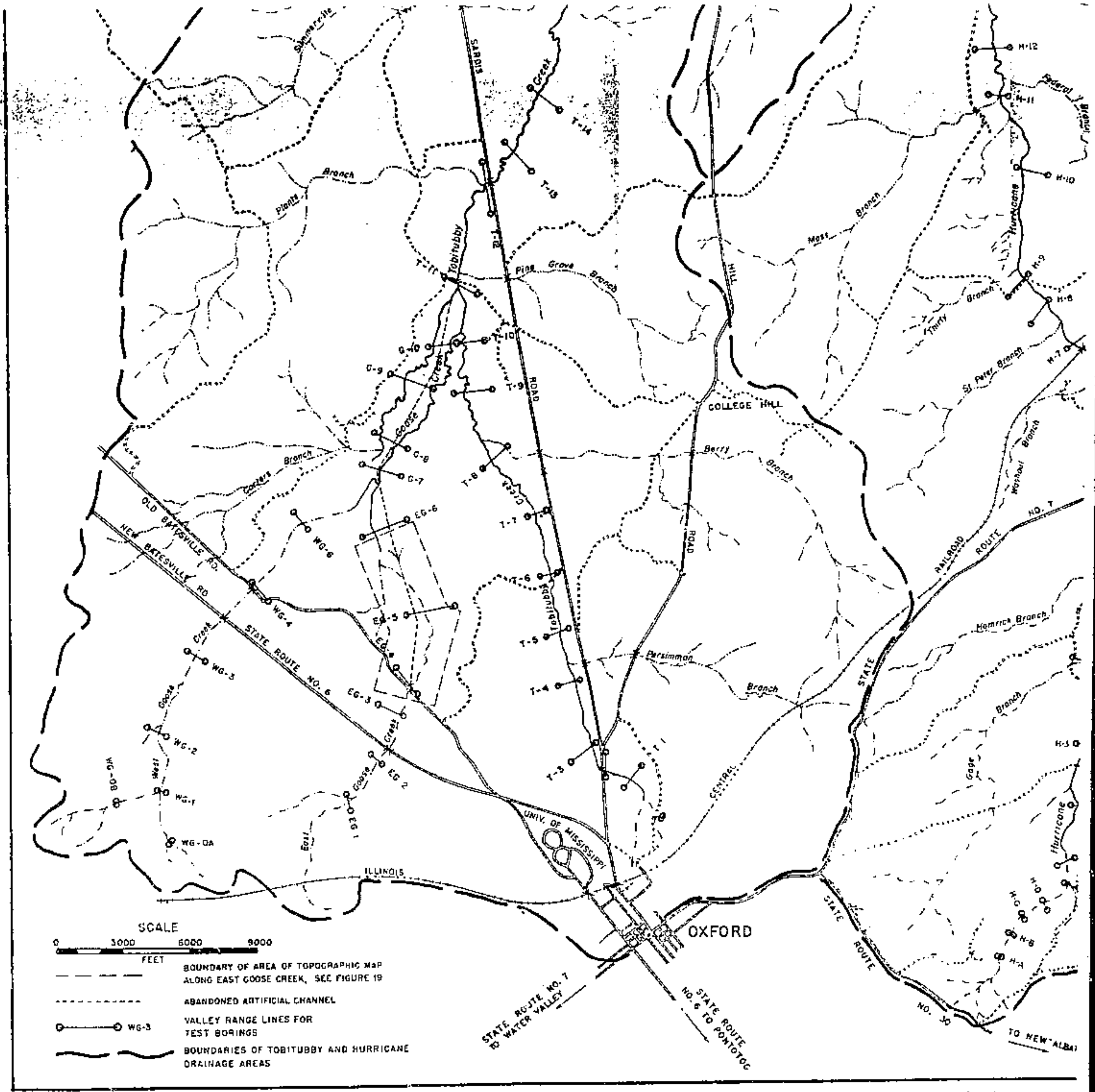


FIGURE 3.—Map of Tobitubby and Hurricane Creek drainage basins, showing location of boring ranges.

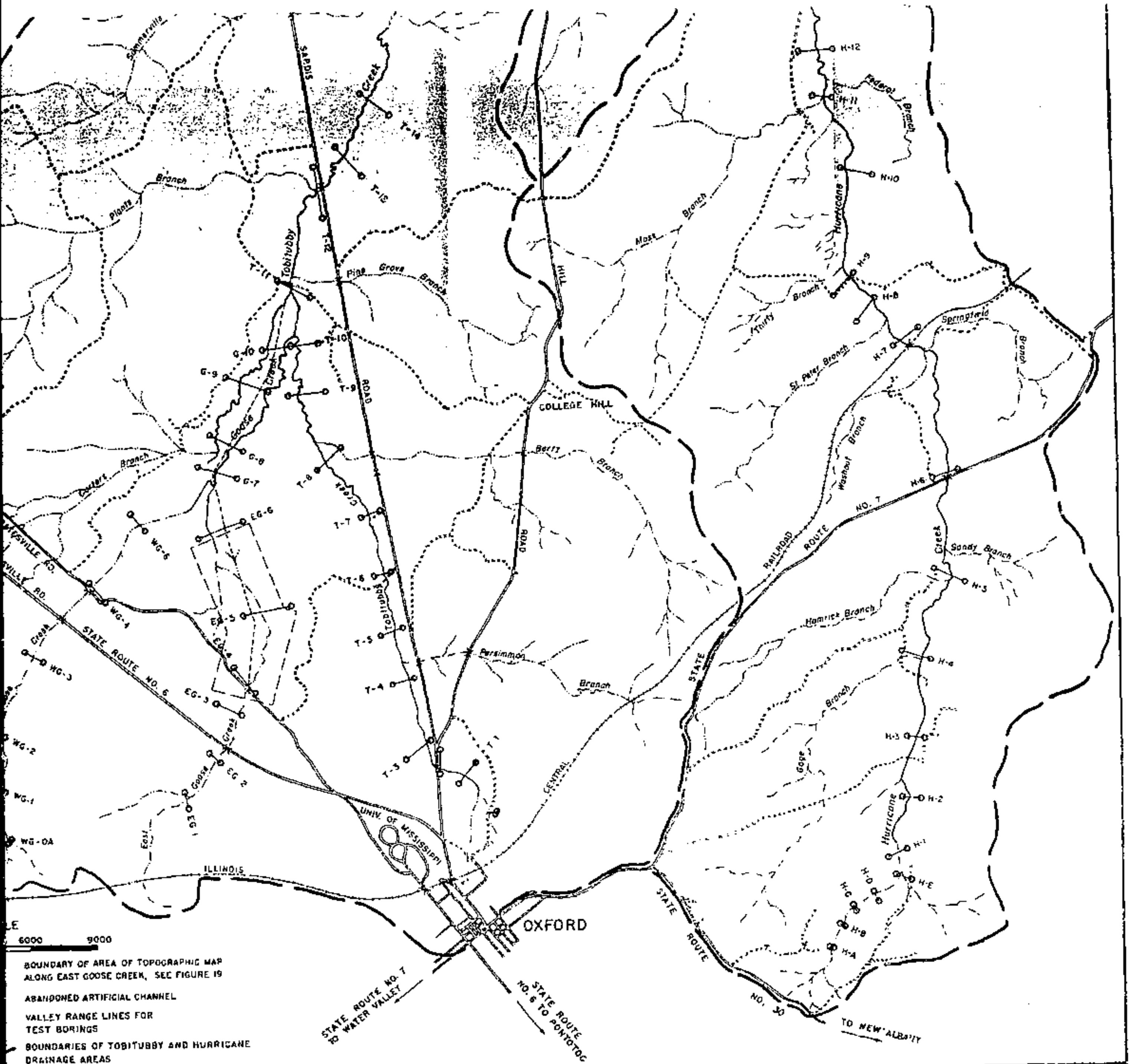


FIGURE 3.—Map of Tobitubby and Hurricane Creek drainage basins, showing location of boring ranges.

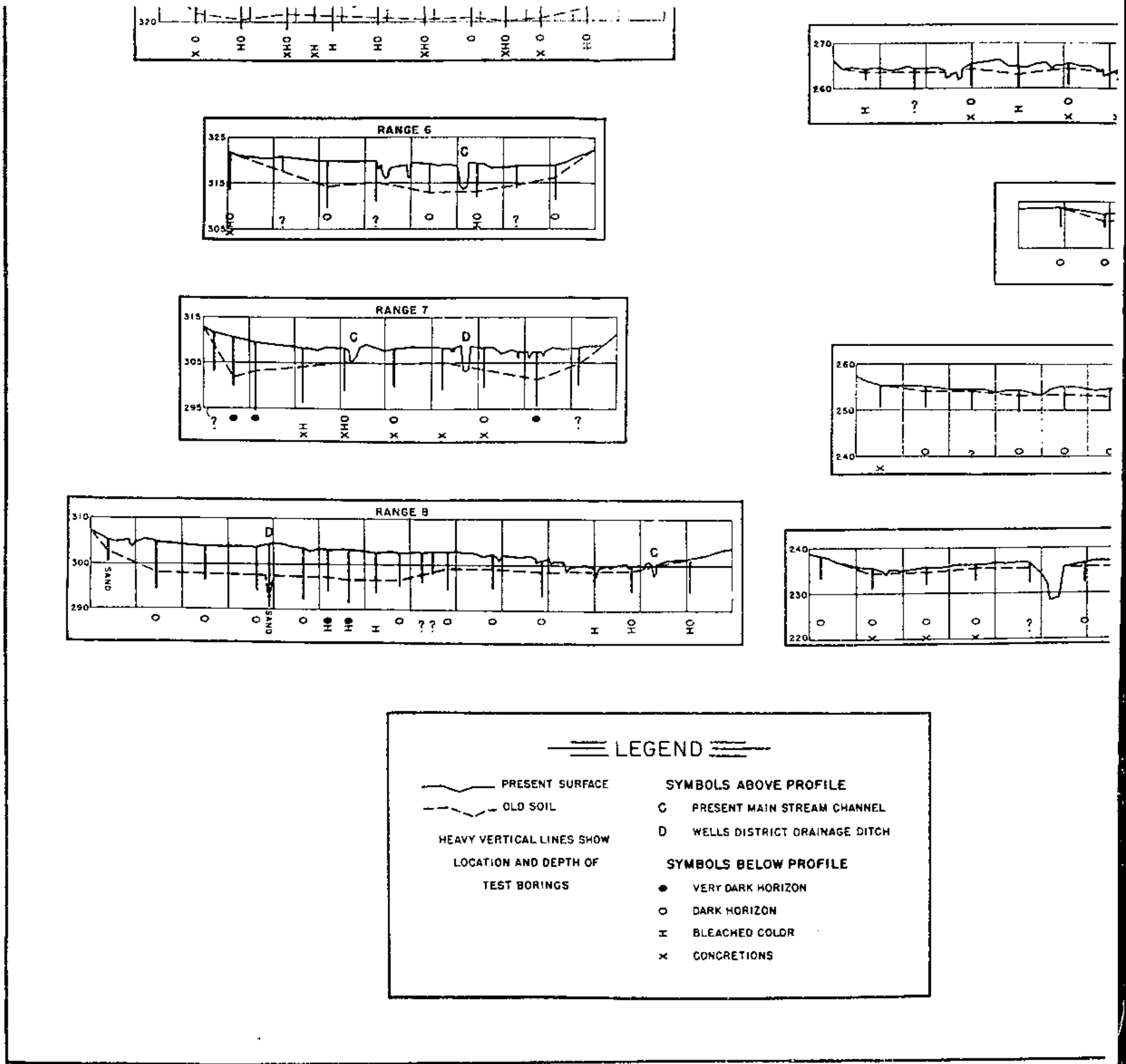
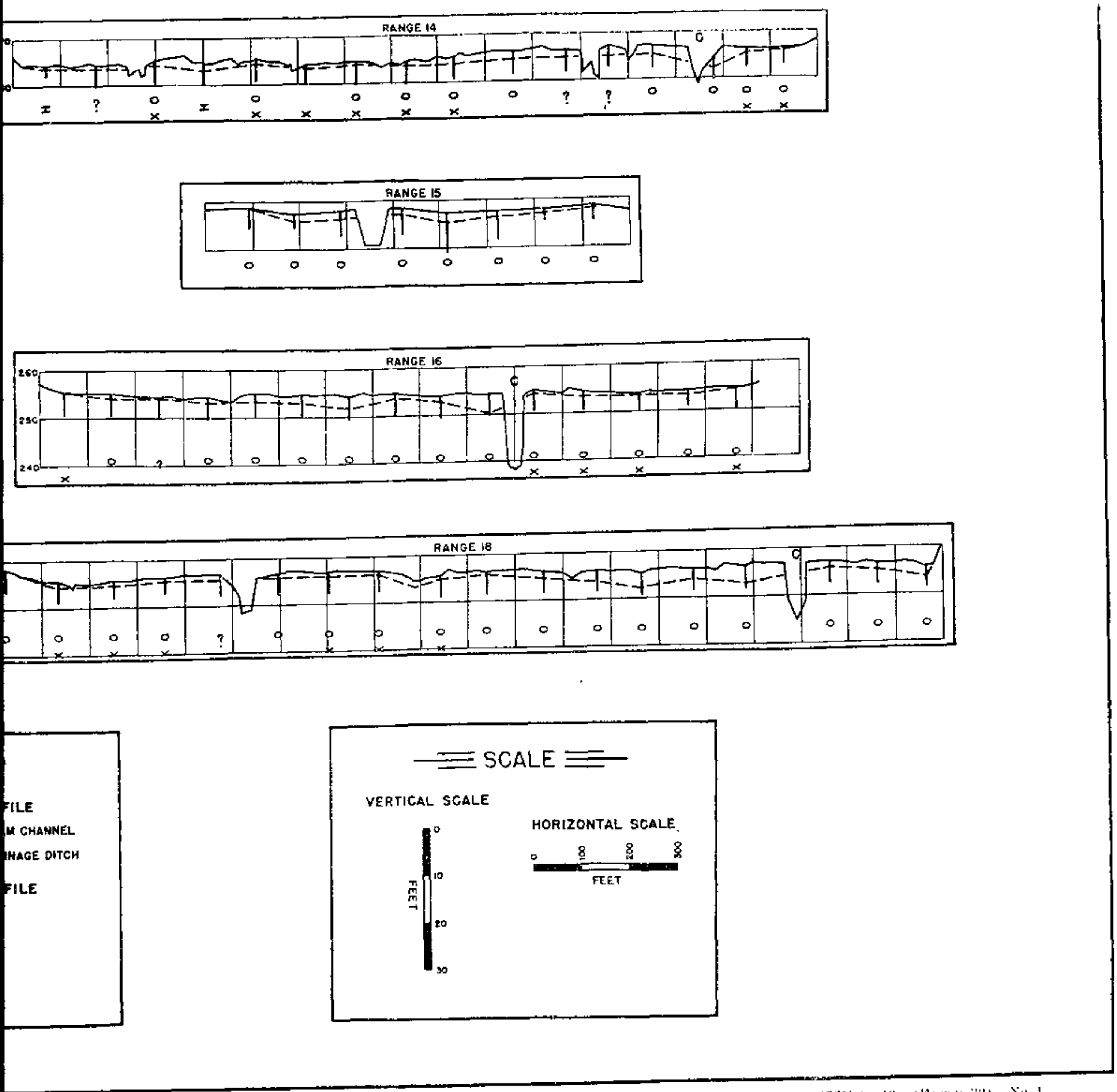


FIGURE 8.—Cross sections of Tobitubby Valley, showing thickness of modern d



Valley, showing thickness of modern deposits as determined by test borings.

115619—16 (Face p. 32) No. 1

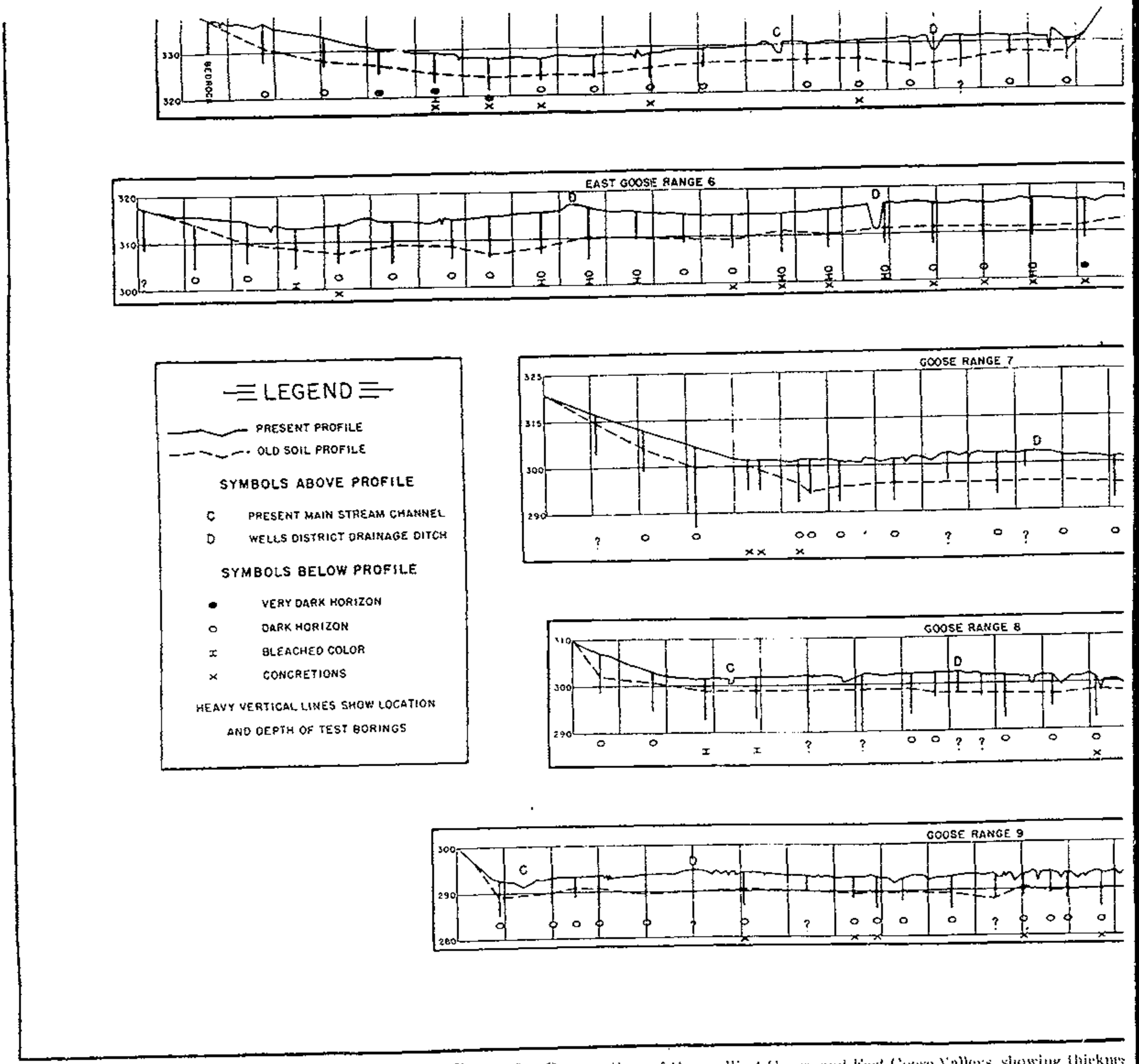
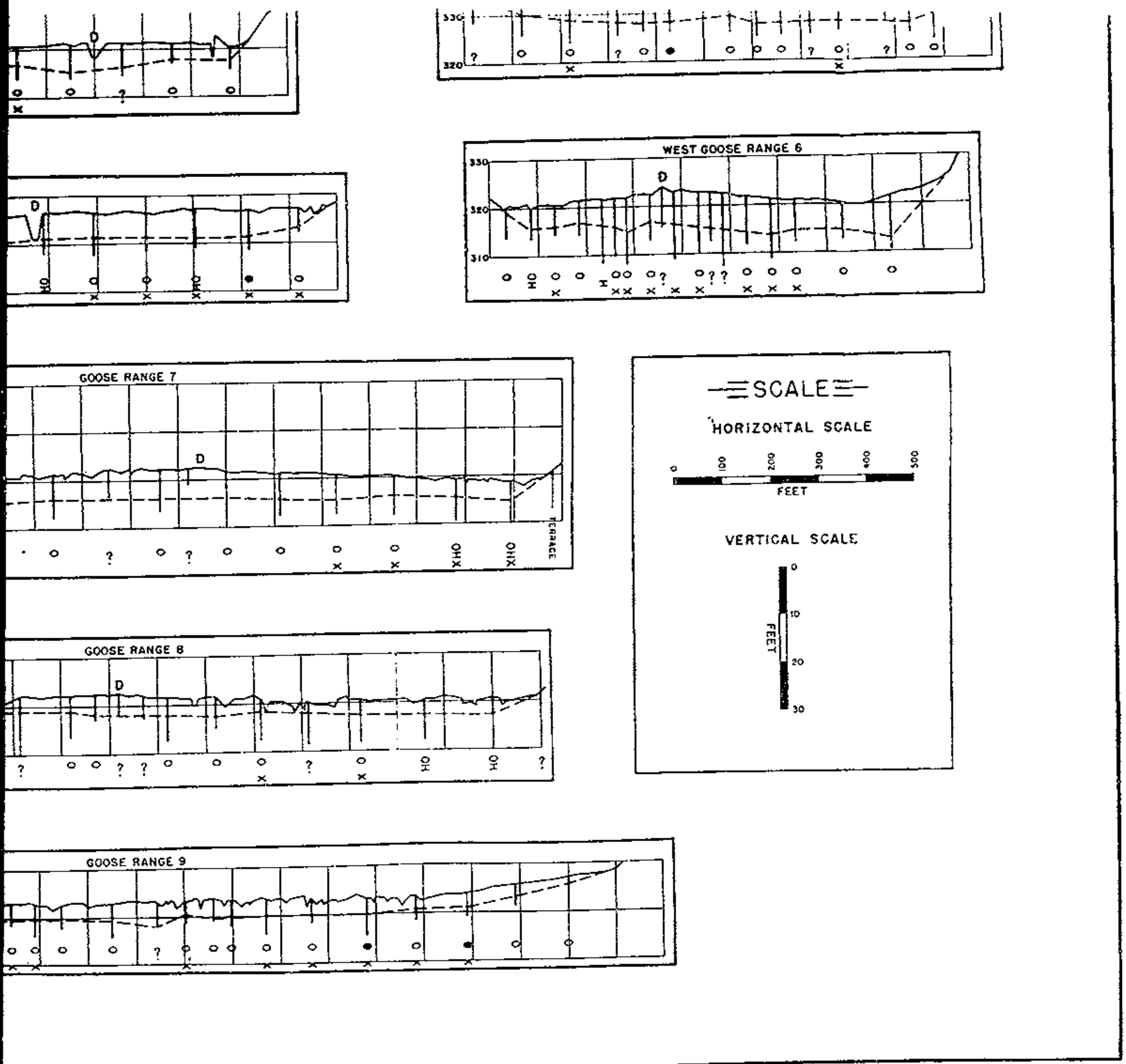


FIGURE 9.— Cross sections of Goose, West Goose, and East Goose Valleys, showing thicknes

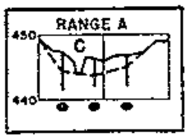


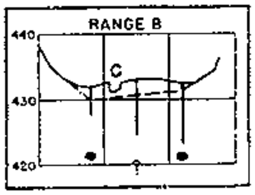
East Goose Valleys, showing thickness of modern deposits as determined by test borings.

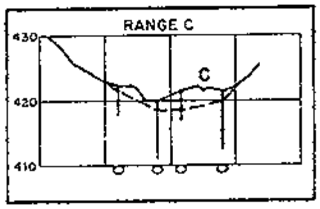
145619°—40 (Face p. 32) No. 2

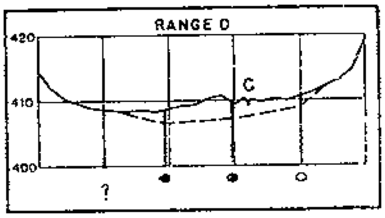
TB 695 (1940) USDA TECHNICAL BULLETINS UPDATA
SOME PRINCIPLES OF ACCELERATED STREAM AND VALLEY SEDIMENTATION
HAPP, S C , RITTENHOUSE, G , DOBSON, G C 3 OF 3

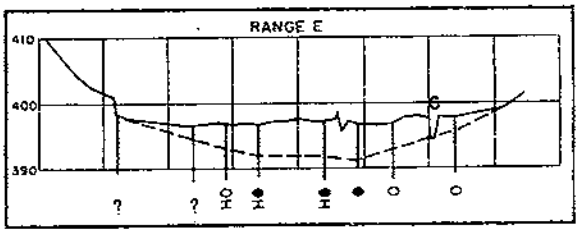
CROSS SECTIONS OF HURRICAN

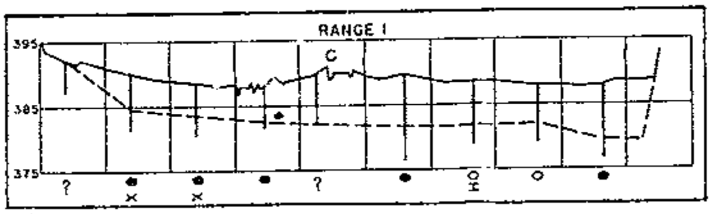


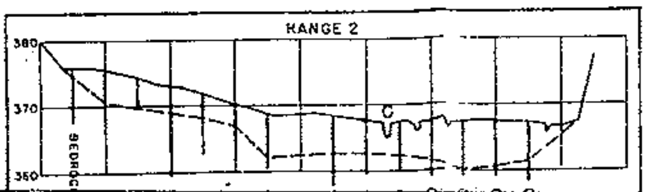












LEGEND

PRESENT GROUND SURFACE

OLD SOIL

SYMBOLS ABOVE PROFILE

C PRESENT MAIN STREAM CHANNEL

SYMBOLS BELOW PROFILE

● VERY DARK HORIZON

○ DARK HORIZON

H BLEACHED COLOR

× CONCRETIONS

HEAVY VERTICAL LINES SHOW LOCATION AND DEPTH OF TEST BORINGS

SCALE

HORIZONTAL SCALE

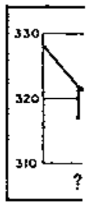
0 100 200 300

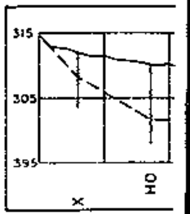
FEET

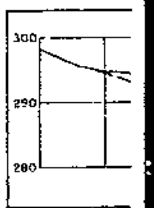
VERTICAL SCALE

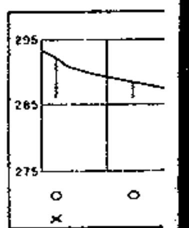
0 10 20 30

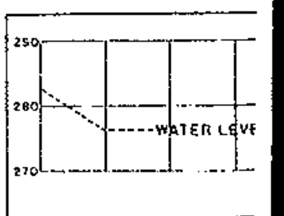
FEET

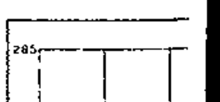












IONS OF HURRICANE VALLEY

D

UND SURFACE

ROFILE

REAM CHANNEL

PROFILE

ON

OW LOCATION

ORINGS

ALE

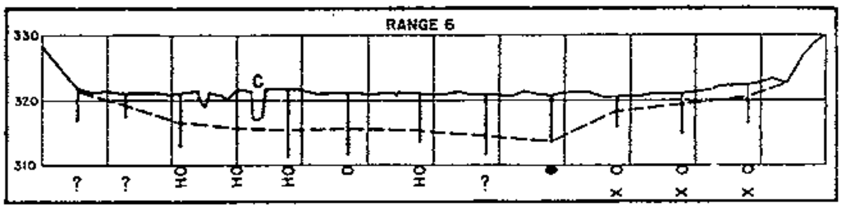
TAL SCALE

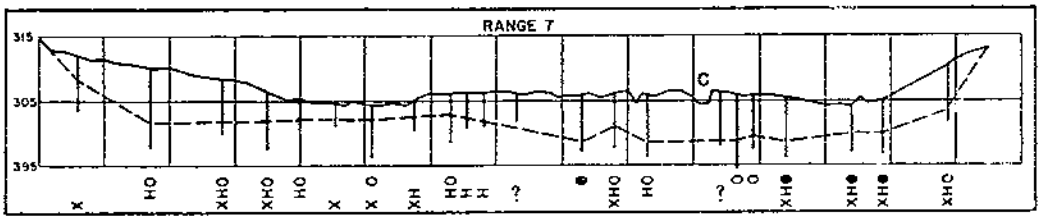
200 300

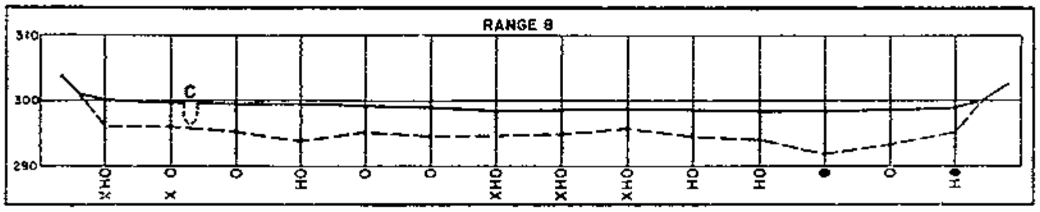
EET

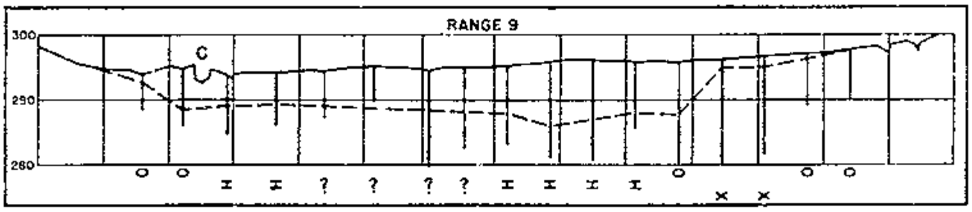
AL SCALE

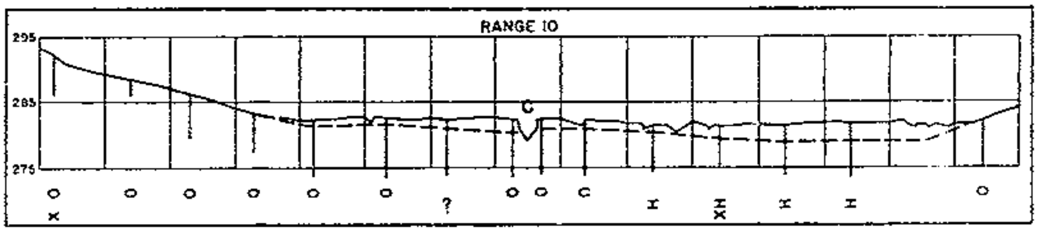
0 10 20 30

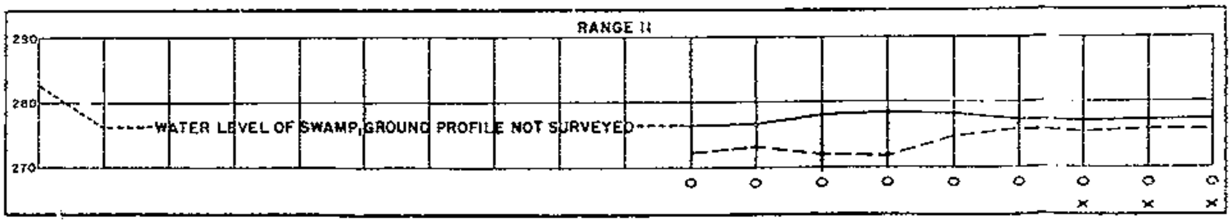


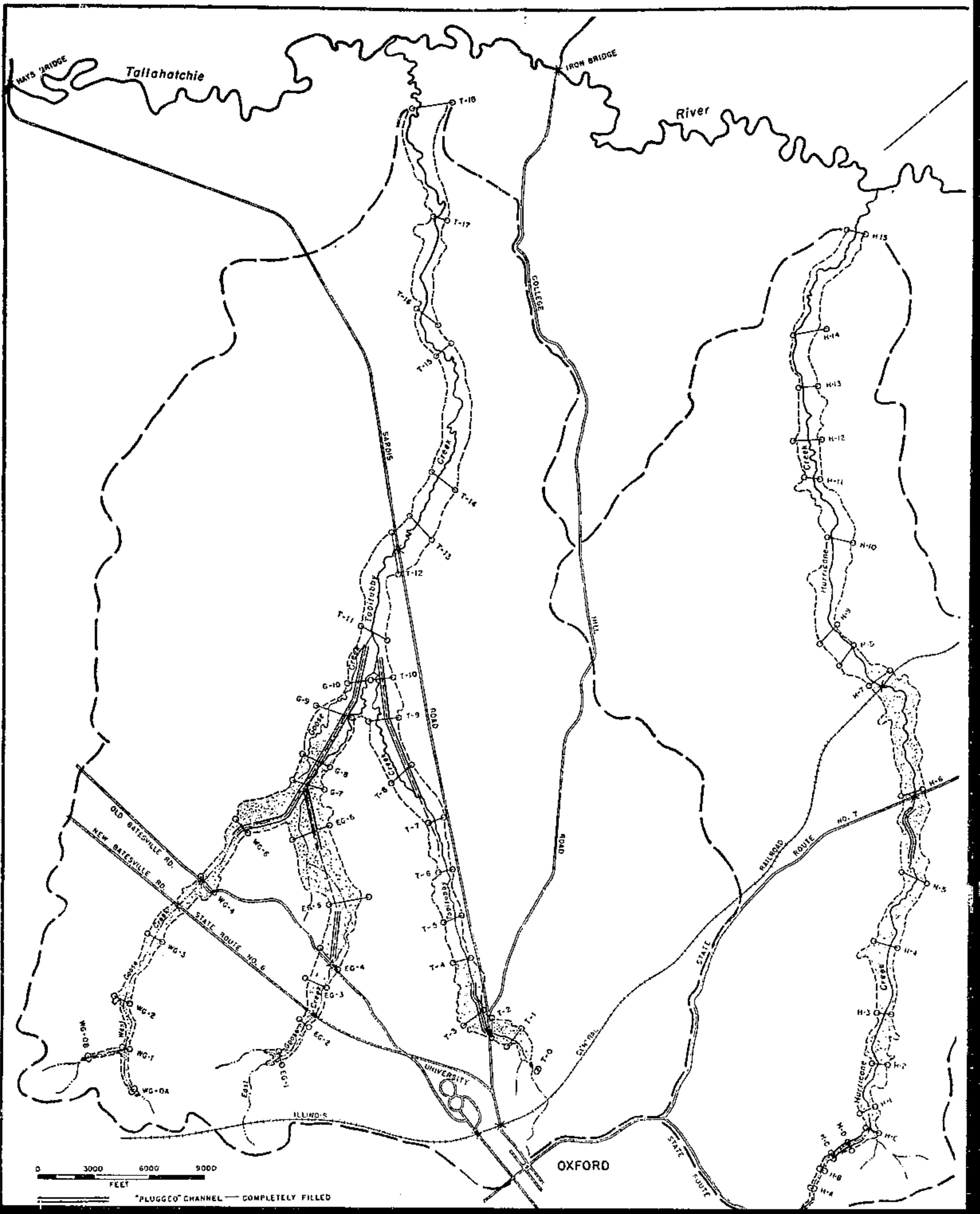


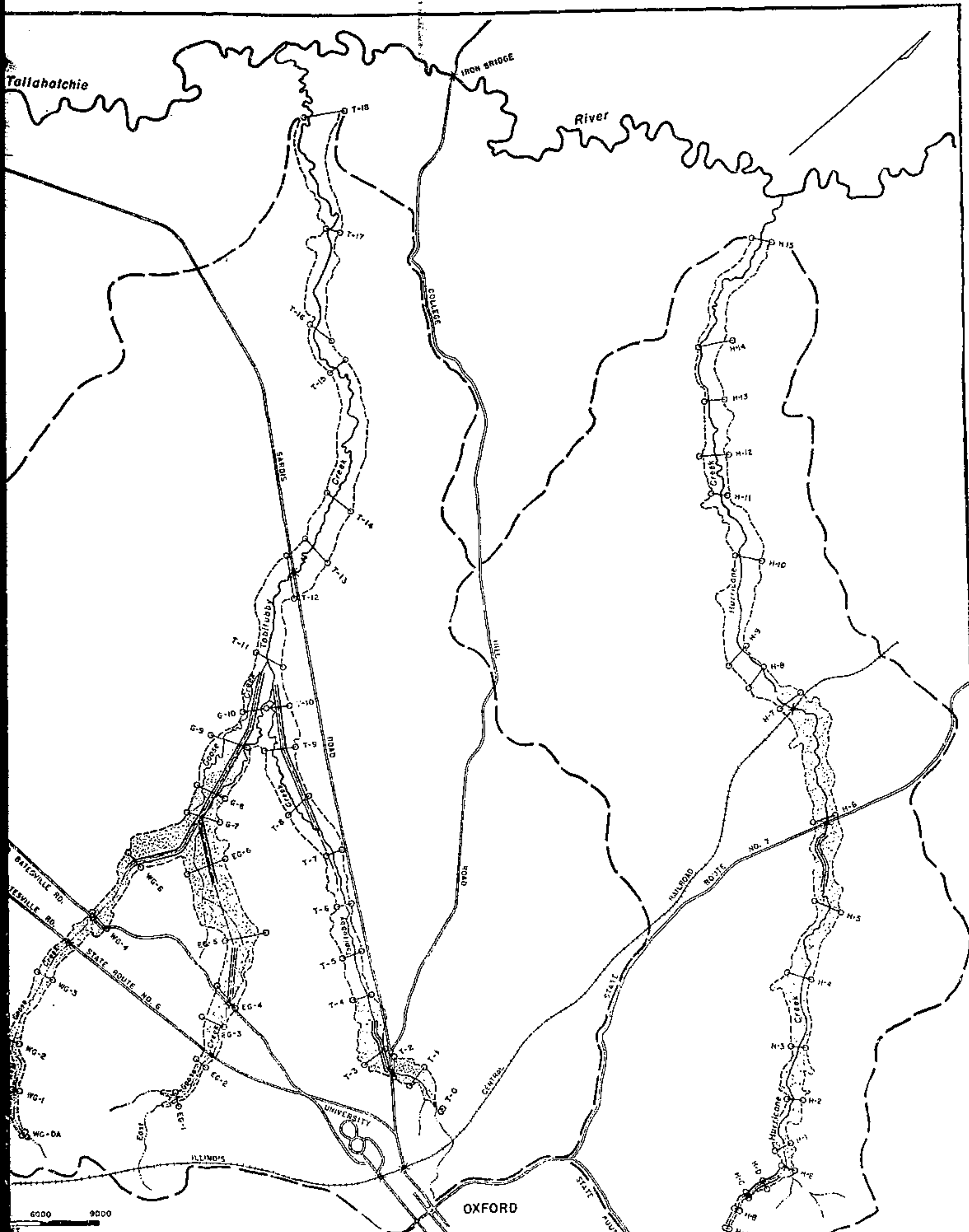




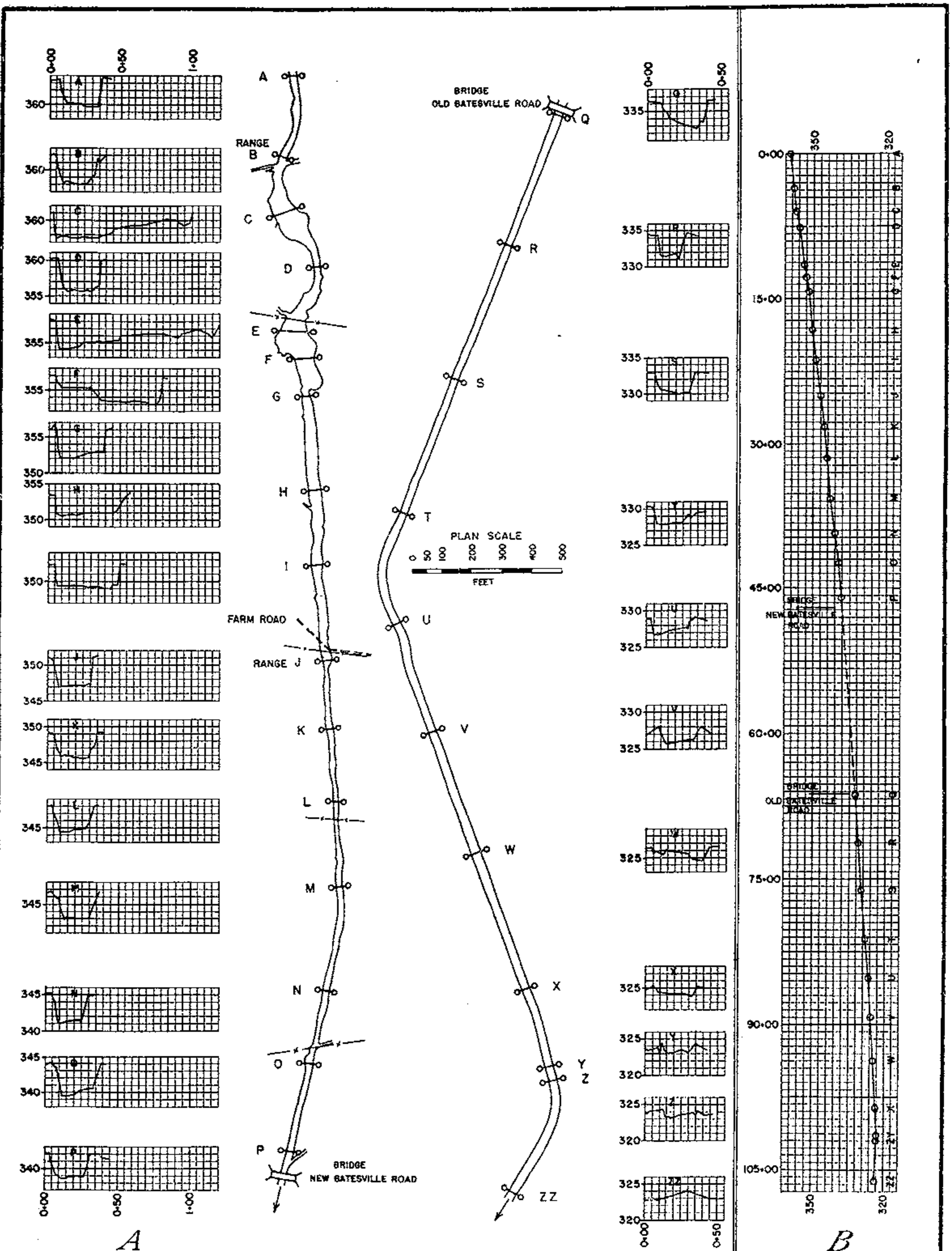





Tallahatchie
River
HAYS BRIDGE
IRON BRIDGE
COLLEGE
HILL
ROAD
SARDIS
ROAD
Toolfubby
Creek
Hurricane
Creek
Goose
Creek
East
West
OLD BATESVILLE RD.
NEW BATESVILLE RD.
STATE ROUTE NO. 6
STATE ROUTE NO. 7
RAILROAD
STATE
ROUTE
CENTRAL
ILLINOIS
UNIVERSITY
OXFORD
0
3000
6000
9000
FEET
"PLUGGED" CHANNEL
COMPLETELY FILLED



"PLUGGED" CHANNEL — COMPLETELY FILLED



BRIDGE
OLD BATESVILLE ROAD
RANGE
FARM ROAD
RANGE
BRIDGE
NEW BATESVILLE ROAD
PLAN SCALE
FEET
BRIDGE
NEW BATESVILLE ROAD
BRIDGE
OLD BATESVILLE ROAD

A

B

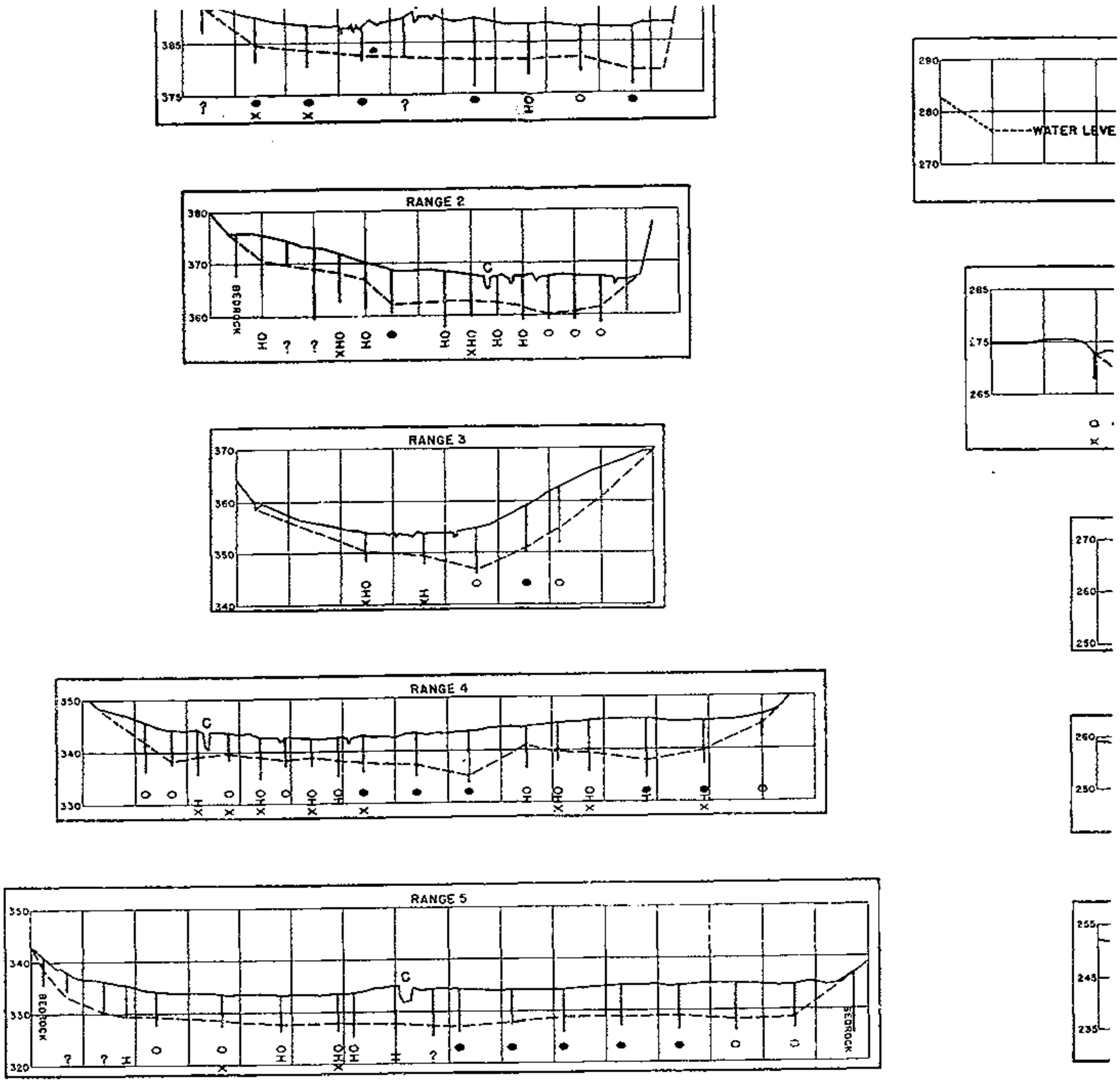
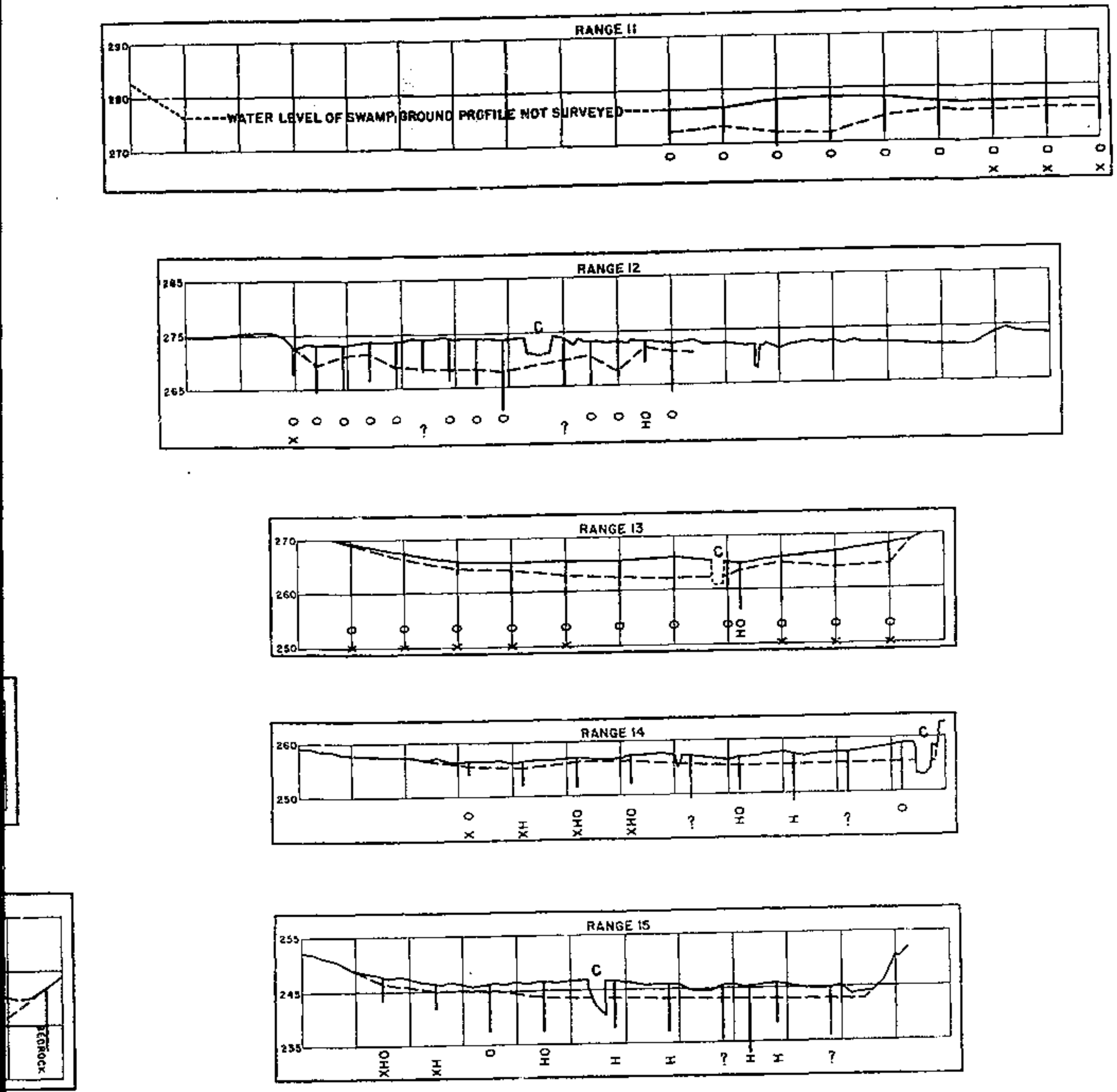


Figure 10.—Cross sections of Hurricane Valley, showing thickness of mode



Valley, showing thickness of modern deposits as determined by test borings.

145619°—10 (Face p. 32) No. 3

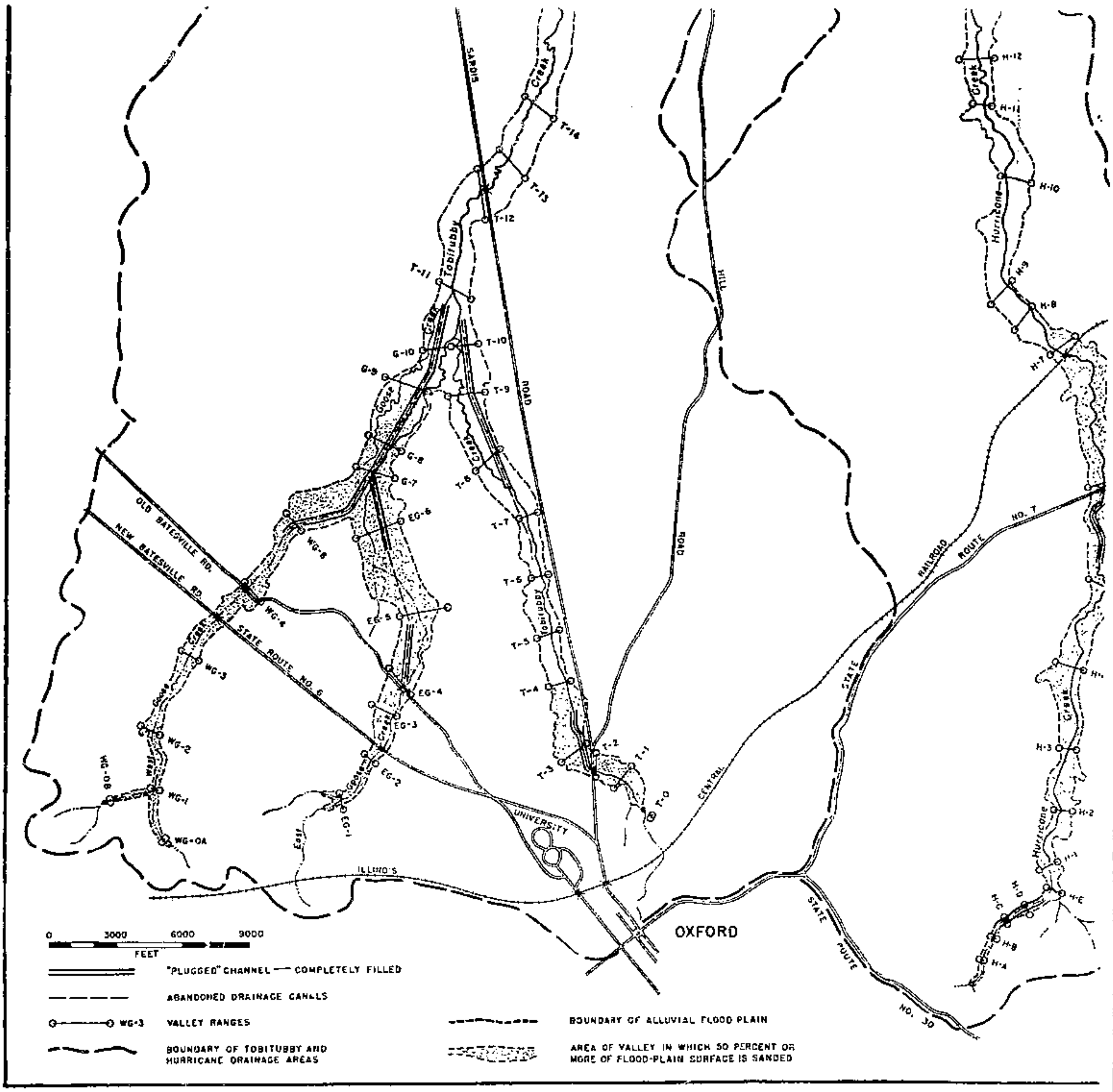


FIGURE 15.—Location of channel plugs and areas of sanding in Hurricane and Tobitubby Valleys.

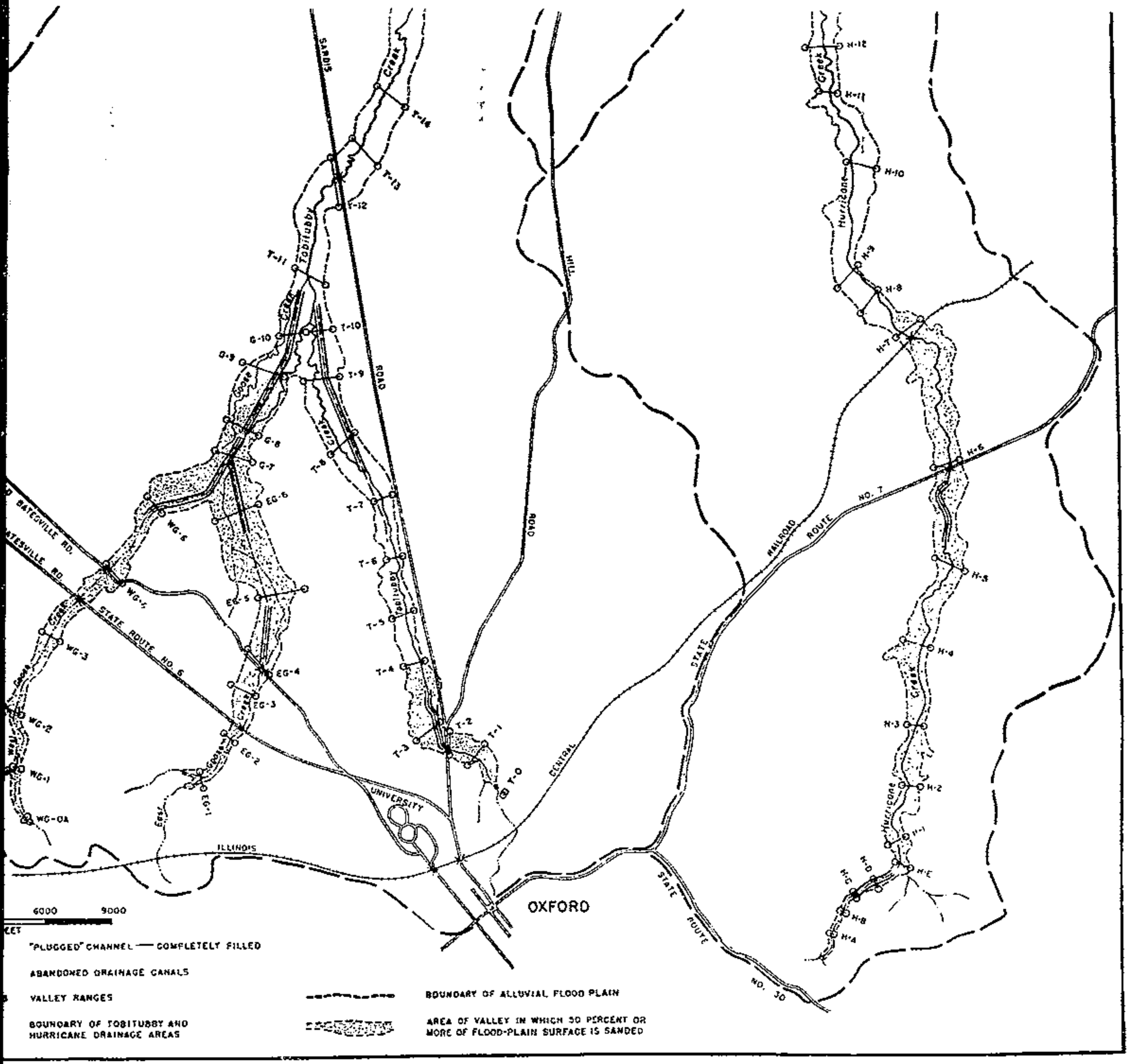


FIGURE 15.—Location of channel plugs and areas of sanding in Hurricane and Tobitubby Valleys.

143619—40 (Face p. 42)

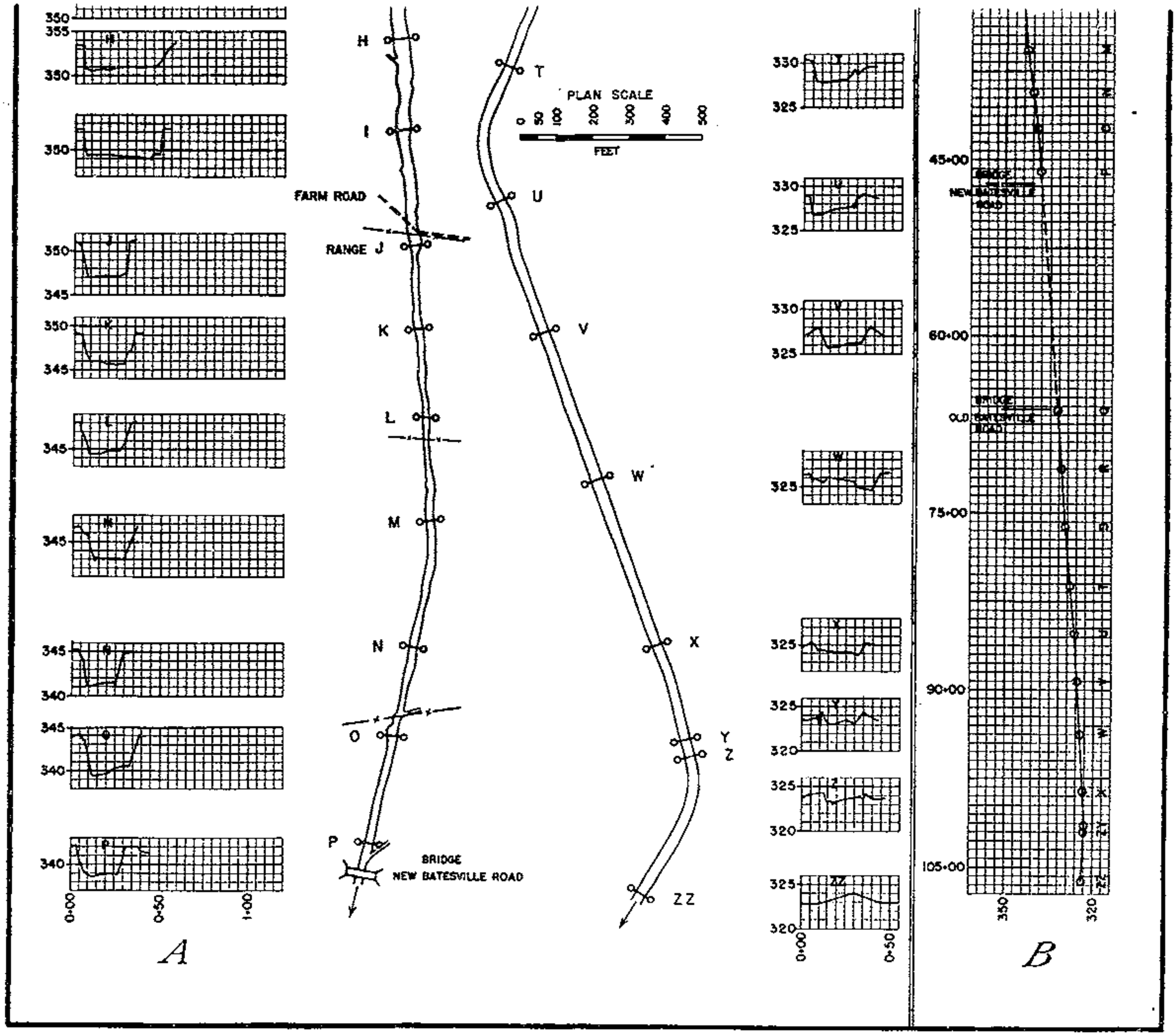


FIGURE 17.—*A*, Plans and cross sections of a part of West Goose Creek drainage ditch, illustrating widening by erosion of cleared banks and decrease in channel capacity above a completely filled channel. The channel banks have been cleared above cross section J, but not below that place. Cross section ZZ is at the head of the completely filled channel, and the channel bend near cross section Z is also shown at the left of the center of Plate 8, *A*. Plate 8, *B* is a photograph near cross section ZZ, and Plate 9, *A*, is at cross section Y. There is a gap of 1,950 feet between the new Batesville Road at the lower end of segment A–P and the old Batesville Road at the upstream end of segment Q–ZZ. *B*, Longitudinal profile of West Goose Creek steam bed.

END