The Swallow-holes of Lost River, Orange County, Indiana[1]

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Abstract

Lost River of southern Indiana has an upper area of surface drainage on an upland limestone plain, a middle area of subterranean drainage through a perched sinkhole plain, and a lower area of intrenched drainage at or near baselevel. Intrenchment of the lower section of Lost River permitted the lowering of the watertable of the middle area and sinkhole topography and sinking drainage followed. The upper area of surface drainage on the limestone upland remote from the intrenched lower part of the stream basin remains unaffected and still has a watertable limited by the stream itself. The sinkholes, the sinking streams, the lengthened and little used dry-bed section of Lost River, and the capacious cavernous underground drainage routes of the middle section have been developed during the present cycle of drainage intrenchment, and they are the products of invading surface waters keeping pace with a progressively lowered or withdrawn watertable in the perched section of the limestone upland.

Foreword and Acknowledgments

The field work upon which this paper on Lost River is based was begun in the early 1920's and has continued intermittently through a period exceeding 25 years. The later years of the study have consisted chiefly in observations on the stormwater behavior of this most interesting drainage system in Indiana. In the early work the dry-bed channel was planetabled and at least 135 square miles of the drainage basin were mapped by contours based on carefully checked aneroid barometer determinations of altitudes and closely spaced traverses. The altitudes given in the present paper are relatively correct and are presented without apology. The descriptive material deals mainly with the drainage characteristics and topographic features of some 160 square miles of the upper Lost River basin which characterizes a section of the Southern Indiana Karst. It is the most complete and accurate report ever made on Lost River, and the writer hopes that it will prove useful to others interested in subterranean drainage studies and the characteristics of a fairly large stream which has sought underground routes through cavernous conduits many miles in length. It should be especially helpful in indicating the location and characteristics of the leading features associated with Lost River as a subterranean stream system. The efficiency of the surface waters to develop cavern-

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ous routes and caverns themselves is inescapably manifested in a region which runs rife with cavernous routes, and the conditions under which caverns originated and the machinery which developed them in a limestone region are given considerable attention.

Grateful acknowledgment is made to the Waterman Foundation of Indiana University for subsistence and expense funds during the summers of 1926 and 1929; also to the Department of Geology, Indiana University, for funds to defray expenses for shorter periods of study and trips made to the Lost River region over a period of years. Further, grateful acknowledgment is made to Robert R. Shrock, now of Massachusetts Institute of Technology, for help in the mapping of some 30 caverns and holes in the Lost River region during the summer of 1929. Only 3 important caverns of those explored and mapped have been described and their details published. One other is mapped and described in the present paper.

Lost River Drainage System

The entire Lost River drainage system occupies approximately 355 square miles in portions of Washington, Orange, Lawrence and Martin counties in southern Indiana. The system extends mainly westward for an airline distance of 33 miles, draining a broad area in two diverse physiographic terrains. Its upper section is largely on the Mitchell plain, an upland of slight relief underlaid by the Middle Mississippian limestones, dipping gently westward, and characterized in part by sinkholes, sinkhole topography and sinking minor streams. Much of the headwater section and the trunk stream of Lost River to near Orangeville are on the St. Louis limestone, though most of the dismembered sinking streams and much of the sinkhole plain are developed on the superadjacent Ste. Genevieve limestone. Only minor intermittent streams descending sharply from sandstone ridges pass over the still higher Chester formations. The lower section of the drainage system is in the rugged Crawford upland west of the Mitchell plain, where the relief is much greater, and where the terrain is characterized by deep valleys and rugged standstone ridges developed on the Upper Mississippian (Chester) and Lower Pennsylvanian (Mansfield) sandstones. The eastern border of the Crawford upland of southern Indiana is formed by the much eroded and irregular Chester escarpment which rises 100 to 200 feet above the Mitchell plain adjacent to it. The irregular Chester escarpment has been pushed westward where it is crossed by Lost River, but it swings abruptly eastward along the southern edge of the upper part of the basin for a distance of 15 miles or more (Fig. 1). The sprawling drainage of Lick Creek, an important tributary entering the lower section of Lost River near West Baden, lies south of the eastward extending escarpment and wholly within the Crawford upland area. A considerable section of the lower course of Lost River is on the Ste. Genevieve limestone which forms the floor of the valley in the eastern part of the highly dissected upland. Farther west in Martin County the stream in turn passes over the various Chester formations of the Upper Mississippian and terminates on the massive Mansfield sandstone of the Lower Pennsylvanian.

Lost River and its tributaries originally formed a normal dendritic system throughout its area, but a considerable part of its upper section has been disrupted by the development of subterranean drainage and many of its former tributaries have been diverted from their former surface courses. At least 160 square miles of the drainage system in whole or in part have succumbed to subterranean drainage, and in large areas a sinkhole plain has been developed with little or no evidence of the former tributary courses (Fig. 1). The rainfall on such areas

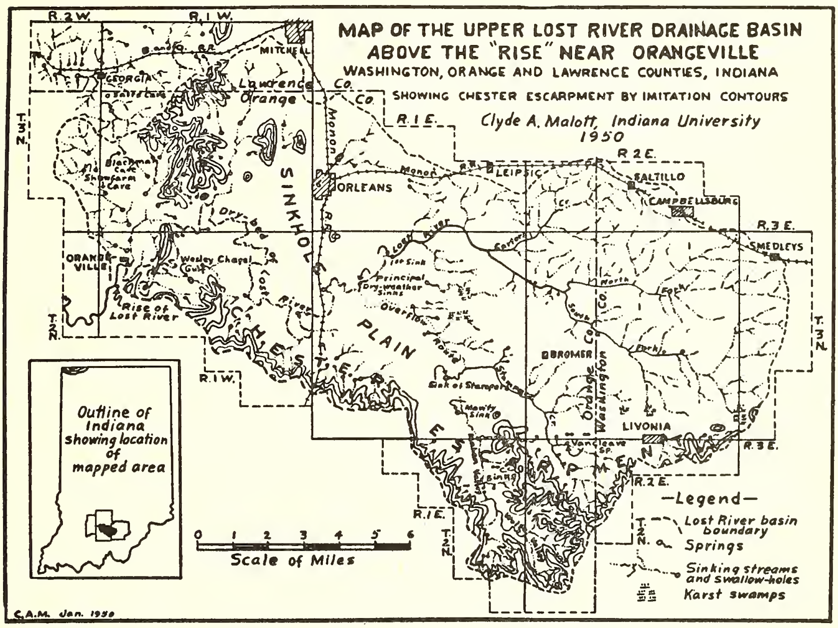

Fig. 1. The drainage basin of Lost River above the resurgence of the underground stream near Orangeville comprises an area of 160 square miles. Some 47 square miles of the drainage in the headwater region is normal surface drainage which sinks in swallow-holes into an underground system and re-appears more than 7 miles west of the first sinks. The sinkhole plain in the middle of the mapped area contains thousands of sinkholes, and all former tributaries have been dismembered from the dry-bed course of Lost River. Stampers Creek is the largest of these dismembered streams, but its system is also greatly broken up by sinking drainage diverted from it. Its perennial head is at several springs which get some of their supply from waters diverted underground from the South Fork of Lost River near Livonia. In the rugged upland back of the Chester escarpment underground drainage is developed in karst valleys, the surface drainage descending from the sandstone-capped ridges. The drainage of an undetermined area of many square miles along the B. and O. Railway in Lawrence County has been diverted underground southward into Lost River, the waters re-appearing at the Orangeville "rise". A portion of this diverted drainage is shown on the map.

almost immediately becomes subterranean. Some areas, however, discharge their drainage waters through normal surface courses from upland areas, but become swallowed up on reaching the lower sinkhole plain. These surface stream courses are the upper parts of former streams which reached the trunk stream of Lost River, but now are the distal and dismembered branches ending in swallow-holes. This drainage condition is especially prevalent where the drainage descends from the sandstone-capped hills of the Chester escarpment or comes from the areas within the Crawford upland along the south side of the drainage basin and in the region west of Orleans and north of Orangeville.

Stormwaters in several small intermittent former tributaries sink in successive swallow-holes in the upper parts of their shallow valleys and along their former courses now within the sinkhole plain. "Old Sulphur", heading some 3 miles east of Orleans, and Pearson Creek, heading near Mitchell, are two examples. Stampers Creek, along with the partially karsted floors of Mahan and Wolfe valleys, formerly composed an area of approximately 40 square miles which drained into Lost River, but now is diverted underground southward and westward to the deeply intrenched Lick Creek where the waters return to the surface as springs and resurgences. In very exceptional rainfalls Stampers Creek floods a large area about its terminal swallow-hole and excess waters follow a former surface route for 4 miles across the sinkhole plain and enter the trunk stream of Lost River a short distance below the main dry-weather sinks of that stream. This nearly lost course is scarcely discernible in normal times and roads cross it without bridges. At one place a cemetery partly occupies it and a church is dangerously nearby. The Stampers Creek system itself has been greatly disrupted and dismembered through subterranean diversion, so that now scarcely 15 square miles of drainage discharge into its terminal swallow-hole (Fig. 1).

Lost River itself heads on the broad divide south of Smedleys at an altitude of 900 feet, and with its various branches occupies a broad, gentle westerly sloping area between Campbellsburg and Livonia in Washington County (Fig. 1). Its two forks join one mile west of the county line in Orange County where the main stream has descended to an altitude of about 685 feet in a distance of a little more than 6 miles. Two miles farther west it is joined by Carters Creek which is a normal surface stream. The relief of the upland limestone plain in the headwater region is slight, but in the localities of the junction of the two forks and Carters Creek the main stream occupies a broad, open valley 60 to 80 feet below the upland surface. The headwater region with its many branches in Washington County is essentially without sinkhole development and its small branches carry waters intermittently in the manner of normal headwater branches. Near the county line several small springs appear along the two forks of Lost River and others enter below the junction of the two forks in Orange County. The waters of these springs are clear and their flows do not fluctuate greatly. All of them are situated close to the streams which their waters enter. Their aggregate flow is sufficient to keep water running in the main stream west of the Washington county line. The largest spring noted is the Johnson spring in the NW¼ of sec. 7, T. 2 N., R. 2 E., 1¾ miles west of the Washington county line. Its average flow is estimated to be about 75,000 gallons per day. These springs represent the terminals of small initial subterranean systems which originate upon the limestone upland nearby. They are incipient underground systems so small that they have not yet affected the topography and are bedrock seepage routes wholly above the streams into which their terminals discharge. They are gravity springs fed by percolating waters draining from the rock and do not have any significant amounts of waters from sinkholes or sinking streams entering their systems.

Below the junction of Carters Creek only a few rather small stormwater tributaries enter Lost River, and shallow sinkholes make their appearance on the upland. Here the upland surface has descended to an altitude of 700 feet. Three miles below Carters Creek, Lost River has reached westward well into the sinkhole plain, and the first sink appears in the stream channel, and with it the perennial stream ends. Here the stream has descended to an altitude of 625 feet, and the sinkhole plain adjacent to it is only 650 to 675 feet in altitude. The sinkhole drainage of the upland is complete, beginning at or near the 700-foot contour line. Few surface streams survive on the upland below 675 feet in altitude. The drainage absorbed in the sinkholes no longer reaches the surface stream; instead, it goes below into the same subterranean system that has sapped the waters of the main stream. It is here, also, that the intermittent dry-bed channel of Lost River begins.

The dry-bed channel of Lost River is a well developed channel which passes westward across the sinkhole plain in a tortuous course at least 22½ miles in length to the large resurgence or rise at Orangeville. This distance is three times the direct distance of 7½ miles (Fig. 2). The channel is 12 to 16 feet in depth, and in the first 11 miles of its course its rather gently sloping banks are largely composed of soil normally covered with grass or other vegetation. Trees are commonly present on all parts of the banks and locally in the bed of the channel itself. The outer banks are rather far apart, in many places exceeding 100 feet. The channel bed is locally quite narrow, but in places it is 50 feet or more in width. Islands are not uncommon. Locally both the gently sloping banks and the bottom form rich pastures of grass, and occasionally crops are planted across the entire channel and it becomes a part of the cultivated fields through which it passes. The downstream gradient of the upper 11 miles of the course is rather gentle, averaging only about 4 feet per mile. The remaining 11 miles or so of the dry-bed course has a gradient of nearly 8 feet per mile. This section has a wider flooor, and a rough, rocky bottom prevails. Its banks are locally steeper and in many places composed of exposed rock. The complete descent of the dry-bed between the first sink and the Orangeville resurgence or rise is 130 feet,

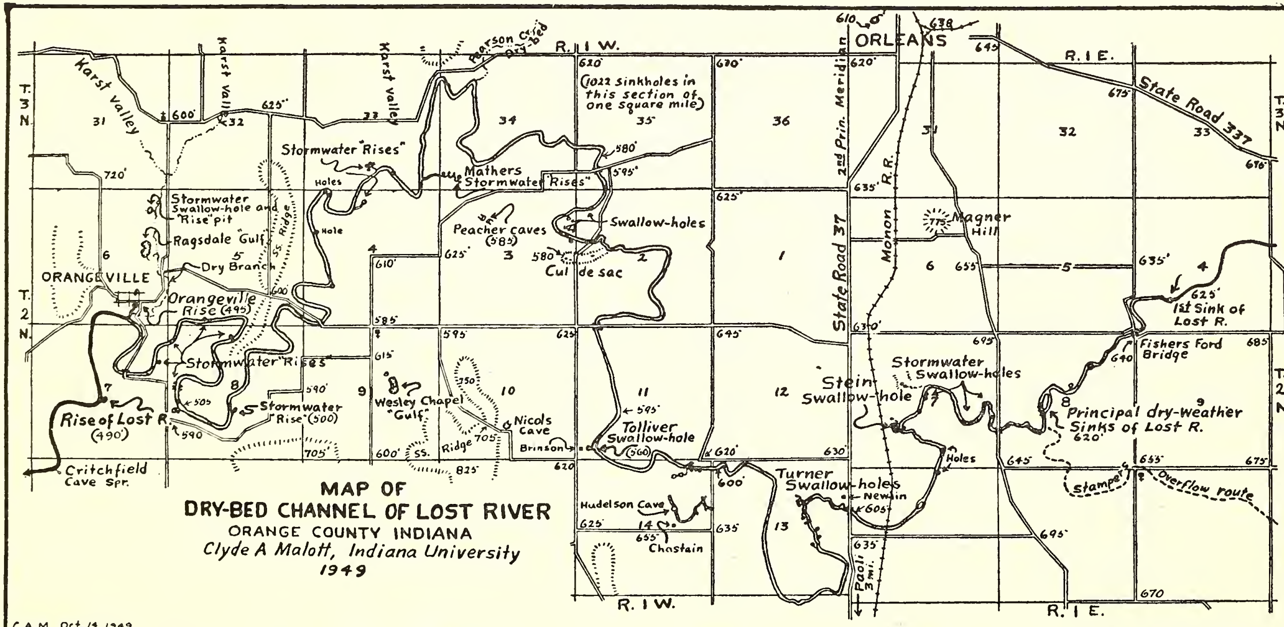

Fig. 2. The tortuous dry-bed channel of Lost River across the sinkhole plain is 22½ miles in length. The map shows both the locations of its known swallow-holes in the upper perched section of the dry-bed and the stormwater resurgences in the intrenched lower section reaching to the terminal and perennial "rise" of underground Lost River south of Orangeville. Underground Lost River is a complex, multi-channel course which passes westerly beneath the surface from the principal dry-weather sinks to the perennial "rise". The underground system may be entered at the Tolliver swallow-hole and at the Wesley Chapel "gulf". The dry-bed course is a stormwater channel only. Its middle portion is used only following very heavy rains. Its upper and lower sections are used more frequently. Figures indicate altitudes along and adjacent to the dry-bed channel.

the latter having an altitude of 495 feet. In the first 10 or 12 miles below the first sink in the channel the dry-bed is but little below the sinkhole plain itself, but it becomes deeply intrenched before reaching the Orangeville resurgence. The lower part of the dry-bed channel and the resurgences near Orangeville are in the rugged Crawford upland where sandstones cap the ridges between the deeply set limestone valleys. Below Orangeville the remaining 30 miles or so of Lost River to East White River is a winding, deeply intrenched stream with a rather low gradient at the baselevel of the region.

Topographic expression and physiographic development

Physiographically all of the Lost River drainage system is in the driftless area of southern Indiana, and the upland surface is a part of the widely extensive Tertiary peneplain characterizing much of the upland area south of the glacial boundary in the central interior region of the United States. This widely developed upland peneplain is characterized by two or more topographic levels, and is therefore compound or multiple in topographic expression. One topographic level is at an altitude of 900 feet or more, and the other is developed below it at an altitude of about 750 feet, though local areas have been reduced below the latter level. The 750-foot level adjacent to the main streams in southern Indiana is characterized by local areas of upland gravels generally assigned to the Lafayette formation of late Pliocene age. The altitudes and topographic expressions of the upland areas are dependent upon the lithologic characteristics of the rocks underlying different sections of the terrain, upon former baselevel controls, and upon nearness to important drainage lines. The compound upland plain locally has been greatly modified by erosive reduction and stream intrenchment below the upland levels. A considerable part of the sinkhole plain of the Lost River region has been greatly reduced by solution of the limestone under its soil cover and only limited areas are preserved at the 750-foot level.

Lost River heads upon the higher and remnantal surface of the Tertiary peneplain at an altitude of 900 feet. This surface is preserved only on divides in southern Indiana. Much of the drainage reaching from the 900-foot topographic level and descending to the 750-foot level is surface drainage in the limestone terrain. It does not become subterranean, however, until it reaches still lower altitudes. The sinkhole plain proper is developed in the Lost River region almost entirely below an altitude of 700 feet, and down to 600 feet along the western edge where it abuts against the irregular Chester escarpment. The altitudes at which sinkholes are developed, however, are greatly dependent upon nearness to or distance from intrenched drainage, or upon only slightly lower drainage areas in a down-dip direction of the underlying limestone strata. Some sinkhole areas are developed at 800 feet in altitude or even slightly more, such as the local sinkhole development in the locality of Livonia between some of the branches of the South Fork of Lost River and headwater resurgences of Stampers

Creek on the west. The latest developed Tertiary partial cycle, typically represented at an altitude of 750 feet, undoubtedly had some subterranean drainage of its own, but much or all of it is lost, or so overshadowed by the lower and later developed sinkhole plain and its underground drainage that little is left which may be assigned to it. It is possible that some of the sinking drainage descending from the Chester escarpment along the south side of the upper Lost River basin may have been inherited from the latest Tertiary partial cycle.

The Chester escarpment marks the irregular eastern edge of the Crawford upland and ascends to an altitude of 900 feet or more. The escarpment is capped by clastic rocks (principally sandstones of Upper Mississippian or Chester age). In its easterly swing a short distance east of Orangeville it forms the entire southern margin of the upper Lost River drainage basin, and the stormwaters of scores of sharply descending intermittent streams become separately subterranean at or near the foot (Fig. 1). Although the upper surface of the Crawford upland stands 150 to 200 feet above the karsted limestone terrain, it is deeply trenched and eroded through valley development. Many of its main valleys are cut to much lower levels than the upland limestone plain and reach through the clastic rocks into the same limestone sequence. Lost River itself passes westward into the rugged upland in a deeply cut valley and reaches an altitude of less than 500 feet at Orangeville. The subterranean waters of Lost River and the sinkhole plain return to the surface within this rugged region, and many of the smaller valleys of the eastern section of the upland have karsted limestone floors with local and individual subterranean drainage. The large and well known resurgence or rise at the village of Orangeville is the terminus of the underground drainage of a series of karst valleys to the north, and possibly also from considerable areas of the sinkhole plain itself, and its entrance into Lost River terminates the dry-bed channel. This resurgence is not the rise of Lost River. It is, however, an important tributary of that stream.

The present underground drainage of Lost River, the cavernous routes, the detached former surface tributaries, and the thousands of sinkholes of the extensive sinkhole plain are all products of the present geomorphic cycle and are post-Tertiary in development. They are features developed on an upland surface that is considerably below the level of the latest Tertiary partial cycle. The regional uplift which closed the latest Tertiary partial erosion cycle marked the beginning of the present valley intrenchment and the dissection and reduction of the partial peneplain. Lost River cut the lower part of its valley deeply below the partial peneplain, eventually leaving the upper part of the meandering course of the stream perched upon the limestone plain 200 feet or more above its deeply intrenched section downstream from near Orangeville. The present meandering course of the dry-bed was inherited from the preceding cycle.

The intrenchment of Lost River in the Orangeville region and the effective rejuvenation of the upland limestone plain upstream was not suddenly accomplished. Only slight entrenchment, however, permitted some development of underground drainage and the watertable to be drawn down, thus initiating the present cycle. The western section of the perched limestone plain was affected much earlier than areas farther east and more remote from the intrenched section of Lost River. As a consequence of the nearness of the western section of the upland plain to the intrenched section of Lost River, the lowering of the upland surface began in an early stage of the present cycle, while the more remote and eastern part of the upland plain and of Lost River itself were little affected, even as they are today. The western section of the limestone upland has been greatly lowered, both by surface erosion and solutional reduction, and much of it is below 700 feet in altitude and the westernmost areas are 600 feet or even less. Also the perched limestone upland adjacent to Lost River has been pushed farther west by the stripping away of the Chester sandstones and shales, and the exposed limestone there has become well karsted at much lower altitudes than the largely destroyed Tertiary partial peneplain.

The development of underground drainage and the lowering of the watertable in the karsted area of the Mitchell plain was progressive from west to east. In the earlier stages relatively shallow underground drainage passages were made and are now either eroded away or are represented by the present higher cavern levels, some of which are quite dry. Sinkhole development and the loss of surface drainage to underground routes were more or less restricted to the western margin of the limestone upland. Lost River probably sought underground routes in which only limited parts of the present dry-bed were involved in partial disuse. It is quite possible than an early sink was developed in the SW¼ of sec. 8, T. 2 N., R. 1 W., about 1 mile southeast of Orangeville, with the sinking waters returning at the present resurgence or rise on the Allen farm three-fourths of a mile south of Orangeville (see Fig. 2 for locations.) Another sink was developed in the NE¼ of sec. 3, T. 2 N., R. 1 W., about 2½ miles southwest of Orleans, with its underground route leading through the decadent Peacher cave system and to the present stormwater resurgence in the steep-head on the Mathers farm in the SW of SW¼ of sec. 34, T. 3 N., R. 1 W. Still later Lost River sank farther up stream at the Tolliver swallow-hole in the SW of SW¼ of sec. 11, T. 2 N., R. 1 W., and its waters developed the present underground route through the Shirley or Wesley Chapel gulf and thence on to the present resurgence on the Allen farm. In the meantime the lowering of the watertable on the perched limestone plain allowed regional solution to take place in the well-bedded and well-jointed limestones and the sinkhole topography became quite extensive, enveloping large areas. Still later Lost River probably began sinking at the Turner swallow-holes in the NE¼ of sec. 13, T. 2 N., R. 1 W. In turn the Stein swallow-hole, in the SW¼ of sec. 7, T. 2 N., R. 1 E., was developed, and eventually sinks were developed upstream to the present main dry-weather sinks in the NE of SW¼ of sec. 8. The last sink to form in the stream is still farther upstream in the SW¼ of sec. 7. It appears to mark the very initiation of a sink which in time may become well developed. Concomitant with the progressive development of sinks farther and farther up stream and the lengthening of the dry-bed channel, regional sinkhole development and detachment of former surface tributaries took place, producing the extensive sinkhole plain and the sinking streams which characterize the region today.

The Sink of Lost River

Lost River sinks in its channel because of the development of underground channels in the upper portion of the St. Louis limestone slightly below the level of the stream channel. The subterranean channels are the product of subsurface solution by waters which penetrated along the slightly dipping bedding planes and along the vertical joint cracks of the limestone. Under hydrostatic pressure and along a westerly sloping watertable the earlier waters seeped through and dissolved small passages at or slightly below the watertable. These small passages joined others already made and enlarged in the downstream direction. When the initial, small, tube-like channels became enlarged along the permissive bedding planes and joint cracks, waters from the stream entered in larger quantities and further enlarged them, eventually to such extent that all the normal waters of the stream and great quantities of flood waters are now carried through them. The development of the underground system beneath the sinkhole plain has been progressive in an upstream direction, having been initiated far down the dry-bed from the present perennial sinks of the stream. Some of the earlier sinks developed in or near the dry-bed channel are now the sites of large swallow-holes which convey great quantities of stormwaters to the underground system. These stormwaters reach them by flowing along the dry-bed channel following heavy rainfalls which overtax the capacity of the smaller holes near the upstream end of the dry-bed.

The present normal dry-weather sinks of Lost River are not characterized by abrupt descents of the stream waters into deep holes to a lower level. The waters rather simply flow into small nondescript openings only in part discernible. Upstream from the sinks, waters are fed into the stream channel from groundwater sources as well as from rainfalls and the channel is a receiving surface conduit quite similar to other surface streams. The channel serves as a limiting level of the watertable of the region nearby. In the area of the sinks the channel is slightly above the watertable and the stream loses its waters to the subterranean system beneath it, though the openings leading to the subterranean system are relatively small. The loss of the surface waters in the stream at the upper end of the dry-bed channel is far from spectacular, though it is impressive.

The first known loss of the stream waters is in a shallow pool in the channel about one-half of a mile upstream from Fishers Ford bridge, near the center of the SW¼ of sec. 4, T. 2 N., R. 1 E., 2½ miles southeast of Orleans (Fig. 2). Only in prolonged dry seasons may this sink become evident. During such times the small flow of the perennial stream above enters the pool, but none flows out at the lower end. No actual swallow-hole is discernible. It is possible that some loss of water from the stream occurs farther upstream from this site, but if such is the case it has never been in sufficient amounts to cause the stream to cease flowing. When the water disappears in this pool, many of the pools below also go dry. No holes have been observed in any of them for nearly 1½ miles down the dry-bed. The first actual swallow-holes in the dry-bed are in the NE of SW¼ of sec. 8, T. 2 N., R. 1 E. It appears that several openings have developed, probably along a bedding plane just below water level on the western side of the channel. Several of them are close together immediately below a rather large river island, and others lie 100 to 150 feet upstream in the western prong of the channel about the river island. The latter are frequently dry and the lower ones receive the waters during much of the low-water periods, as the flowing stream is then confined to the eastern channel about the island. Frequently, however, some of the waters flow upstream to these small sinks. The waters of the stream simply flow into these openings nearly on the level of the stream itself, and there is little evidence of descent to a level much below the channel itself. The watertable here is only slightly below the river channel, and the capacity of the subterranean channels developed along the bedding plane appears to be rather limited. A slight increase in the volume of water in the channel causes some of the water to flow farther downstream to other swallow-holes in the channel. These small receiving swallow-holes are not littered with timber and trash carried downstream by stormwaters, but are exposed, such as they are.

Stormwater Drainage along the Dry-bed

The dry-bed channel below the present dry-weather sinks of Lost River is a stormwater channel and is occupied only when the streamflow, during or after rains, overtaxes the capacity of the dry-weather sinks. The dry-bed channel is characterized by numerous small holes into which the stormwaters descend to reach the underground system. The locations of those observed have been indicated in Fig. 2. Doubtless numerous smaller unobserved holes occur into which waters descend. Some of those observed occasionally become obstructed and appear ineffective, and new openings are developed locally along the upper part of the dry-bed course. The smaller holes are usually on one side or the other of the dry-bed channel, and some of them are out of the channel entirely, but are connected with it by subsidiary stormwater channels, usually at a higher level than the dry-bed itself. In addition to the numerous small swallow-holes of the dry-bed, three large swallow-holes have been developed which receive large volumes of stormwaters following heavy rains in the drainage basin. These large swallow-holes are not directly in the dry-bed channel, but are connected with it by short subsidiary channels leading into them. These large swallow-holes are important gathering orifices of the underground system. They are not necessarily directly over the main underground course of the subterranean system.

The stormwater swallow-holes immediately downstream from the dry-weather sinks are much more frequently used than those farther down the dry-bed. Of the large swallow-holes the Stein swallow-hole is used quite frequently, but the Turner swallow-holes, west of the bridge across the dry-bed on State Road 37, 3½ miles south of Orleans, are used only following rather heavy rainfalls. The Tolliver swallow-hole is used still less frequently, and when large volumes of stormwaters reach it, much passes by and follows the dry-bed throughout its course. Perhaps the dry-bed is flooded throughout on an average of about 3 times a year, though periods as long as a year or more occur in which the entire length of the dry-bed is not used. Below the Tolliver swallow-hole the dry-bed makes a broad northward detour through a meandering course more than 10 miles in length before returning to the line of the westward course of the main underground route (Fig. 2). Only a few swallow-holes are present along this section of the dry-bed, except for a group in the sharp westerly meander turn in the NE¼ of sec. 3, T. 2 N., R. 1 W. The western limb of this long northward detour of the dry-bed is cut sharply below the general level of the sinkhole plain. Although it has a few minor swallow-holes, it is chiefly characterized by stormwater resurgences which contribute flooding waters to the lower part of the dry-bed course. These waters rise from pits adjacent to the dry-bed and flow into it after heavy rains. These stormwater resurgence pits are referred to locally as "wet-weather rises". The waters come largely from the sinkhole plain and the sinking streams to the north and northeast of the course of the dry-bed. In the section of the dry-bed below the broad northward detour, several important openings are present from which stormwaters from the underground course of Lost River rise, and further flood this section of the dry-bed course. The dry-bed ends at the entrance of the perennial waters coming from the great Orangeville resurgence or rise which frequently pours out great volumes of muddy stormwaters derived from the karst valleys north of Orangeville.

When stormwaters overtax the swallow-holes along the dry-bed, the excess waters appear to build up a head or a front and surge down the dry-bed as a wave or series of waves, quickly flooding it to a considerable depth. The surging advance of the flood waters is probably in part a result of impeding vegetation growth in the dry-bed, which slows down the advance of the first normal overflow of small volume and allows an accumulated volume to make a sudden advance. Another factor, however, appears to be a main contributing cause of the sudden surging advance of the waters. The swallow-holes, their conduits and the cavernous routes of the underground courses are voids of great capacity. When these once become filled, stormwaters enter the swallow-holes in considerably reduced volumes, and great volumes of excess waters are shunted rather suddenly down the dry-bed channel. Farmers report the occasional drowning of stock along the dry-bed course by these rather sudden advances of surging waters.

The Swallow-holes of Lost River

Small Swallow-holes Below the Dry-weather Sinks. Some 15 or 20 holes have been observed along the dry-bed channel between the dry-weather sinks and the Stein swallow-hole (Fig. 2). These small holes are sufficient to absorb the waters from light rains discharged down the dry-bed channel, and, during the recession period following a flood, they continue to take waters for some time when the stream falls short of the Stein swallow-hole. Since the capacities of these holes are limited, the stormwaters descending the dry-bed flood them one after another, and their locations are usually well obscured in the rising waters soon after they become filled to capacity. During the waning periods when the flood waters are receding, the terminus of the storm-water stream recedes upstream hole by hole, abandoning them in reverse order. A view of one of these small swallow-holes is shown in Fig. 3. The flowing waters enter them rather quietly, or with only a

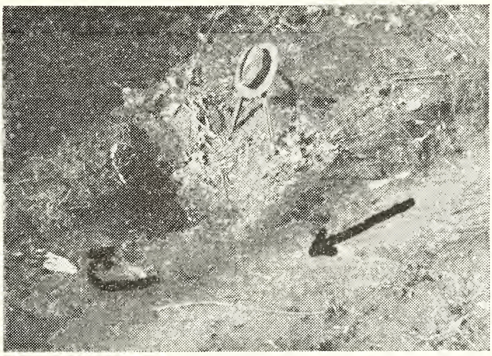

Fig. 3. View of a small swallow-hole receiving stormwaters along the dry-bed channel of Lost River about 1 mile below the principal dry-weather sinks, in the SE¼ of sec. 7, T. 2 N., R. 1 E., The stormwaters entering here at the moment form the terminus of the surface stream, but in a short time the terminous will retreat upstream to other swallow-holes and finally to the nomal dry-weather sinks. Note that the waters pour or fall into the small swallow-hole.

subdued gurgle. Vortices or whirlpools above the holes are only rarely observed, though they are undoubtedly present over some of the holes for short periods of time. They appear to be formed only when the waters below the orifices are able to get away faster than they can come through the orifices leading to the underground conduits. Some years ago a rather large noisy one was observed by the writer, and a view of it is shown in Fig. 4. It has not been observed since, though it has been looked for on many subsequent occasions.

A short distance upstream from the Stein swallow-hole, two holes on the left bank receive considerable quantities of water during flood periods. These swallow-holes are not in the dry-bed channel, but they are connected with it by a shallow channel at a higher level than the dry-bed. Small quantities of floodwater trash have accumulated about

Fig. 4. View of a noisy vortex in the stormwaters of the dry-bed channel of Lost River 100 yards below the Johnson bridge in the SE¼ of sec. 7, T. 2 N., R. 1 E, about ½ of a mile down the channel from the principal dry-weather sinks. Vortices like the one shown are temporary and are rarely observed.

them. Opposite these holes on the right side of the dry-bed, a low area leads to the west and northwest which is widely flooded after heavy rains. No prominent swallow-holes are obvious, though undoubtedly waters do sink into an underground route below. Perhaps this low, frequently flooded area was once the site of a swallow-hole somewhat similar to that of the present Stein swallow-hole, but in the course of time it has been largely plugged by inwash and accumulating silts and muds brought to it by the stormwaters during floods. It has the appearance of being an older area which has been succeeded by the present active, large Stein swallow-hole a short distance to the south.

The Stein Swallow-hole. The Stein swallow-hole is located near the center of the SW¼ of sec. 7, T. 2 N., R. 1 E., just east of the Orleans-West Baden branch of the Monon Railway, 3 miles south of Orleans. It is slightly more than 1 mile west of the dry-weather sinks of Lost River, and nearly 2 miles by way of the dry-bed route. It is about 75 yards west of the dry-bed channel, and is connected with it by a crooked, mud-lined channel 120 yards in length. The ground plan is shown in Fig. 5. The swallow-hole is developed in the top part of the St. Louis limestone. The floor of the main pit is covered with a timber-raft about 100 feet long (north and south) and 60 feet wide. The western side of the pit, where most of the waters disappear, is a steep, rocky cliff, 20 to 25 feet in height (Fig. 6). The stormwaters enter quietly at the south end of the pit. They flow swiftly along the connecting channel and into the timber-raft, descending only a few feet below the level of the dry-bed. Subsidiary holes have been developed and are used during high-water periods, some of them only when the waters have overspread the channels.

The watertable at the Stein swallow-hole appears to be 20 or 25 feet below the dry-bed, and the underground channel leading away is

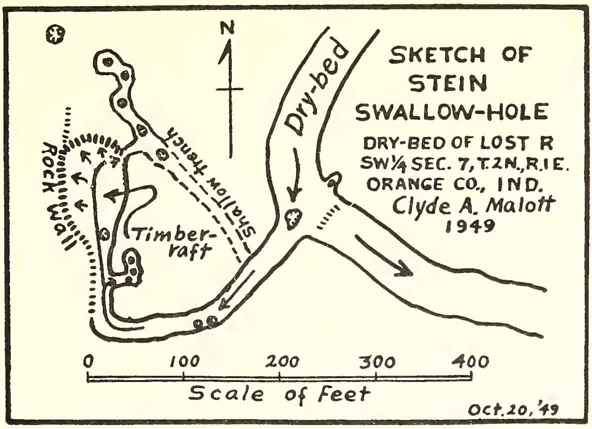

Fig. 5. Sketch of the Stein stormwater swallow-hole adjacent to the dry-bed about 2 miles down the channel from the principal dry-weather sinks of Lost River. Large quantities of stormwaters descend to the underground system through this swallow-hole following heavy rains. Its capacity is estimated at 750 cubic feet per second. The underground route and the watertable are 20 to 25 feet below the dry-bed here.

45 to 70 feet below the undulating surface of the sinkhole plain west of the swallow-hole. When floods come, the Stein swallow-hole is able to take a stream of water as much as 7 or 8 feet deep from the dry-bed. Its capacity is estimated to be about 750 cubic feet per second. When its capacity is exceeded, the extra stormwaters proceed on down the dry-bed to the Turner swallow-holes west of the bridge on State High-

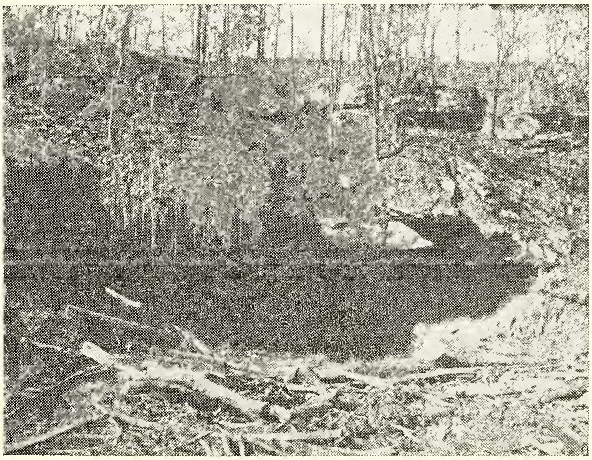

Fig. 6. View of the west wall of the Stein stormwater swallow-hole showing the overhanging St. Louis limestone and a portion of the timber-raft in the main pit of the swallow-hole.

way 37. Only 2 small holes have been observed in the dry-bed stretch of the channel of nearly 2 miles between these two major swallow-holes.

The Turner Swallow-holes. The Turner swallow-holes form a complex of more than 40 individual holes along and near the dry-bed channel in the NE¼ of sec. 13, T. 2 N., R. 1 W., about 1 mile southwest of the Stein swallow-hole, and in a loop of the dry-bed a short distance west of the bridge across the dry-bed on State Road 37, 3½ miles south of Orleans. A map of the chief swallow-holes and their relations to the dry-bed channel is shown in Fig. 7. All the swallow-holes are in the St. Louis limestone near the top of that formation. The largest loss of stormwaters from the surface is in a series of holes just west of the dry-bed. These holes are connected with the dry-bed by a short, crooked, subsidiary channel 12 to 15 feet in depth. Shows of bedrock walls are present along the western edge of some of these holes,

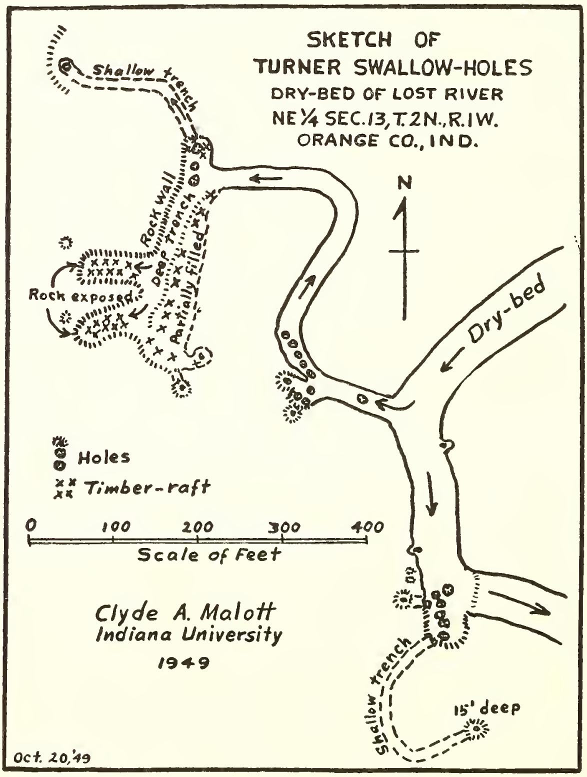

Fig. 7. Sketch of the main Turner stormwater swallow-holes along the dry bed of Lost River on the Earl Newlin farm west of the bridge across the dry-bed on State Road 37, 3½ miles south of Orleans. About 40 individual stormwater swallow-holes have been counted in this locality along and near the dry-bed course. The watertable here is about 35 feet below the dry-bed channel.

though the holes and walls are partially obscured by accumulated rafts, now much smaller than they were when first observed by the writer some 25 years ago. The larger holes extend sharply westward from the subsidiary channel. Some of them are nearly half-way across the narrow neck of the long southward meander loop of the dry-bed. About 200 feet farther down the dry-bed from the subsidiary channel is a second group of swallow-holes in the dry-bed channel or partly back from the channel, but connected with it by shallow subsidiary channels 10 to 12 feet above the bottom of the dry-bed. Other holes are present along the dry-bed for a distance of a quarter of a mile or more, and most of them are reached only during overflow stages. A number of them are on the east side of the dry-bed and a short distance from it. Several are in the soil only, and appear to be collapse holes where the sod or turf has fallen into bedrock channels below.

The total capacity of the Turner swallow-holes is equal to or greater than that of the Stein swallow-hole. During heavy floods they appear to have a greater capacity in the earlier stages, apparently becoming surfeited or stagnated in later stages. This change in capacity to receive stormwaters is probably a result of the filling of the underground conduits in the lower part of the system. Consequently a greater excess of stormwaters descend the dry-bed channel past the swallow-hole orifices than at the Stein swallow-hole.

A well about 100 yards northwest of the bridge across the dry-bed on State Road 37 gets its water supply from the St. Louis limestone at a depth of 130-135 feet. When first drilled in 1897 it was cased to a depth of 30 feet which placed the bottom of the casing near the level of the dry-bed. With every rain the water in the well became muddy. It was later cased to a depth of 86 feet, which shut out the underground stormwaters, and since then only clear waters have been pumped out. The water is quite "hard". The watertable itself appears to be at a depth of 30 to 35 feet below the dry-bed channel. As at the Stein swallow-hole, no openings are sufficiently large in the Turner swallow-hole complex to permit investigation of the subterranean system which carries the waters westward beneath the upland sinkhole plain. It is reported, however, that in early days a large cavern entrance was present in the woods at the Turner swallow-hole area, but this has been washed full of timber and silt and the locality now shows few signs of the existence of any such cavernous opening.

About 1 mile west of the Turner swallow-holes, a lengthy section of 3,200 feet of the underground system was explored and mapped by the writer and Robert Shrock in 1929. The opening to the underground system is an abrupt sinkhole on the farm of Austin Chastain, in the SW of NE¼ of sec. 14, T. 2 N., R. 1 W. The underground system is developed at three levels beneath the sinkhole plain, and the watertable is at an altitude of 555-560 feet, or about 40-45 feet below the dry-bed channel nearby. Details of this dangerously flooding cavern system were recently presented in a publication by the writer (8).

While no holes were actually observed in the long southward loop of the dry-bed channel below the Turner swallow-holes, some undoubtedly exist. Stormwaters as much as 3 feet deep have been observed adjacent to State Road 37 in the SE¼ of sec. 13, below the Turner swallow-holes, while none flowed across the road near the northwest corner of sec. 13. A short distance farther west, however, in the NE¼ of sec. 14, a group of 4 swallow-holes of considerable size is present in and adjacent to the dry-bed. Three of them lead southward from the dry-bed and one loops backward on the north side through a subsidiary channel. One of these holes was entered and followed for about 30 feet some 15 feet below the dry-bed. The dry-bed at this locality occasionally overflows to the south and storm waters enter two sink-holes developed at or slightly below the level of the dry-bed. Undoubtedly the stormwaters entering this group of swallow-holes and overflowing into the two deep sinkholes reach the underground system a short distance north of the explored section entered through the sink-hole on the Austin Chastain farm a short distance south of the dry-bed.

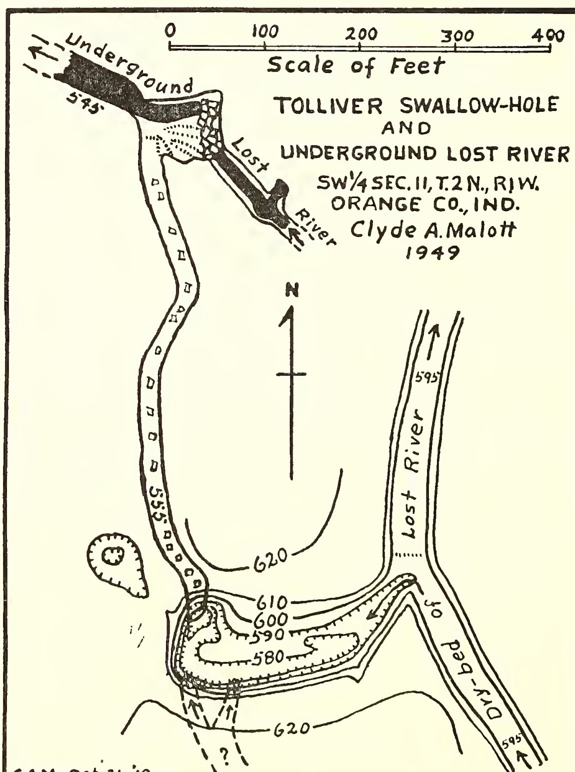

Fig. 8. Sketch of the Tolliver stormwater swallow-hole and its underground cavernous route to a mapped section of underground Lost River. The Tolliver swallow-hole is 7½ miles down the dry-bed channel from the principal dry-weather sinks of Lost River. Underground Lost River is 50 feet beneath the dry-bed here.

The Tolliver Swallow-hole. The Tolliver swallow-hole is located in the SW of SW¼ of sec. 11, T. 2 N., R. 1 W., just west of the dry-bed channel, with which it is connected by a short, descending channel. Curiously, all of the large swallow-holes are at the apices of westerly loops in the dry-bed channel. The Tolliver swallow-hole is 3¾ miles down the dry-bed channel from the Turner swallow-holes and about 7½ miles from the dry-weather sinks of Lost River. The dry-bed channel here is at an altitude of 595 feet, only 25 feet lower than at the dry-weather sinks. The lead from the dry-bed descends sharply to an orifice which receives the entering stormwaters. The orifice is usually obscured by a considerable timber-raft, though at times it may be readily seen. The lead from the dry-bed channel is approximately 300 feet in length, curving southwest to west and then sharply northward to the orifice. The opening leads downward to a cavernous channel developed at an altitude of 555-560 feet, which leads northward for 565 feet and joins the underground route of Lost River at an altitude of 545 feet. A map of the Tolliver swallow-hole and its relations to the short explored section of Lost River are shown in Fig. 8. Underground

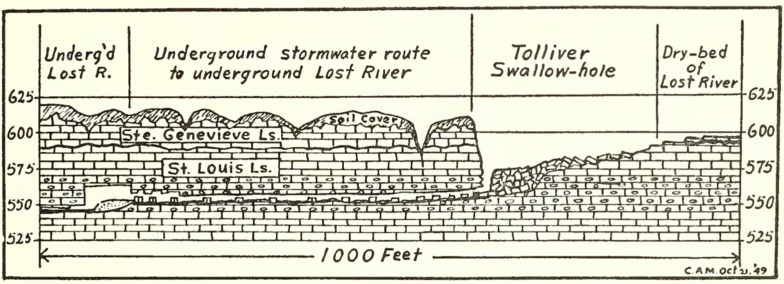

Fig. 9. Diagrammatic section extending from the dry-bed of Lost River through the Tolliver swallow-holes and along its cavernous route to underground Lost River. The entire section shown in the diagram is 1,000 feet in length. The contact of the St. Louis limestone below and the Ste. Genevieve limestone above is at an altitude of 590 feet.

Lost River is 50 feet beneath the dry-bed at the Tolliver swallow-hole. The vertical and geological relations are depicted in Fig. 9.

The Tolliver swallow-hole is the most spectacular and interesting of the many swallow-holes along the dry-bed course of Lost River. Its western end is an abrupt rock wall about 35 feet in height, and its orifice at the bottom is the only one of the many swallow-holes sufficiently open to permit entrance and underground exploration. The opening is uninviting and the passage leading to underground Lost River is difficult and dangerous. Both the opening and the passage are damp, drippy and muddy. The cavern channel is developed in a cherty phase of the St. Louis limestone about 30 feet below the contact with the Ste. Genevieve limestone which forms the general upland sinkhole plain of the locality. Ragged, sharp, cherty masses extend out from the sides and ceilings of the low, cavernous route, and the floor is strewn with loose cherty slabs and many large rock masses.

The route is 10 to 25 feet in width and only 3 to 4½ feet in height. Passage along it is slow, tedious and painful. When first entered and partially mapped by the writer and Robert R. Shrock, Aug. 12, 1929, an accumulation of carbon dioxide, derived from the decaying timber raft above and in the orifice and along the upper part of the passage, made the exploration and mapping hazardous, and the work had to be discontinued. Full exploration and mapping underground was accomplished by the writer and Robert Bates, July 16, 1931, at which time the air was without contamination and danger from "damps".

Entrance into the cavernous route leading from the Tolliver swallow-hole to underground Lost River is not always easy or even possible, because of the accumulated timber-raft which may remain in place over the orifice for months or even years. At times, however, the swallow-hole is relatively free from accumulated timber and trash, and entrance may be made with little difficulty. The writer made many trips to the swallow-hole before it appeared possible to enter it, though on some of the trips lack of sufficient courage may have been a factor delaying entrance and exploration. On the two occasions that it was entered, it was noted that packed logs filled a considerable part of the opening along the north wall, indicating the presence of a broad opening 30 feet or more in width, if the rafted timber could be entirely removed.

The orifice of the swallow-hole was entered through an opening in the timber-raft, descending vertically about 10 feet (Fig. 10). The

Fig. 10. View of the timber-raft in the Tolliver swallow-hole showing the hole through which entrance was made to reach underground Lost River 565 feet to the north. The view was taken Aug. 15, 1930. The timber-raft at the present time is much reduced in size.

cavernous channel averages but little more than 3 feet in height for a distance of 435 feet. No solid rock shows on the floor. In the first 100 feet large mud-covered rock blocks are much in evidence, while the remainder of the low section has loose slabby rock on the floor with only a few large blocks. Everywhere the floor and rocks are covered with sticky mud an inch or more in thickness. The ceiling is composed of a roughened limestone bed with scarcely a break for the 435 feet. The roughness is due to the presence of porous chert masses which extend downward several inches from the bed of limestone. The low ceiling is also mud-covered. Logs and timber are present along the rough-hewn route, though after the first 100 feet these do not hinder progress. At 435 feet from the entrance the cherty limestone forming the ceiling ends and the ceiling rises 7 to 10 feet above the slippery mud floor. On approaching underground Lost River the channel widens and enters a great rectangular room 80 feet long (east-west), 75 feet wide (north-south), and 15 to 20 feet in height. Lost River occupies a trench on the farther or northern side of the room, and the noise of its waters rippling over the cherty gravel in a descent of less than 1 foot may be heard in the cavernous channel for a distance of 200 feet or more. The flowing waters come from the east and pass under the western wall of the room into a still pool about 40 feet in width and 1 to 3 feet in depth. The ceiling in the downstream passage is low and in about 75 feet descends to within 1 foot of the water, preventing further traverse in the downstream direction.

The floor of the large room is composed of mud bars between shallow trenches which come from the eastern end of the room. A large mud bar is banked high at the right of the swallow-hole channel just inside the room. The trench occupied by Lost River is 20 to 25 feet in width, but is partially filled with mud in which a narrower channel is cut. Underground Lost River is at an altitude of 545 feet, only 5 feet higher than the low water level in the deep pit in the Wesley Chapel "gulf" 1½ miles to the west. The underground channel apparently marks the level of the watertable which has been drained down 50 feet below the dry-bed and 70-80 feet below the undulating sinkhole plain adjacent to the Tolliver swallow-hole. Lost River comes through a mass of fallen rock at the eastern end of the big room. The rocky mass is mud-covered and extends 10 feet or more above the river waters. The waters of Lost River flow into the rock mass just beyond the southeastern corner of the big room, and the upstream section of the cavern channel extends southeast. The channel is 20 feet in width and has a mud-covered floor over which the waters quietly flow. Approximately 100 feet upstream the waters rise out of a pool about 15 feet in width on the north side of the channel. Waters also come in from the right through a low cavern channel which could not be reached because of soft miring mud composing the floor beneath the waters of the stream. Only about 300 feet of underground Lost River could be examined. The course and the chief features are depicted in Fig. 8.

The lead into the Tolliver swallow-hole starts on solid rock in the dry-bed. The rock ledges compose the very top of the St. Louis limestone. The rock exposed in the dry-bed just below the entrance to the swallow-hole is composed of the base of the Ste. Genevieve limestone. The floor of the lead passes into loose slabby limestone. The rock-strewn stormwater trench follows closely the steep south wall. Towards the western end of the swallow-hole the outer walls are nearly 100 feet apart, and a broad section of the floor of the swallow-hole is composed of a vegetated ridge of silt with a shallow secondary trench on the north side. The accumulated silt appears to rest upon broken rock. Following heavy rains muddy waters enter the swallow-hole from the south side through broken-down masses which obscure the two cavernous channels which convey them. Long before waters descend the dry-bed the swallow-hole becomes partially filled by the waters entering from the hidden cavernous channels. It is quite probable that the hidden channels connect with those explored on the Austin Chastain

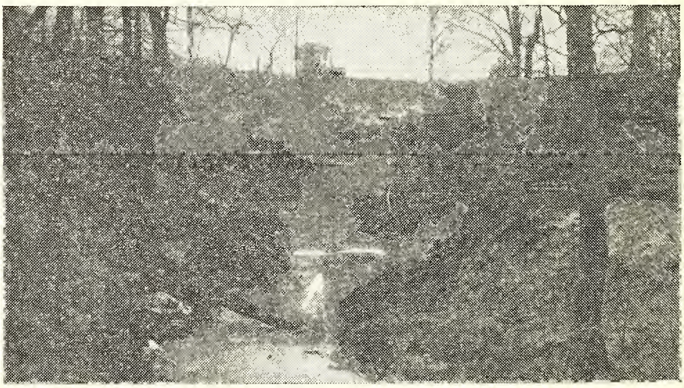

Fig. 11. View of the Tolliver swallow-hole showing the waning stormwaters entering from the dry-bed following heavy rains, March 21, 1933. Slimy silts cover the sides and surfaces as much as 15 feet higher than the entering waters, indicating the much higher level of the stormwaters before the view was taken. The timber-raft is imperfectly shown floating in the stormwaters near the distant (western) terminus of the swallow-hole.

farm a little more than ½ of a mile to the southeast, and that the waters re-appearing here for a short stretch enter the underground system at the Turner swallow-holes. Mr. Martin Tolliver reported that agitated waters whirl in the pit after heavy rains. This action always precedes the coming of stormwaters down the dry-bed course. A view of the swallow-hole is shown in Fig. 11, with a small flow of stormwaters entering from the dry-bed. When the stormwaters in the dry-bed descend in large volumes, the swallow-hole is soon filled to its capacity and excess waters proceed on down the dry-bed past the swallow-hole and course down the entire channel. The flooding of the entire dry-bed channel usually does not occur more than 2 or 3 times a year, and occasionally periods of a year or more elapse without the flooding of all the dry-bed channel. During heavy floods the stormwaters in the Tolliver swallow-hole stand as much as 65 feet above the low-water course of underground Lost River, and the great hydrostatic head exerts a strong pressure on the underground stream.

The Tolliver swallow-hole appears to have originated through the collapse or stoping of the roof-rock over a broad or compound section of the cavernous channel some 35 to 50 feet beneath the sinkhole plain. The collapse pit was then breached by stormwater overflows from the dry-bed. The swallow-hole is in reality one of the gulfs of Lost River. It was referred to as a gulf by Richard Owen, who made a wood-cut illustration of it 90 years ago (10, 141). Elrod (3, 212) referred to it as "the fourth sink of Lost River." It represents, however, only an early stage in the development of a gulf as compared to the large one over underground Lost River at the Shirley or Wesley Chapel gulf 1½ miles to the west.

Swallow-holes below the Tolliver Swallow-hole. Below the Tolliver swallow-hole the dry-bed channel of Lost River makes a broad northward detour away from the direct underground course for a distance of about 3 miles (Fig. 2). The dry-bed channel in the northward detour is a winding course 10 or 11 miles in length. It then continues some 3 miles farther in a winding, deeply intrenched course before receiving waters at the Orangeville rise. The eastern limb of the northward detour continues the low-gradient course for a channel distance of nearly 4 miles below the Tolliver swallow-hole, reaching an altitude of about 580 feet. The western and southern sections of the northern detour of the dry-bed channel show a marked increase in the gradient, so that in about 6 miles of its route it descends 70 feet to an altitude of 510 feet, and becomes sharply intrenched below the general level of the sinkhole plain which is itself becoming fragmentary because of the presence of sandstone-capped ridges rising above it. Swallow-holes in this course of the dry-bed, except for one locality, are few in number. The western limb of the northern detour is characterized instead by stormwater resurgences or rises.

A single swallow-hole is present just east of the dry-bed and south of the cement bridge in the NW of NW¼ of sec. 11, T. 2 N., R. 1 W., nearly 1 mile north of the Tolliver swallow-hole. It does not appear to take a significant amount of water and floods easily. A series of swallow-holes taking considerable quantities of stormwaters from the dry-bed is present in the western meander of the dry-bed chiefly in the E½ of NE¼ of sec. 3, T. 2 N., R. 1 W. At least 5 swallow-holes are present in this bend, and some of the sinkholes to the west of it are lower than the dry-bed itself. The dry-bed here has an altitude of 585 feet. One deep rocky sinkhole just west of the apex of the westward loop of the dry-bed descends at least 20 feet below the dry-bed. The stormwaters lost from the dry-bed here pass underground to the northwest and return to the surface in the stormwater resurgences or "wet-weather rises" on the former Mathers farm in the SW of SW¼ of sec. 34, T. 3 N., R. 1 W. A short distance south of the westerly bend is a low alluviated *cul de sac* connected with the dry-bed, which contains several small swallow-holes as low as or lower than the dry-bed (Fig. 2). This *cul de sac* has the appearance of a partially filled swallow-hole complex into which waters from the dry-bed formerly entered in considerable volumes. It is probably a nearly abandoned swallow-hole terminal through which waters were once directed northwest through the Peacher caves underground route and on to the resurgence on the former Mathers farm. The Peacher caves in the southern part of the NE of NW¼ of sec. 3, T. 2 N., R. 1 W., are remnants of a broken down and partially filled cavern system, marking a former high-level underground route of Lost River across the northern part of the northern detour of the dry-bed. This route was local and lost out when the Tolliver swallow-hole and other swallow-holes farther up the dry-bed became sufficiently developed to take much or most of the stormwaters through the present more direct and deeper underground route.

Except for one locality, no swallow-holes of any significance are present along the dry-bed below those in the sharp bend in the NE¼ of sec. 3. Far down the dry-bed in the area of deep intrenchment and normally occupied by stormwater resurgences, a small group of 2 or 3 swallow-holes and a large collapse pit, probably over the main underground channel of Lost River, are present on the south side of the dry-bed near the junction with a small ravine in the NW of SW¼ of sec. 8, slightly less than 1 mile southeast of Orangeville. The swallow-holes are small, only a few feet above the dry-bed, and contain much mud and intermingled small trash. Another hole is present in the dry-bed about 150 feet downstream. The large collapse sinkhole immediately west of the small swallow-holes is developed in the edge of a steep bluff rising more than 100 feet above the dry-bed, and its conical bottom descends to the level of the dry-bed (505 feet above sea level). This large collapse feature is about 150 feet across and its partially broken-down eastern rim rises 25 feet above the dry-bed. Its conical bottom is composed of angular blocks of moss-covered rock fallen from above. The western side of the collapse pit is a combined talus slope of loose rock and a perpendicular wall of Ste. Genevieve limestone strata rising 85 feet above the rocky bottom. Above this, it rises steeply back to 105 feet above the bottom to a capping of the massive Mooretown sandstone of Lower Chester age which exhibits a tension crack 10 feet wide, indicating creep and slippage of the rock forming the steep eastward-facing wall. Undoubtedly a large cavity has collapsed to form this feature close to the dry-bed. Quite possibly it is immediately over the underground route of Lost River itself. It is directly in line with the terminal rise of Lost River along the westward course of the underground route (Fig. 2). The feature marks the beginning stage of a gulf. The swallow-holes and the large collapse sinkhole make a distinct recess in the steep valley side and indicate the possibility that one of the earlier sinks of Lost River took place here. Midway up the cliff of the steep wall of the collapse sinkhole some openings are present which suggest a high-level cavern, though these openings were not investigated. The location of the features here in a western bend of the dry-bed is only a little more than ½ of a mile east of the terminal rise of Lost River on the Allen farm, whereas the route around the course of the dry-bed and the stream is in excess of 3½ miles. The location and the features are quite suggestive of an earlier developed swallow-hole which has nearly lost out as a place of sinking waters. Continued down-cutting of the dry-bed course and the development of other sinks farther upstream and higher on the perched sink-hole plain were factors in the near disuse of the sink at this locality.

The Course of Underground Lost River

Underground Lost River in a general sense is a system of subsurface drainage which acquires the greater part of its discharge from an area of approximately 120 square miles (excluding Stampers Creek system), in part diverted from surface streams and in part from sink-hole drainage. A much smaller part of its discharge is lithic drainage of waters more slowly feeding into the system from the rocks themselves. The lithic drainage is in part composed of phreatic waters and in part from local seepages and underground springs coming from higher levels than the watertable. The clear waters which filter through the roof-rock of the underground passages drip slowly into the system locally, frequently coming from the ends of stalactites. Also many small underground springs feed into the cavernous channels, representing local lithic drainage from above the watertable. Many of these small seepages and underground springs cease to flow during long continued dry periods. The source of some of the incoming seepages and underground springs is from surface springs issuing from the Chester formations in the ridges in the western part of the area, which, after flowing over the surface for short distances, sink into the limestone and descend to the underground passages 100 feet or more below the surface. The lithic drainage, therefore, is only in part composed of phreatic waters. Moreover, the clear waters of the lithic drainage cannot be distinguished from the clear waters entering the sinks at the upper end of the underground system after they have entered the main lines of discharge of the underground routes.

The passages of the subsurface system are well co-ordinated and integrated into a regional system spreading as a great network pattern throughout the karst area of the drainage basin. The larger and deeper conduits have become the main runways which readily carry incoming waters through long distances to the orifices of discharge or terminal resurgences. The network system is three-dimensional, dominantly developed along the slightly westerly-sloping bedding planes and the vertical joint system, both well displayed in the limestone exposures at the surface and in the caverns beneath. Integrated parts of the network system slope to tributary subsurface routes, and the master routes descend westerly from the higher karst areas on the east to the resurging terminals at low levels on the west. The network system with its larger and major cavernous courses is relatively well opened, so that surface waters readily enter from the inumerable sinkhole hoppers and the sinking surface streams. The flooding waters of heavy rains are taken below and conveyed through the subterranean system for many miles to the orifices of discharge.

In the eastern edge of the sinkhole plain where many separate surface streams have their first sinks, the subterranean waters come from a wide area and are directed through individual routes which apparently merge into lines of more concentrated passage in the western area of the system. Although several stormwater resurgences are known, they are relatively narrowly restricted along the lower course of the dry-bed of the intermittent surface course. Only two perennial and terminal resurgences are present in the system, and they are only ¾ of a mile apart, at and below Orangeville, where Lost River becomes the watertable limit of a low-level surface stream.

The main course of underground Lost River undoubtedly has its beginning in the locality of the first sinks where surface waters descend below the bed of the stream. The terminus of the sinking stream reaches nearly two miles west of the eastern edge of the sinkhole plain which absorbs the rainfall and the stormwaters of smaller sinking streams at altitudes 50 to 75 feet higher than the sinks in the Lost River channel. The principal dry-weather sinks near the center of sec. 8, T. 2 N., R. 1 E., are 7 miles due east of the terminal resurgence of Lost River, and the brief appearance of Lost River waters in Wesley Chapel gulf is directly on the line between them. The Stein, Turner and Tolliver swallow-holes are somewhat south of the due west line, and it is likely that the notable amounts of stormwaters coming from these great swallow-holes and from many lesser ones along the dry-bed enter the main course from shorter or longer tributary channels. The main course of the underground stream is undoubtedly westerly, though it very probably has some detours from a due west general course. Also, it probably has parallel passages both at or near the watertable and at higher levels occupied during high-water periods. The main course westward from the principal dry-weather sinks of Lost River is occupied continuously by waters from the surface stream. This continuous stream is very probably along the lowest depressed watertable section of the westerly descending system. Locally it may have some development actually below the watertable in certain stretches of the underground route. In any case it is a westerly descending route having a vertical descent of at least 130 feet in the 7 miles of its westerly course.

Little is known about the main underground course of Lost River in the first 3½ miles of its course to near the Tolliver swallow-hole. A short stretch of its course has been described near the latter place where it is a well-developed cavernous channel 50 feet below the dry bed. It has a descent of 75 feet in this westerly course from 620 feet to 545 feet in altitude. Westward from the short section reached through the Tolliver swallow-hole, the main course is fairly well determined. It passes close to and under the deep Nicols cavern half a mile west, near the center of the S½ of sec. 10, T. 2 N., R. 1 W., and thence slightly north of west for 1 mile to the Shirley or Wesley Chapel gulf, where it rises to the surface in a deep pit, a short distance east of the center of sec. 9. Sinking immediately, it continues west, passing close to a stormwater resurgence a short distance south of the center of sec. 8, to its final resurgence on the east bank of the surface stream south of the center of sec. 7, ¾ of a mile south of the village of Orangeville and 2 miles west of the Wesley Chapel gulf.

The Nichols cavern leads northeast and rather steeply downward from a broad, circular, steep-sided collapse sinkhole to a deep, muddy pit close to the northern terminus of the cavern 205 feet from the entrance. The bottom of the pit is 100 feet below the surface and at an altitude of 560 feet. Although a small stream carries stormwaters into the broad cavern from a small drainage area, no waters stand in the deep pit during low-water periods. During flood periods, however, muddy waters from underground Lost River rise in the pit to a height of about 20 feet. These waters recede with the drop in the flooding stormwaters of underground Lost River, clearly showing the connection of the cavern with the underground stream. The underground stream is probably only a short distance north of the cavern. Just west of Nicols cavern the underground course passes 200 feet beneath the crest of a ridge capped with Chester sandstone and forming a part of the irregular margin of the Chester escarpment. A little more than ½ of a mile farther west the underground stream issues from the deep pit in Wesley Chapel gulf.

The Wesley Chapel Gulf

The Shirley or Wesley Chapel gulf, the rise and sink of Lost River within it, and the network of cavernous routes of underground Lost River west of the gulf constitute the most interesting features of the entire Lost River region. The gulf has been a subject of local interest for more than a century. In the early days it was a source of water supply for the community and was known as the Shirley gulf. But since its first introduction into geological literature by Elrod in 1876, it has been known chiefly as the Wesley Chapel gulf, named for its nearness to the Wesley Chapel Church at the cross-roads a short distance to the north. Elrod (3, 225) states that Lost River "comes to the surface at Wesley Chapel gulf, in section 9, township 2 north, range 1 west, where the superincumbent rocks have fallen in and forced the stream to the surface. The subterranean stream may also be reached at this point through a cave in the side of the hill. Some years ago a boat was taken in and the channels explored for some distance to a fall beyond which it was impossible to pass." Elrod (4, 263) mentioned Wesley Chapel gulf in a subsequent paper bearing on the features of the Lost River region. A brief description of the gulf was presented by the present writer (5, 208) in a general description of the features of Lost River, and again in a paper describing cavern stages (6, 202), the Wesley Chapel gulf was briefly described and stated to be the most spectacular topographic feature of the entire Lost River basin. In 1929 the present writer and Robert R. Shrock entered and mapped much of the network of cavernous passages west of the gulf. Additional work was done in the underground system and a detailed map of the gulf was prepared. Rather full descriptive details of the gulf and the underground passages occupied by Lost River and available from it were published by the writer in 1932 (7). In the meantime, Davis (2, 538-539), in his memorable treatise on the origin of limestone caverns, published a section of the network of the underground system of Lost River and

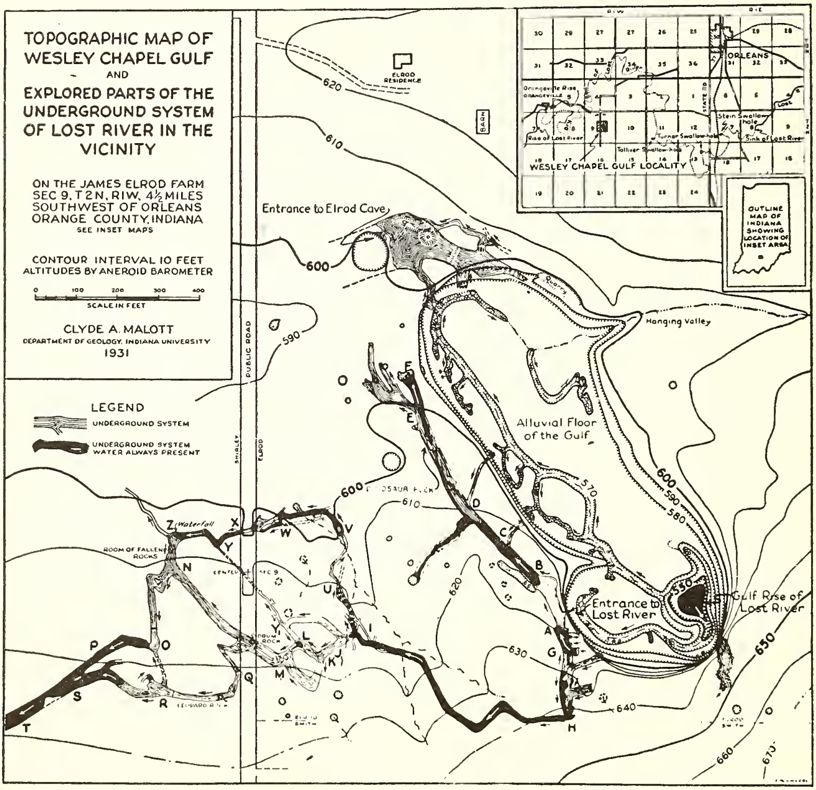

Fig. 12. Topographic map of the vicinity of Wesley Chapel Gulf, with a smaller scale inset map of the general region.

presented a brief description of the gulf from data furnished by the present writer at Davis' request. The topographic aspects of the gulf and the explored and mapped network of underground Lost River, as presented in Fig. 12 of the present paper, are from the map published by the writer in 1932.

The features of the gulf, the associated aspects of underground Lost River, and its probable method of development are presented again in some detail. Wesley Chapel gulf is an abrupt, steep-sided, tree-lined depression in a gently undulating, soil-covered area of cultivated farm and pasture land in the western edge of the Lost River sinkhole plain closely adjacent to the irregular eastern margin of the Chester escarpment. Its steep-sided perimeter, largely composed of the broken-off, weather-fretted edges of limestone strata, encloses an area of 8.3 acres. The gulf is 1,075 feet in length, extending north-northwest, and averages 350 feet in width. Its ends are rounded, forming semicircles of nearly equal size, between which it narrows slightly. On the eastern side near the northern end, stormwaters from a hanging valley have cut a V-shaped notch in the perimeter. A counterpart of this notch is present on the opposite side near the southern end where a mass of collapsed and broken limestone extends out into the gulf area. The altitudes about the perimeter vary from 595 feet along the northwestern edge to 640 feet on the southeastern edge, and the walls form a continuous circumscribed cliff or bluff 25 to 95 feet in height about the floor of the depression. The floor of the depression embraces an area of 6.1 acres and is largely composed of flat alluvial soil in which are stormwater trenches and a deep, mud-lined pit from which the waters of Lost River rise.

The steeply-sloping conical pit containing the rising waters of Lost River is at least 125 feet in diameter at the level of the alluvial floor of the gulf, but at the level of the low-water stand of the pool, 30 feet below, the diameter is approximately 75 feet. The rise-pit is under the shadows of the steep and partially overhanging high wall of the southeastern edge of the gulf, and along the cliff it has two wings which curve slightly into the gulf floor. The northern wing pours muddy waters into the pit during flood periods, while the southern wing receives the waters which issue from the pit during low-water periods, and, in its westward curve into the alluvial gulf floor, it shallows and continues as a stormwater channel with several swallow-holes. This channel terminates in a northern and easterly curve on the western side of the gulf floor, 250 feet west of the pit from which it comes. Here it contains several large swallow-holes partially obscured by an accumulated timber raft. Another stormwater trench leads northwest from the rise-pit and extends parallel with the western side of the gulf, well out in the alluvial floor, to the north end of the gulf where it recurves back out into the alluvial floor, and thence to several well-defined swallow-holes along the eastern side of the gulf a short distance south of the hanging valley. At the north end it contains numerous swallow-holes, and along its course parallel with the western side of the gulf several short distributaries and loops reach numerous swallow-holes close along the western wall. One distributary cuts directly across the middle of the gulf floor to the swallow-holes on the eastern side. (Fig. 12). Several acres of the alluvial floor of the gulf were formerly planted in corn every year, but in recent years the rich alluvial floor has been abandoned and is becoming a thicket of growing bushes and trees.

During low-water periods the pool in the rise-pit is a beautiful azure blue in color and perfectly calm. The waters issue quietly and enter the southern wing and disappear with only slight turbulence in the mud-covered talus rock at the foot of the cliff. After rains the issuing waters in the pit increase in volume and become muddy and silt-laden. Heavy rains fill the pit to overflowing and discharge down the stormwater trenches in the alluvial floor of the gulf. Occasionally the waters flood the entire alluvial floor to several feet in depth. At such times the waters issuing from the pit are violently turbulent and great boils of rising waters discharge from it. As much as 4,000 to 5,000 cubic feet per second issue from the underground course of Lost River during times of heavy floods when all the swallow-holes of the dry-bed are receiving their maximum capacities. These waters, overflowing the gulf floor, are returned to the underground system through at least 100 swallow-holes in the gulf floor and they fill the underground system west of the gulf to its full capacity.

The walls of the Wesley Chapel gulf are composed of the Ste. Genevieve limestone which in the locality has a total thickness of 115 feet. The lost River chert bed is displayed at several places slightly above the level of the alluvial floor of the gulf and 20 feet above the base of the Ste. Genevieve limestone. Underground Lost River is developed in the St. Louis limestone approximately 40 feet below the floor of the gulf. The alluvium of the gulf floor appears to be about 35 feet in depth and probably lies upon broken masses of rock into which alluvial silts have filtered and compacted. The alluvial accumulation of the gulf floor completely obstructs the passage of the underground waters of Lost River through the area occupied by the gulf. The waters of underground Lost River either have to pass around the compacted silts through underground passages developed in the St. Louis limestone about the ends of the gulf or have to rise out of the pit and flow across the top of the alluvial floor to the swallow-holes where they are conveyed to the underground system mainly on the western side of the gulf. In low-water periods the waters of the stream pass around the south end of the gulf, but in flood periods passage appears to be in part around both ends of the gulf and in part over the alluvial floor.

The Wesley Chapel gulf and its deeply alluviated floor of clays and silts clearly indicate the destruction and removal of approximately 720,000 cubic yards of native limestone. The width of the gulf is far greater than any known section of underground Lost River with which the gulf is genetically related. The gulf is not merely a fallen-in cavern whose collapse rock has been dissolved away. The shape of the gulf and its present relations to the underground water courses suggest something concerning the nature and method of its development. It very probably was initiated as one or more collapse sinkholes of rounded outline over a broad and weakened portion of the underground system. The collapsed rock obstructed free passage of the waters and their energies were concentrated about the collapse rock which in time undermined the walls about the collapse depression. Further collapse increased the perimeter of the initial collapse depression. If two or three collapse areas were formed in a row, their perimeters in time were merged to form a large and enlongated depression with semicircular ends, such as Wesley Chapel gulf possesses. Horns of rock would extend out in the depression for a time, but eventually they would melt away through enhanced weathering and solution. One such horn of rock, tumbled and broken, still extends into the floor of Wesley Chapel gulf.

A study of the behavior of the flows of Lost River waters around and about the impassable barrier of the compact and insoluble silts of the gulf floor indicates that practically the entire gulf is surrounded by active stream waters which in times of flood forcibly lave and dissolve the entire perimeter of the gulf through a rock thickness up to 40 feet or more. Waters issuing from the deep pit immediately enter the talus rock at the southeast side and in times of high floods enter a cavern opening 30 feet above low-water level. These waters pass around the south end of the gulf and join the explored passages of underground Lost River on the west (Fig. 12). Great quantities of stormwaters descend through the swallow-holes along the western wall of the gulf and enter the underground system either through masses of subsurface talus between the alluvium and the underground passages or through large tubular passages connecting with the main system. At the northern end of the gulf large quantities of stormwaters enter Elrod cavern (Malott, 7, 308-311) through several passages where they are undermining the steep perimeter of the gulf. Elrod cavern is well flooded with stormwaters, and its great width of up to 125 feet indicates the probability of near-future collapse close under the northern wall. Already a circular collapse 90 feet in diameter has taken place in the illy supported roof-rock of the cavern only 125 feet northwest of the northern end of the gulf (Fig. 12). An underground stream very probably passes about the eastern and northern perimeter of the gulf, as indicated by the swallow-holes just south of the V-shaped notch in the perimeter made by the waters entering from the hanging valley. It is probably this same stream which may be seen at a low level along the undermined northern side of Elrod cavern near the eastern end.

The processes which have formed the gulf are still in operation and the growth of the gulf has been progressive. It is a product of progressive perimeter collapse and dissolution of the fallen rock. The enveloping underground streams are thin but vigorous dissolving agents which insidiously sap the foundation of the gulf walls. These walls are hollowed out and weak at their bases. They do not stand on solid rock. 720,000 cubic yards of rock have been undermined, tumbled in, dissolved away, and a new level created. As such, Wesley Chapel gulf is a local, circumscribed valley stretch, a *uvala*, surrounded by rimming rock which fails to imprison the streaming waters which work to enlarge it into a lengthening valley expanse. It is yet but a window in which a hidden stream in low-water and in fearsome flood has been brought into the light of day.

Underground Lost River at Wesley Chapel Gulf

The artesian issue of the waters from the deep pit under the high cliff at the southeastern end of Wesley Chapel gulf is evidently from the main subterranean course of underground Lost River. The waters of this course are forced to rise 20 feet or more from the submerged passage during low-water periods, and as much as 50 feet or more during flood periods. The blocking of underground Lost River by the alluvial material composing the floor of the gulf is quite complete. The underground channel is filled with ponded waters very probably as far east as the Tolliver swallow-hole, where aneroid determinations indicate the pooled waters at the lower end of the explored section of the underground stream are only 5 feet higher than the low-water pool at the gulf. Such ponding indicates that no parallel or subsidiary underground channels at low levels by-pass the dam formed by the floor of the gulf. It appears quite probable that before the development of Wesley Chapel gulf the main channel of underground Lost River turned northwestward along strike joints and connected with the broad section of Elrod cavern, and thence slightly southwest along dip joints, as indicated in Fig. 12. If this conjecture is true, then much of the cavern system explored west of the gulf, as shown in Fig. 12, and now receiving the waters issuing from the deep pit of the gulf, is relatively new and still in process of development. Such an interpretation is further borne out by the fact that the altitudes of the floors of the system west of the gulf are near the level of the pool itself, except in the remote sections where abrupt descents are made to a lower level. Under this interpretation the angular anastomosing network and the partially mapped distributaries have been fashioned from various local passages and primitive tubes which had previously been partially vacated. Many of the passages are only partially reamed out by the invading waters forced into the higher passages by the obstruction imposed on the system when Wesley Chapel gulf was formed through progressive collapse of the roof-rock over a more capacious, overwidened, mature section of its course. The chacteristics of the system immediately west of Wesley Chapel gulf, then, are special, and not necessarily typical or representative of the more matured sections of the underground system.

Waters rising from the deep pit in the floor of Wesley Chapel gulf enter the southern wing-like extension of the pit and disappear in the mud-covered talus rock along the wall at the southeast edge of the gulf. The rising waters of floods enter in greater and greater amounts and finally reach the cavern opening 30 feet above the low-water level. After washing over solid ledges of rock at the cavern opening, the waters descend southward over and through masses of tumbled and broken rock which nearly fill the cavern. The roof-rock of the cavern descends in about 100 feet to near the level of low water in the pool of the pit. Here the cavern turns southwesterly and west around the south end of the gulf. In the meantime large quantities of turbid flood waters pass through the two high-water channels in the alluvial floor of the gulf and descend through numerous swallow-holes into the explored underground system west of the gulf.

Entrance to the underground system is made through a small opening between the overhanging wall of the gulf and an inside talus slope directly westward across from the rise-pit of Lost River. It leads directly downward to a nearly north-south stretch of underground Lost River 35 feet below. The massive rock at the level of the opening is the Lost River chert zone 20 feet above the base of the Ste. Genevive limestone formation. The cavernous routes of the underground system are in the St. Louis limestone which is locally characterized by numerous dark nodules and ball-like chert, especially some 15 to 25 feet below the top of the formation. The ball chert is well exhibited in many places in the underground system.

The north-south stretch of the underground channel just below the opening in the western wall of the gulf is about 325 feet in length. Northward it leads over a rugged floor above low-water level along the inside talus slope for about 100 feet to a broad, water-coursed, rock-floored passage which leads northwest nearly parallel with the western wall of the gulf for about 625 feet. During high-water periods it receives waters coming from the south over the rugged passage, waters coming through the talus rock just east of the beginning of the northwest course, and from two tubular passages which lead to the passage from the talus rock along the western edge of the gulf (Fig. 12). The tubular passages are a few feet above the low-water level of the main passage and at their debouchures rather deep plunge basins have been developed by the stormwaters entering from the gulf. During low-water periods these plunge basins are partially filled with soft, miring muds and cannot be waded safely. Opposite the entrance of the second tube, the waters of the main channel pass under the overhanging wall of the left side and part of them follow a distributary extending southwesterly as a low, wide passage for 210 feet to a breakdown in roof, beyond which it cannot be followed. The main passage to the northwest is 5 to 15 feet in height and 15 to 35 feet in width. The back part of it has much mud on the floor and on the large masses of rock which have fallen from the roof. Locally peculiar mud stalagmites are well developed on the mud surfaces (Malott and Shrock, 9, 55-60). The walls and ceiling are also thickly covered with muds, and the stalactites hanging from the roof are composed of alternate layers of mud and mineral calcite. At the end of the mapped route the waters pass into dissolved-out crevices where it appears that the rock masses from above have settled down without much disruption. A short distance back from the terminus, a passage leads upward 10 to 25 feet, or slightly more, to higher levels which terminate in two passages of broken down rock 150 and 295 feet back to the northwest. The muddy waters of flood periods have left watermarks as much as 35 feet above the floor of the main passage. Stalactites and flowstone above the watermarks are white and composed of pure calcite. A total of 1,440 feet of passageways were mapped in this section of the underground system. This section very probably connects with the unmapped section of the older and deeper system leading westward from Elrod cavern (Fig. 12).

A much larger and more complex section of underground Lost River is available in the passage leading southward from the entrance hole in the western wall of the gulf. A rather broad passage 15 to 30 feet in width and 5 to 15 feet in height leads almost directly southward for 215 feet to an abrupt westward turn (Fig. 12). Numerous small and several large passages debouch waters into the system from around the southern end of the gulf. In the first 65 feet the waters entering the passage flow northward, while in the next 150 feet the entering waters turn southward and proceed down the larger and more complex section of the system. A considerable part of the southward stretch is covered with accumulated muds and large masses of rock more or less cleanly washed. At the abrupt westward turn, 215 feet from the entrance, waters cover the entire floor and a well developed cavernous passage 12 to 30 feet in width and 7 to 15 feet in height leads away from the gulf in a generally western direction. Its cleanly washed floor is composed of rock. During low-water periods the waters of the passage may be waded easily except at the sharp turn 165 feet down the western passage. Here the water exceeds 5 feet in depth. The sides of the passage are rather rough with cherty masses and numerous solution scallops at or near water level. During high-water periods the passage is entirely filled with muddy stormwaters.

At the end of the water passage, briefly described above, the waters enter a low passage to the northwest in association with a network complex, depicted in Fig. 12, and described in detail in a former publication by the writer (7, 301-308). This remarkable network is developed at 3 levels, varying from 515 to 540 feet in altitude and 60 to 120 feet below the surface, all of which are entirely filled during flood periods. The network is developed chiefly along two intersecting joint sets in the St. Louis limestone, one nearly parallel with the dip of the formation (west-southwest) and the other nearly parallel with the strike of the formation (north-northwest). Some 200 feet west of the public road and about 1,000 feet west of the gulf entrance to the underground system, the main passages descend abruptly as much as 15 feet to ponded water passages in the lowest level of the explored section. The northern water-coursed passage descends noisily into crevices over rapids and a small waterfall which can be heard readily throughout much of the network system. The water-coursed passage follows a route 2,170 feet in length from the entrance hole in the gulf to the waterfall. The entire traversed network southward from the entrance aggregates a distance of nearly 5,000 feet in the system, though an airline distance to the most remote section reached is only 1,400 from the opening in the western wall of the gulf.

The network system above the descents to the lowest level is developed at two levels 5 to 10 feet apart, and in places the rock separating them has been removed. The upper level consists of tube-like passages which appear to have been developed from much smaller passages. The main and larger passages have been cut from the upper level into such sizes that they no longer show the original tube-like characteristics except by their network or anastomosing pattern. They are several feet above the low level and carry large volumes of water during floods. The complex system of water passages in the lower of the two levels, northwest and west from the disappearance of the flowing waters from the main passage at the beginning of network system and thence on to the waterfalls to the northwest, has the appearance of being unfinished or young as an underground system. The waters passing through it play hide-and-seek through the low channels which were originally small tubes developed below the water table. The invasion of the river waters through the primitive tubes of the lower level is so recent that integration has not been completed. The waters follow the network rather than any selected passage through it. The network system is but little modified from its primitive condition as formed below the watertable by phreatic waters independent of the influx of surface waters which now course through the system.

In the remote part of the cavern passages beyond the abrupt descents to the lowest level explored in the system, the channel is quite mature and attains a width of 30 to 40 feet. It appears to be developed at the very level of the watertable at an altitude of about 515 feet. Waters stand in the broad passageway nearly to the ceiling, and it is impossible to follow it for any considerable distance beyond the abrupt descents into it. It appears to dip slightly westward and becomes permanently water filled all the remaining distance to the final resurgence of the underground stream south of Orangeville where it terminates at least 20 feet below the watertable.

Stormwater Resurgences along the Dry-bed

The winding course of the lower 11 miles of the dry-bed of Lost River has a relatively steep gradient, descending 85 feet to the Orangeville resurgence. The course is largely over a rocky floor, except in the last mile where both the bottom and sides of the channel are composed of alluvial silts and where pools of water are present during dry weather. The dry-bed becomes deeply intrenched below the sinkhole plain in the lower section of its course, and intermittent resurgences of stormwaters occur at several places along the route.

The first known stormwater resurgence or "wet-weather rise" along the dry-bed route is from pits and holes on the former Mathers farm in the SW of SW¼ of sec. 34, T. 3 N., R. 1 W, a little more than ¼ of a mile east of the dry-bed. The largest pit is 50-60 feet across and 20 feet deep. Its bottom is 540 feet above sea level. A mud-banked channel 15 to 20 feet in width leads away from it 12 to 15 feet above the bottom of the pit. The bottom of this large, cone-shaped pit is 45 feet below the swallow-holes in the dry-bed at the sharp westerly bend less than 1 mile to the southeast. The large resurgence pit is close to the north wall of a flat-floored, steep-sided gulch the head of which terminates abruptly nearby. Eight smaller intermittent resurgences were noted close to the channel leading away from the large one. All but one are on the north side (Fig. 13). Eastward from the steep-headed gulch several large, deep sinkholes descend abruptly below the upland plain. A row of sinkholes occurs in a broken-down strip leading southeast to the Peacher caves. These denote the decadent and nearly destroyed course of a high-level subterranean channel which once probably conveyed Lost River waters in a short course from its dry-bed channel to the Mathers resurgence.

After heavy rains, large volumes of muddy stormwaters rise from the main pit of the Mathers resurgence and reach the dry-bed a short distance to the west. While some of these waters occasionally may come through an underground route from the swallow-holes in the dry-bed nearly 1 mile to the southeast, the chief sources of supply are from the sinkhole plain and its sinking streams northeast of this stormwater resurgence. A former surface tributary of Lost River heads about 3 miles east of Orleans and once passed through the town. It now terminates there, and after heavy rains overflows its terminal swallow-hole and floods much of the western part of the town (Fig. 14). Pearson

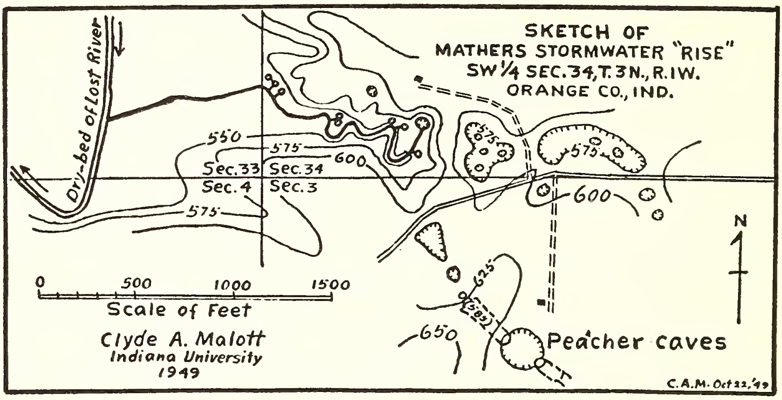

Fig. 13. Sketch of the Mathers stormwater resurgences near the partially intrenched section of the dry-bed course of Lost River, about 3½ miles west-southwest of Orleans. Large quantities of stormwaters issue from the pits here and flow into the nearby dry-bed. The waters probably come from sinking drainage northeast of the "wet-weather rises" and are not from the underground Lost River itself. The contour interval is 25 feet, and some of the deep sinkholes are shown nearby. The broken-down Peacher caves are indicated in the sketch.

Creek, heading southwest of Mitchell in Lawrence County, sinks in the southeast corner of sec. 15, T. 3 N., R. 1 W., though it occasionally overflows southward to the dry-bed. It is quite probable that its waters join with the underground stream coming from Orleans and the waters of the two streams furnish most of the stormwaters rising at the Mathers resurgence. The Mathers resurgence discharges stormwaters only. The watertable is considerably below the bottom of the rise-pit, and undoubtedly an underground stream of some size passes under or close to the pit. This underground stream carries all the normal waters and some of the stormwaters entering it, and only an excess of stormwaters rises to the surface and flows into the dry-bed nearby. The underground course of the stream passes on and probably joins underground Lost River about 2 miles southwest of the Mathers re-

Fig. 14. View of a flooded section of the town of Orleans near the terminal swallow-hole of "Old Sulphur", a former surface tributary of Lost River rising some 3 miles east of Orleans. The flooding waters frequently remain many days before retreating into the underground system which is 20 to 30 feet below the surface at Orleans. These waters probably in part return to the surface in the Mathers stormwater resurgences or "rises", 3½ miles west-southwest of Orleans.

surgence, though possibly it joins the underground stream which terminates at the Orangeville rise.

A group of 4 resurgence pits is present near the mouth of the karst valley 100 yards from the dry-bed in the SE of SW¼ of sec. 33, T. 3 N., R. 1 W., about ¾ of a mile west of the Mathers stormwater resurgence. Two of the pits are relatively large with a smaller one between them. The one on the north coalesces with another, and is faced on the north side by limestone. These pits are stormwater resurgences which empty large quantities of muddy stormwaters into the dry-bed following heavy rains. The waters very probably come principally from the karst valley heading near the center of sec. 21 and passing through the middle of sec. 28 and the eastern part of sec. 33. Minor amounts may come from the small karst valley to the northwest of the rises.

A little more than ¼ of a mile south, in the NE¼ of NW¼ of sec. 4, T. 2 N., R. 1 W., a stormwater resurgence of considerable size issues from an opening about 100 yards east of the dry-bed. It is more frequently used than the Mathers resurgence, being somewhat lower and closer to the dry-bed. The waters rising from it may come from the same underground stream, though their actual source is unknown. Several small holes were noted along the dry-bed along the western side of sec. 4, but it was not determined whether these holes are swallow-holes or resurgence pits. They have the appearance of swallow-holes.

The next resurgence is downstream in the more deeply intrenched section of Lost River valley about 330 yards south of the center of sec. 8, T. 2 N., R. 1 W., (Fig. 2). Here the dry-bed is at an altitude of about 510 feet. The resurgence pit is relatively large and deep, and is connected with the dry-bed by a rising, mud-lined channel 200 feet in length and directed obliquely downstream. The resurgence pit itself appears to be a hole in the roof of a water-filled cavern or conduit of considerable size. In dry weather it contains clear water standing at a depth of about 10 feet below the dry-bed nearby. The water surface is a measure of the watertable here, and is only about 10 feet above the level of the water in the perennial resurgence pit of Lost River 1 mile to the west. During local rains this resurgence pit acts as a swallow-hole and conveys waters to the underground system before stormwaters from farther up underground Lost River arrive. Its location is rather significant. It is almost directly along the line of the underground course of Lost River and about half way between the underground channel at the Shirley or Wesley Chapel gulf and the perennial resurgence on the Allen farm ¾ of a mile south of Orangeville. Possibly it is an opening to the surface of the main water-filled underground course of Lost River itself, though it may be merely an opening in a subsidiary underground conduit connected with the main underground route.

In the compound deeply intrenched meanders southeast of Orangeville, at least 5 localities along the dry-bed have one or more pits which give out stormwaters after heavy rains. These localities are indicated on the map of the dry-bed (Fig. 2). The first of these consists of several small holes on the banks of the dry-bed, in the western loop about ⅜ of a mile west of the center of sec. 8. They appear to be relatively unimportant. Two large holes in bedrock, one in the dry-bed and the other 75 feet to the west, give forth relatively large quantities of stormwaters ⅜ of a mile north of the center of sec. 8. Clear waters stand in these holes about 10 feet below the dry-bed during dry periods. A cavernous opening facing downstream is present in the SW of SE of SW¼ of sec. 5, a little over ½ of a mile east of the Orangeville rise. It is located on the north bank of the rocky dry-bed. Standing waters reach the cavern ceiling about 12 feet below the surface. Apparently large quantities of stormwaters gush out of this opening after heavy rains. Possibly they come from the local karst valleys to the north and east, rather than from conduits connected with the underground course of Lost River. The small holes near the northeast corner of sec. 8 do not appear especially important. A short distance farther downstream, just above the bend to the west, in the SE of NE¼ of sec. 7, is an important stormwater resurgence pit connected with the dry-bed by a mud-lined channel 100 feet in length on the east side of the dry-bed. Some holes also are present in the dry-bed channel on the west side. Large quantities of stormwaters issue from this pit, and they continue to flow for some time after all the others upstream have ceased. Below this intermitten resurgence the dry-bed swings westward along the steep south bluff east of the bridge about ½ of a mile south of Orangeville. Apparently some small sinks are present at the base of the steep slope above the bridge, as waters do not stand in the deep pool here in dry periods. Downstream from the bridge waters stand in pools during dry period, and occasionally stormwaters coming from the Orangeville resurgence flow upstream to beyond the bridge. This upstream flow is associated with the earlier appearance of stormwaters issuing from the Orangeville rise.

The Terminal Resurgences of Lost River

The entrance of the waters from the Orangeville resurgence brings the dry-bed channel of Lost River to an end. The Orangeville rise issues from a semicircular rock-walled pit 110 feet across, and the waters rising from it flow southward in a mud-banked channel 15 feet deep and 40 to 50 feet in width for about 150 yards before entering Lost River. The waters rise some 15 or 20 feet as a great artesian spring from a water-filled cavern the mouth of which is apparently 70 feet in width. The rock wall above the waters is composed of even-lying beds of the lower part of the Ste. Genevieve limestone about 30 feet above the St.

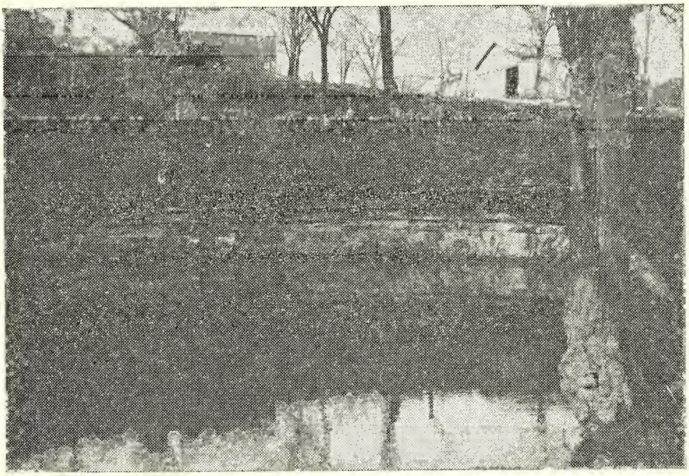

Fig. 15. View of the Orangeville resurgence or "rise" in the deeply intrenched section of Lost River. The entrance of these waters into Lost River marks the terminus of the dry-bed. The waters come from karst valleys to the north and northeast of Orangeville and form an important tributary to Lost River. The perennial "rise" of Lost River itself is along the stream three-quarters of a mile to the south.

Louis limestone. These layers form an overhanging, lunar-shaped cliff about 15 feet above the waters in the rise-pit. The Orangeville rise is quite impressive, and is regarded by many local people as the rise of Lost River itself (Fig. 15). It never goes dry, though in dry weather its flow is reduced to only a few cubic feet per second. After heavy rains its flow is estimated to reach or exceed 2,000 cubic feet per second, and its lunar-shaped, low cliff is submerged and the channel leading to Lost River is filled to overflowing.

The Orangeville resurgence is the terminal orifice of the drainage of several karst valleys to the north and northeast, comprehending 30 square miles or more of rugged terrain composed of sandstone ridges and limestone-floored valleys. As much as 10 or 15 square miles of this drainage comes from numerous sinks and swallow-holes in the Beaver Creek drainage along the B. & O. Railway in Lawrence County 6 miles north of the Orangeville rise (Fig. 1). The whole of the upper part of Beaver Creek drainage is much dismembered, losing it drainage to White River on the north and Lost River on the south through at least 150 separate swallow-holes. One considerable stream enters a swallow-hole 50 feet below the old and nearly destroyed alluviated floor of Beaver Creek valley ½ of a mile west of the old village site of Georgia. The low cavern beneath extends slightly east of due south, though it was not traversed beyond a distance of 250 feet from the swallow-hole. Apparently its deep underground route passes beneath the high sandstone divide between the Beaver Creek and Lost River systems. The waters enter the swallow-hole at an altitude of 610 feet and reappear at the Orangeville resurgence at an altitude of 495 feet, having a fall of 115 feet in the 6 miles of the underground route. Several caverns in the karst valleys north and northeast of Orangeville are local stormwater routes which connect with the underground system. Among these caverns are Salts cave, in the NW of NW of sec. 18, T. 3 N., R. 1 W., in Lawrence County; Black Man cave, in the SE of NW¼ of sec. 19; Showfarm cave, in the SE of NE of NW¼ of sec. 25; and Maple Grove cave, in the NW of NW¼ of sec. 22 (Fig. 1). In addition to the karst valley area north of Orangeville, it is quite possible that the waters which come from "Old Sulphur" at Orleans and from sinking Pearson Creek southwest of Mitchell, except for the intermittent stormwaters issuing into the dry-bed at the Mathers stormwater resurgence and others, also join the underground system and issue at the Orangeville resurgence.

In the karst valley about ½ of a mile north of the Orangeville resurgence a considerable gulf has developed through collapse over the underground stream. It has been called the Orangeville or Ragsdale gulf (Malott, 7, 290-291; Childs, 1, 84-97). It is approximately 600 feet in length and 300 feet or more in width. It has a steep perimeter on the north end which rises 30 to 50 feet above the pits in the irregularly alluviated floor. After very heavy rains it fills to a maximum depth of 30 or 35 feet and overflows to the southeast, but it contains no running waters during dry weather. A short distance north of the gulf, in the NE of NE¼ of sec. 6 (Fig. 2), two swallow-holes receive surface stormwaters in considerable quantities along Dry Branch, but when the underground channel becomes filled beyond its capacity, stormwaters reverse rather suddenly and issue from these holes, turning them into rise-pits. Large quantities of stormwaters issue from the deeper of the two holes and keep waters running in Dry Branch for some time after heavy rains.

The perennial and principal resurgence or rise of Lost River is a deep, mud-lined pit in low ground just east of Lost River on the Allen farm a short distance south of the center of sec. 7, T. 2 N., R. 1 W., about ¾ of a mile south and a little west of the Orangeville resurgence. This large pit is grown about by bushes and trees and its steep muddy banks make it difficult to approach. Soundings in it during a low-water period indicated a maximum depth of 17 feet, though its actual water-filled cavernous route from the east may be somewhat deeper. It is so close to the Lost River channel that it joins it almost directly. During dry weather the deep, clear waters issuing from it scarcely show any movement, but its muddy stormwaters "boil" up vigorously from the terminal underground route of Lost River and flow away in rapid movement. After heavy rains the steep muddy pit is filled to overflowing and close approach to it is difficult and perhaps unsafe. It presents a rather forbidding appearance, even in dry weather. It has none of the beauty of the easily accessible and frequently visited cliffed-pit of the Orangeville rise.

It is remarkable that all of the gathered bedrock seepage and phreatic clear waters of the underground Lost River system should have only two outlet orifices, with the one on the Allen farm returning to the surface all the clear waters entering at the sinks of Lost River more than 7 miles away and the lithic and phreatic waters gathered along its lengthy underground course. The low-water courses of the two systems are, indeed, well co-ordinated, ending each in its own single terminal resurgence. In flood, the two systems retain the two spectacular terminal orifices, but in addition have others only slightly less impressive. In times of floods the capacity to carry waters beneath the surface and the ramification of the systems are more fully comprehended when the great volumes of intake waters from diverse and widely separated areas are considered in conjunction with the many resurgences then in operation.

Summary and Conclusions

Lost River sinks in its channel during dry weather at or near the local watertable at an altitude of 620 feet. The same waters return to the surface from an underground route more than 7 miles to the west where the lower part of the stream system and the watertable is at an altitude of 490 feet. The main underground course appears to be relatively directly westward and follows close along the watertable level beneath the sinkhole plain and considerably below the course of the tortuous dry-bed channel which is followed only by the excessive stormwaters gathered from some 47 square miles of the upper part of the stream system. The dry-bed course is at least 22.5 miles in length and is without tributaries. Its upper section is characterized by numerous small and several large intaking stormwater swallow-holes. The lower section of the dry-bed course is relatively deeply intrenched, but still above the westerly descending watertable. It receives considerable amounts of the underground stormwaters which issue as intermittent resurgences at higher levels than the final and continuous resurgence of underground Lost River. Some of these intermittent resurgences come from the sinking stormwaters of certain former surface tributaries which now fail to reach the dry-bed course, while some come from the flooded underground cavernous course of Lost River itself.

Lost River is the largest stream in the karst region of southern Indiana which does not have a continuous open course along the level of the watertable. East Fork of White River to the north and Blue River and Indian Creek to the south arise beyond the limestone sinkhole plain developed on the St. Louis and Ste. Genevieve limestones and follow deeply intrenched courses which determine the watertable levels of the areas through which they pass. Lost River had such an indirect course across the limestone upland that it was not able to intrench its course below the upland plain except downstream from the western margin. Consequently, the upper part of the drainage system and its dry-bed section are perched on the limestone upland. The lower course of Lost River, however, is deeply intrenched and is at local baselevel. Here the stream sets the limits of the watertable level.

The westerly dip of the limestone beds combined with the well developed joint system facilitated the withdrawal of the watertable to lower levels than the perched stream system in a large area of the upper part of Lost River basin. This withdrawal of the watertable was accompanied by the development of multitudinous downward solution-formed openings which conveyed surface waters derived from rainfall to lower levels. The downward dissolved-out leads are wide-spread, and most of them mark the sites of tens of thousands of sinkholes which have become surface hoppers feeding rainfall waters to underground routes. The withdrawal of the watertable below the upland surface first took place closely adjacent to the intrenched lower course of Lost River and sinkholes and sinking drainage were first developed along the western margin of the upland limestone plain. Later the lowering of the watertable proceeded farther east and farther up the course of the present dry-bed. Thus, the sinkholes of the upland limestone plain and the swallow-holes of the sinking streams were developed farther and farther from the resurgences of the waters in the intrenched section of Lost River. The present sinks of Lost River are relatively young and are developed but slightly above the present watertable. The sinkhole plain itself is developed some 2 miles farther east than the sinking stream and several square miles of the former surface drainage now descend into sinkholes and the underground system independent of the surface stream. Thus, of the 53 square miles of Lost River drainage above the sinks, only 47 square miles of actual surface drainage are directed into the underground system at the sinks and in the stormwater swallow-holes of the dry-bed.

It is interesting to note that the entire surface drainage of Lost River above the sinks is completely surrounded by sinkhole topography and underground drainage: It is an island-like area in the midst of a great karst plain. It is a surviving surface drainage on a potentially soluble limestone upland remote from the intrenched drainage which set the condition under which subterranean drainage could develop all about it. It offers an example of surface drainage on a readily soluble limestone upland refuting the conception of deepseated phreatic drainage independent of a lowered watertable.

The development of the underground drainage of the perched sinkhole plain with its sinking streams is definitely associated with rainborn waters which fell upon the surface areas of the system. Certainly it cannot be gainsaid that the thousands of sinkholes which characterize the topography of the areas with a lowered watertable have resulted from the rain waters which fell upon them. They are surface solution sinkholes and have no other supply of waters than rainfalls. The freshly fallen acidulous waters are potent consumers of limestone beneath the soil surface and enormous quantities of rock have been removed over large areas of the general surface and clearly manifested in the deepened sinkhole voids where the watertable is considerably below the upland surface. In areas where the watertable is close to the surface the sinkholes are shallow and pass eastward into

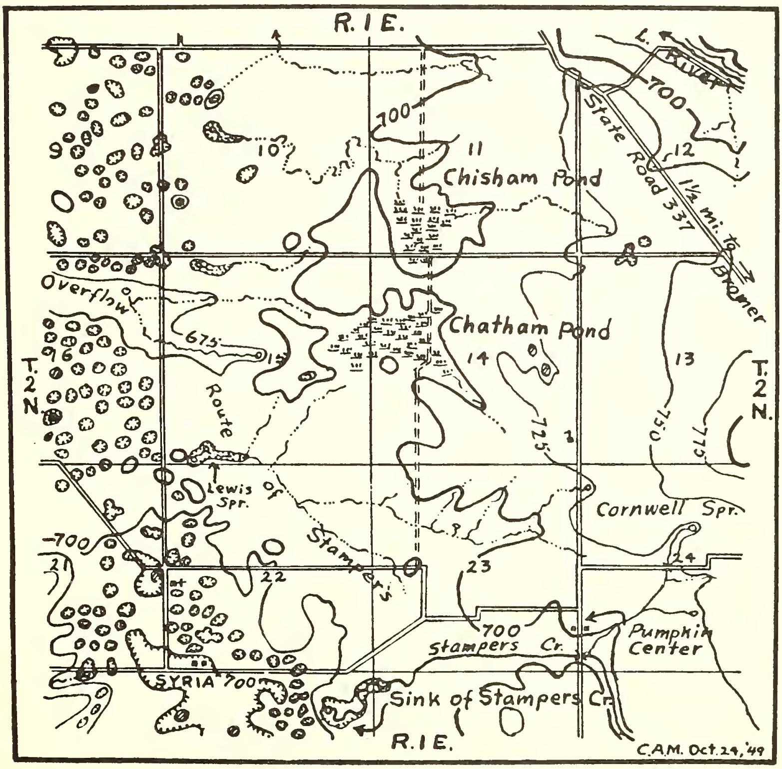

Fig. 16. Topographic sketch showing surface drainage with a high watertable passing westerly into sinking drainage and sinkhole topography with a lowered or withdrawn watertable. Chisham and Chatham ponds are karst fens or swamps in slightly developed solution pans at or near the watertable. The locality of the sketch is south of Lost River 3 to 7 miles southeast of Orleans and southeast of the sinks of Lost River.

barely discernible solution pans and thence into areas of surface drainage. This condition is clearly manifested in the drainage and topography in a strip of terrain some 2 miles in width extending southward along the eastern edge of the sinkhole plain some 2 or 3 miles east of Orleans and west of Leipsic, where surface drainage on the upland passes westward into well developed sinkhole topography. Here also the water table passes from one barely below the surface of the flat upland to one which is withdrawn to considerable depths beneath. The small sinking streams at first discharge into broad, shallow solution pans or into karst fens or swampy ponded areas, such as the drainage westward from "The Flatwoods" just west of Leipsic, or in the localities of the Chisham and Chatham ponds in sections 11 and 14, T. 2 N., R. 1 E. (See Figs. 1 and 16.) Stampers Creek itself sinks into a similar shallow area in the same strip of terrain in the NE of NE¼ of sec. 27, some 2 miles south of the Chisham and Chatham ponds.

If the sinking of rainfall waters on the general upland limestone plain made the sinkholes and the vertical leads which descend to the watertable, it follows that these same waters were directed into the permissive bedding planes down the dip of the beds at or near the westerly descending watertable and dissolved out small tubular routes which lead out from under the lands upon which the waters fell. These small dissolved out routes are multitudinous and of such sufficiency that underground drainage in the sinkhole plain is 100 percent complete. Some of these small watertable leads received quantities of acidulous surface waters from incoming streams and in time were developed to such dimensions that they could carry all of the waters fed to them from the surface streams. Those receiving the waters of surface streams of considerable size have been developed into great cavernous routes of underground drainage through which gathered stormwaters go. Among them is the underground system of Lost River itself. Lost River pours much of rainfall gathered from 47 square miles of surface area into its underground system. These waters enter through the sinks and the various stormwater swallow-holes along its dry-bed channel. The amounts of stormwaters carried by this underground system bear convincing testimony of the size of the underground system and of the efficiency of these waters to develop their own routes beneath the limestone terrain. Waters derived from the surface constitute the agency through which areas have become an extensive sinkhole plain and by means of which great cavernous routes extend for miles beneath a pitted plain whose upland surface acts as a regional sieve to absorb the rainfall and the gathered waters from sinking surface streams. The region furnishes an excellent and convincing example of caverns developed through the invasion of potent acidulous surface waters to underground routes which were originally tiny and little developed.

Literature Cited

1. CHILDS, LEWIS 1940. Unpublished Master's thesis, Indiana University.

2. DAVIS, W. M. 1930. Origin of limestone caverns, Geol. Soc. Amer. Bull. **41**:475-628.

3. ELROD, M. N. 1876. Orange County. Ind. Geol. Survey, 7th Ann. Rept. 203-209.

4. ——————— 1899. The geologic relations of some St. Louis group caves and sink holes. Proc. Ind. Acad. Sci. for 1898, 258-267.

5. MALOTT, C. A. 1922. Lost River and its subterranean drainage, Handbook of Indiana Geology. Ind. Dept. Conserv. Pub. 21, 203-210.

6. ——————— 1929. Three cavern pictures. Proc. Ind. Acad. Sci. **38**:201-206.

7. ——————— 1932. Lost River at Wesley Chapel Gulf, Orange County, Indiana. Proc. Ind. Acad. Sci. **41**:285-316.

8. ——————— 1949. Hudelson Cavern, a stormwater route of underground Lost River. Proc. Ind. Acad. Sci. **58**:236-243.

9. ——————— and SHROCK, R. R. 1933. Mud stalagmites, Amer. Jour. Sci. **25**:55-60.

10. OWEN, RICHARD. 1862. Report of a geological reconnaissence of Indiana made during the years 1859 and 1860, 368 pages, Indianapolis.