WATER RESOURCES REPORT NUMBER 31

a guide for the geologic and hydrologic evaluation of small lake sites in missouri

BY THOMAS J. DEAN
JAMES H. BARKS
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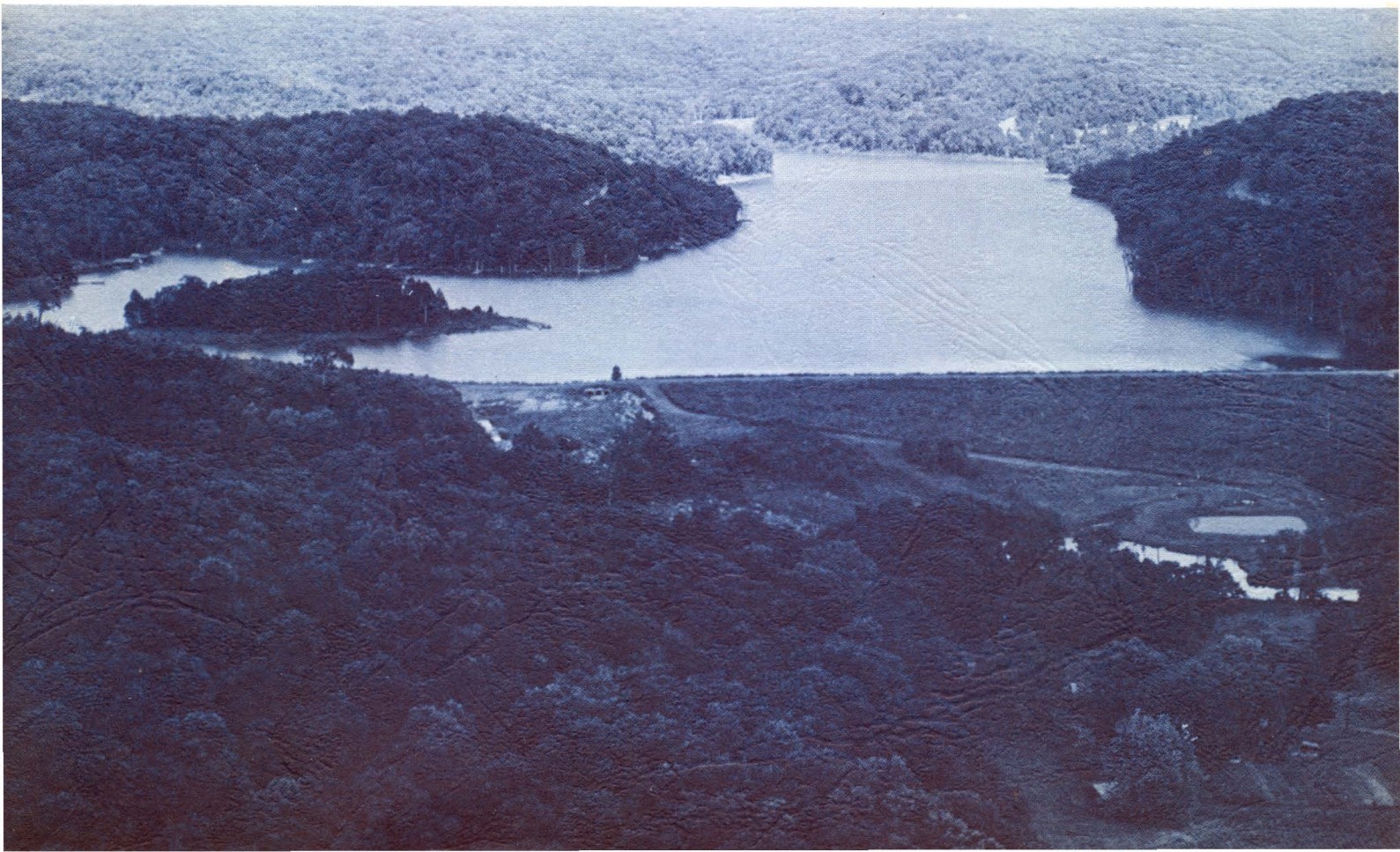

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1976

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MISSOURI DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGY AND LAND SURVEY

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A GUIDE FOR THE GEOLOGIC AND HYDROLOGIC EVALUATION OF SMALL LAKE SITES IN MISSOURI

By

Thomas J. Dean*, James H. Barks**
and James H. Williams***

ABSTRACT

The number of lakes in Missouri with a surface area in excess of 5 acres (2.0 ha) is estimated to be nearly 2,500. Construction costs for each of these relatively small impoundments represent investments of approximately $5,000 to $250,000.

The failure rate of lakes in Missouri is high because of adverse geologic and hydrologic conditions, faulty design and poor construction practices. The primary problem is water loss by subsurface leakage, but others include collapse of the lake bottom, dam failure, landslides, accelerated eutriphication and siltation. Improper location, excavation and placement of the core of the dam and removal of clayey soils from a potential lake bottom are poor construction practices that can lead to lake failure.

Careful evaluation of geologic and hydrologic conditions at potential lake sites and sound design and construction practices can greatly enhance lake development in Missouri.

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INTRODUCTION

Few natural lakes exist in Missouri; however, suitable topography, abundant water and land available for development have resulted in numerous manmade lakes. To date (1975), nearly 2,500 lakes have been formed by damming stream channels and minor drainageways to catch streamflow and runoff from rainfall. The lakes fulfill a variety of needs such as recreation, real-estate enhancement and water supply.

The purpose of this report is to aid landowners, contractors, engineers, government agencies and developers in the early recognition of geologic and hydrologic problems related to lake development. The report contains generalized information about the geology of Missouri and is not intended to replace on-site evaluation by qualified investigators. Detailed comments on engineering design of the dam and spillway sizes are not included in this study. Discussion is limited to those physical features of the terrain at the site of the dam and impoundment that affect design and water-holding capability. Knowledge of runoff available to the impounded watershed, including frequencies of peak and low streamflow and average annual discharges, is of critical importance in dam and reservoir design. Such information is not available for many small watersheds in Missouri and necessary streamflow records must be synthesized from similar, adjacent watersheds in which such records have been obtained. Basic streamflow data are available from the reports, Water Resources Data for Missouri, "Part 1, Surface Water Records" released annually by the U.S. Geological Survey in cooperation with the State of Missouri and other Federal agencies. In addition, flood-frequency analyses are given in reports by Skelton and Sandhaus (1968) and Hauth (1974)a. Storage requirements and low-flow characteristics of Missouri streams are discussed in reports by Skelton (1966, 1968).

For this report, small lakes are defined as manmade impoundments with surface areas of 5 to 250 acres (2.0 to 100 hectares); most such lakes in Missouri are 5 to 50 acres (2.0 to 20 ha).

Construction costs for small lakes vary considerably, depending on geologic and hydrologic conditions prevalent at individual sites. Average costs,

however, are more than $1,000 per acre (0.4 ha) of impoundment, not including land acquisition cost, improvements, or special problems in construction. Evaluation of a lake site is necessary to determine the suitability of the site and accurately estimate construction costs. The geology of a small lake site is usually first studied by reconnaissance investigation. More detailed investigations such as test drilling and laboratory testing of soils, frequently vital to lake-site evaluation, may result in costs higher than the average cited previously.

Problems associated with water impoundments are many and diverse, but the primary one is water loss by subsurface leakage. Others include collapse of the lake bottom, dam failure, landslides, accelerated eutrophication, and siltation. Remedial procedures such as grouting, padding, and recoring of dams are commonly used to prevent leakage, but are expensive and may even exceed the cost of the original structure. These efforts are not always successful, especially in the Ozarks.

In this report, the English units of measurement are used, with the metric equivalent in parentheses. One acre is equal to 0.4047 hectare. One foot equals 0.3048 meter.

This report was prepared under the direction of Dr. Wallace B. Howe, State Geologist and Director of the Division of Geology and Land Survey, Missouri Department of Natural Resources, and Anthony Homyk, District Chief, Missouri District of the U.S. Geological Survey.

TYPICAL LAKE SETTINGS

As a first step in delineating typical lake settings in Missouri, the state was subdivided into five generalized areas as shown in figure 1. The boundaries are based on geologic and hydrologic factors that influence the evaluation of a lake site.

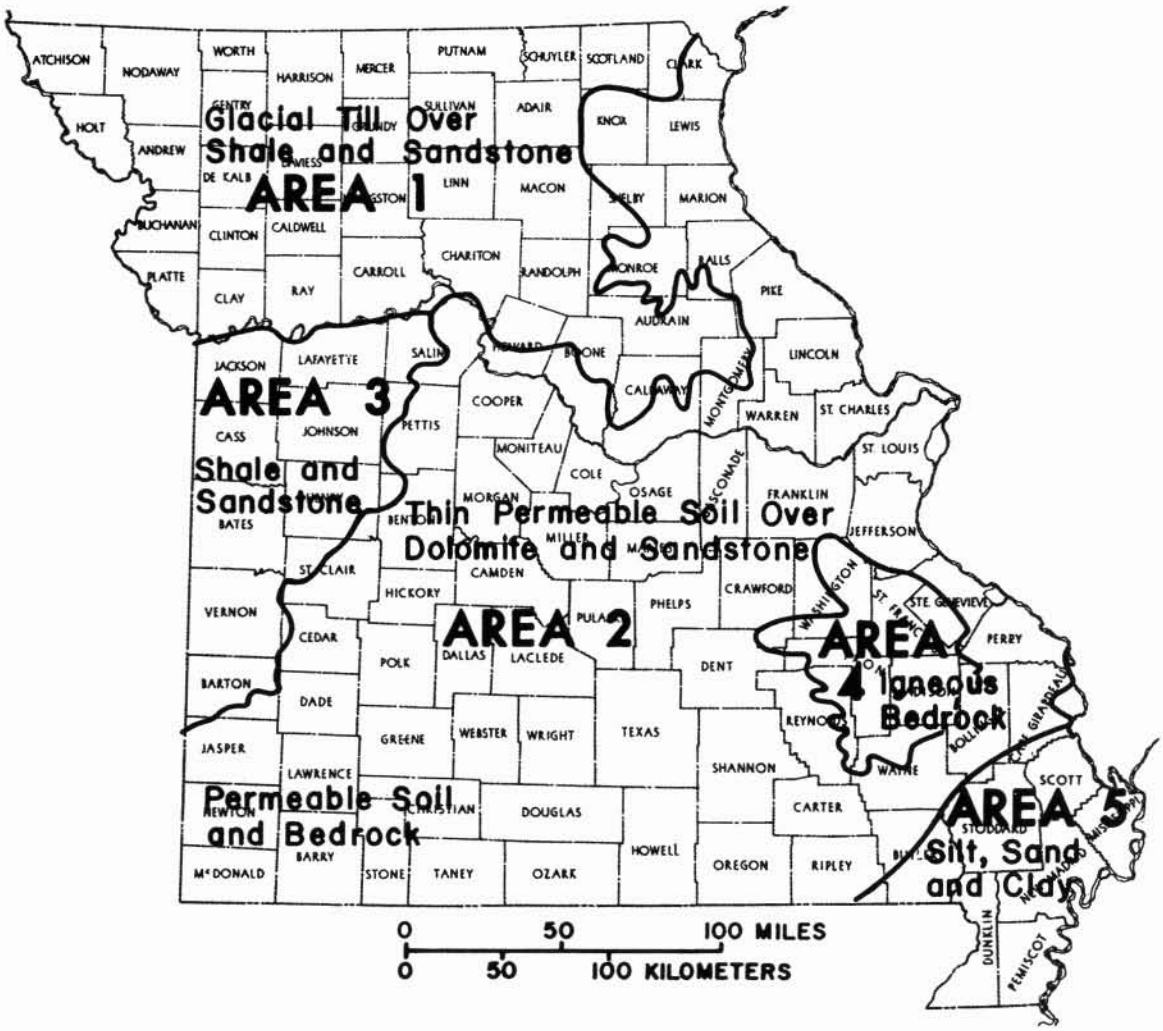


Figure 1

Generalized geologic map showing the five major geologic areas of Missouri.

In the discussions of typical lake settings in various areas of the state, soils are considered as all unconsolidated or fragmented material above bedrock. With few exceptions, soil characteristics are a prime factor in the successful development of small lakes.

Topographic location of a small lake site in the drainage basin is described in this report as upper, middle or lower watershed. Upper watershed lakes are in the upper reaches of the drainage area where the streams originate and soil cover is usually continuous. Middle watershed lakes are those in the central part of the drainage network where some bedrock exposures normally exist. Lower watershed lakes are farther downstream where drainage areas are larger and outcrops may be extensive.

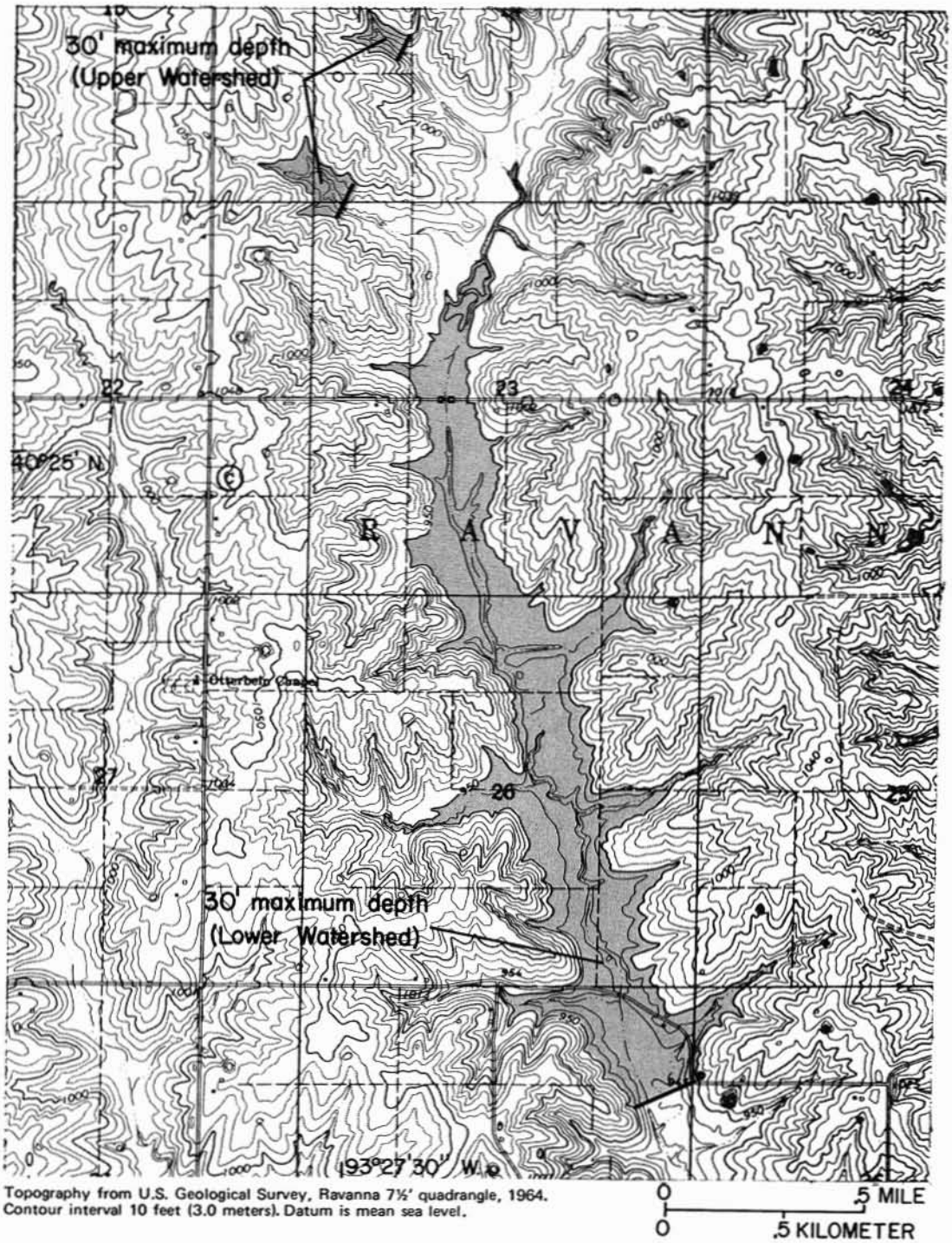


Figure 2

Topographic map showing hypothetical upper and lower watershed lakes in the glaciated area of northern Missouri.

NORTHERN MISSOURI GLACIATED AREA 1

Area 1 includes most of the glaciated part of northern Missouri. Varying thicknesses of till (glacial drift consisting of clay, sand, gravel and boulders) and loess (wind-deposited silty soil) characterize this area. The soils are highly erodible and contribute to siltation problems. Thin-bedded layers of limestone, sandstone and coal underlie the soil deposits, but bedrock outcrops are not widespread. Most of the bedrock is shale; however, where limestone, sandstone and coal exist leakage can be moderate to severe.

Sites that are suitable for lake development are usually in the upper and lower watersheds. Middle watershed lakes as defined in this report are not characteristic of Area 1 because of the topographic and geologic uniformity of the valleys. Figure 2 depicts hypothetical upper and lower watershed lakes and shows that a dam of given height results in a much larger lake in the lower watershed than in the upper.

Upper Watershed Lakes

The upper watershed lake sites have various soil and topographic conditions. Sites where the principal soil type is loess have small drainage areas, steep valley slopes and high stream gradients. Loess has a natural ability to stand in near-vertical slopes, is permeable and is highly erodible. The permeability can be reduced by compaction and artificial sealants. Loess has high strength when dry

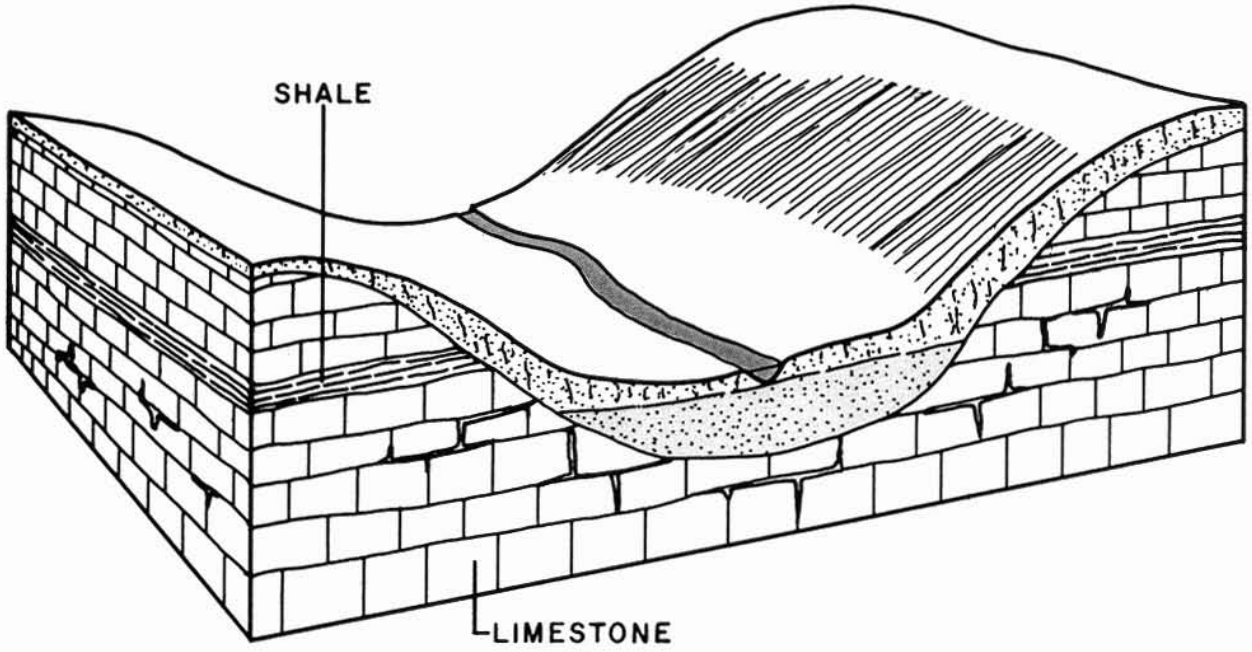


Figure 3

Schematic diagram of a valley cross section showing water loss through fractured or jointed limestone.

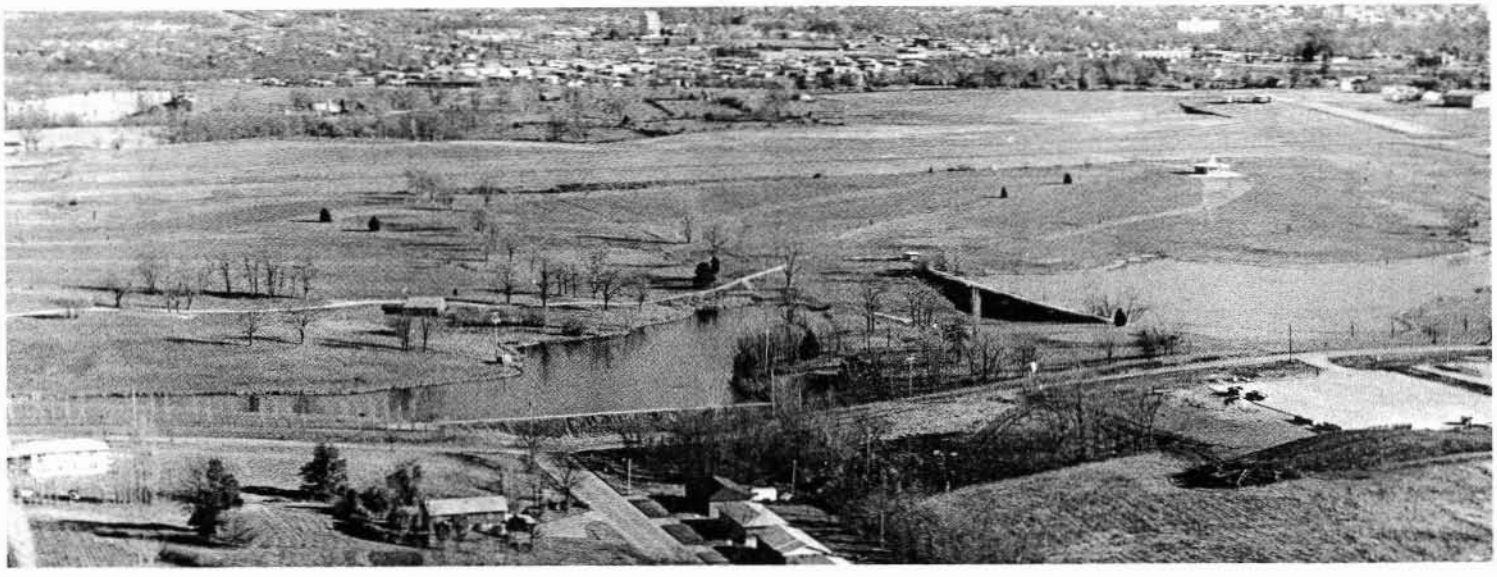


Figure 4

Construction of a low dam creates a large lake in relatively flat areas with low relief topography. Photo by David Rath.

but loses its strength when wet, so slumping of steep valley slopes often occurs near lake shorelines. Bedrock and sand deposits are sometimes exposed in lower valley slopes or gully bottoms.

Valleys in which till is the predominant soil type usually have larger drainage areas, lower stream gradients and less rugged topography than the loess areas. Large sand and gravel deposits in the till can contribute to leakage problems, but where these deposits are absent, the till is relatively impermeable. Some glacial-till slopes have a tendency to slide when saturated or when the toe of the slope has been removed in construction.

Shale or limestone bedrock is at or near the surface in some areas. Figure 3 shows how openings in fractured limestone are the major cause of leakage problems in the upper watersheds.

Lower Watershed Lakes

In the lower watershed, the stream gradient is low, the valleys are wide and drainage areas are large, but of low relief. Large lakes can be created with relatively low but long dams (fig. 4). Runoff is sustained for considerable lengths of time during wet seasons and major floods may occur several times a year.

Bedrock may be exposed in the lower valley slopes in some of the large valleys and buried at depths of more than 100 feet (30 m) in others. Thick alluvial deposits of water-saturated silt are typical in the valley bottom. Having been deposited in water, the alluvium may have zones of permeable sand and silt between clay layers. These zones can cause seepage problems unless they are located and planned for prior to construction.

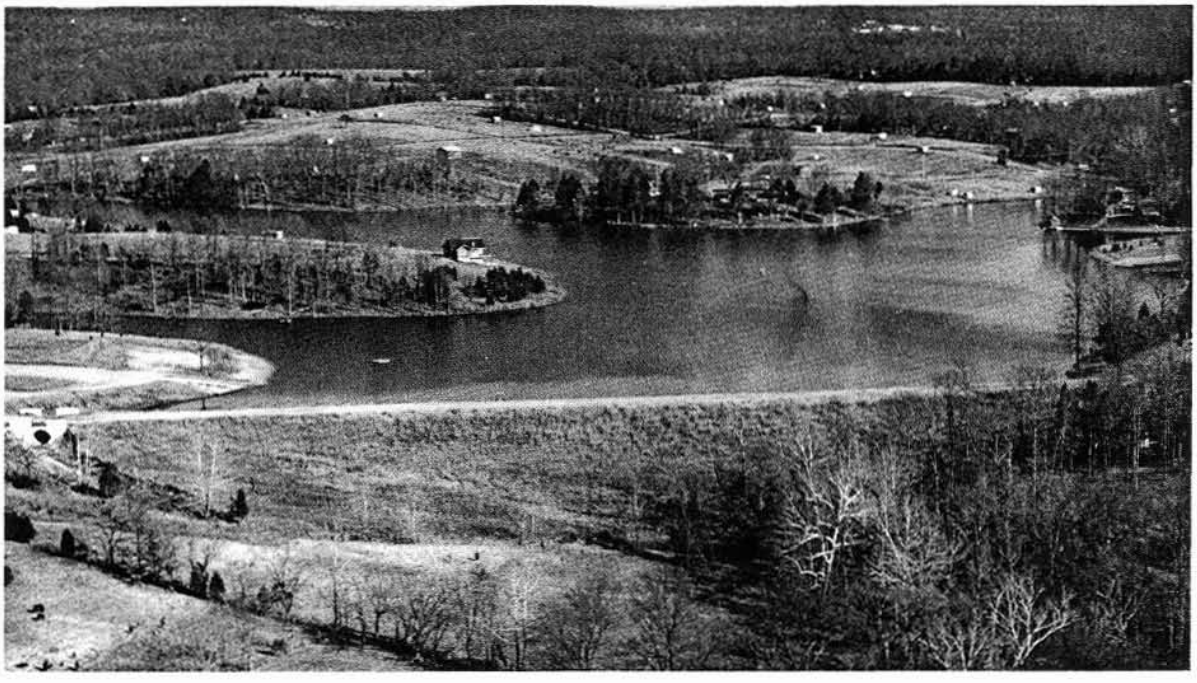


Figure 5

A typical multi-fingered lake in an Ozark setting.

OZARK CARBONATE AREA 2

The Ozarks (including the Springfield Plateau) and the limestone areas north of the Missouri River and in northeastern Missouri along the Mississippi River make up Area 2. Permeable bedrock, varying thicknesses of permeable soil, large springs, caves and massive rock bluffs along the streams characterize the Ozarks. Rugged topography, scenic beauty and abundant ground water make this area desirable for development (fig. 5). However, the undesirable hydrologic and geologic conditions associated with karst topography make the Ozark area particularly susceptible to lake failure due to leakage.

Topographic conditions suitable for construction of lakes exist in all parts of the Ozark watersheds, as shown in figure 6. There are, however, marked differences in the features to be found in the upper, middle and lower watersheds.

Upper Watershed Lakes

Lakes in the upper watersheds of the Ozarks tend to be small (fig. 4) because

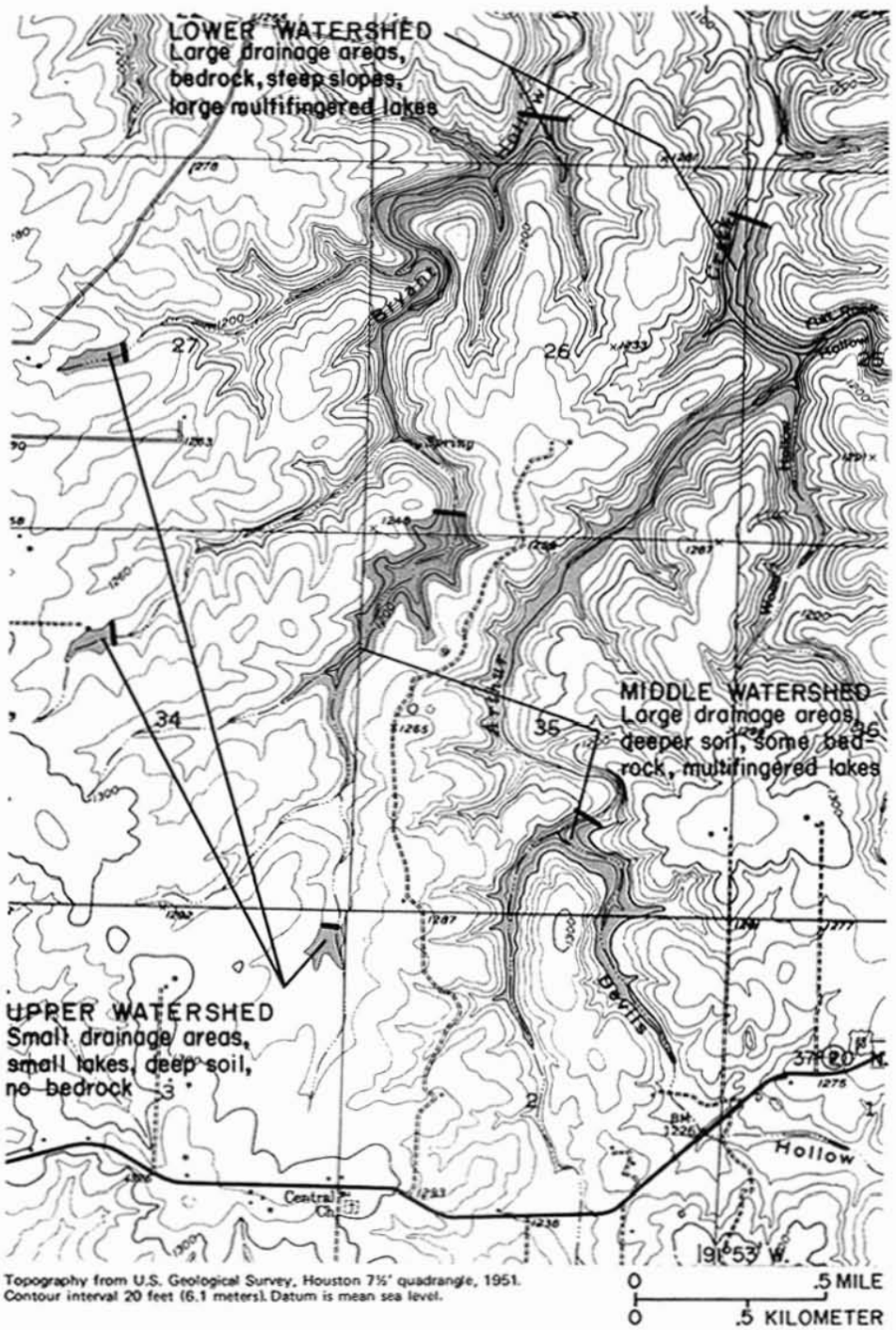


Figure 6

Topographic map showing hypothetical upper, middle, and lower watershed lakes in the Ozark carbonate area.

the topographic relief is large, the valleys are narrow, and the gradients of the streams are relatively high. Even a high dam would not back water very far upstream.

Soils in the upper watershed areas vary in composition and thickness, depending upon the parent material of the soil and the geographic location. Soil thicknesses generally range from several feet to more than 300 feet (91 m). Soils developed from limestone bedrock tend to be permeable, thus reducing the amount of runoff from these areas. Even where these soils are thick, lakes with small watersheds can have fluctuating waterlines. Soils developed from dolomite bedrock in the central Ozarks vary greatly in permeability. Soils over shale bedrock are generally not widespread and are usually plastic and relatively watertight. The permeable soils in the upper watershed areas can be structurally unstable when saturated and can result in collapse of the lake bottom when the water table is very low.

Middle Watershed Lakes

Numerous features are advantageous to lake development in the middle watershed areas. The drainage area is much larger, the valley has enlarged and the stream gradient is not as steep as it is in the upper watershed. This setting is also characterized by the occurrence of side draws or tributary valleys which give the lakes a multifingered configuration, thus increasing their beauty and length of shoreline. This results in more lake area per foot of dam construction. In addition, springs and seeps are more likely to have developed in the middle watershed area, thus adding continuous inflow to the lake. Soil development, although not as great as in the upper watershed area, is usually enough to pad the valley slopes, reducing the problems of water loss into openings in the underlying bedrock. Borrow material is usually available for construction of an earthen dam. Valley slopes are more gentle than in the upper watersheds and dam construction is easier.

Problems associated with permeable soils are the same as in the upper watershed area. Alluvial soils, however, are more prevalent in the middle watershed than in the upper because of lower stream gradients. Thus, permeable sands and gravels in the valley bottom must be considered in the design of dams and the selection of core materials.

Exposure of weathered and permeable bedrock often makes rock excavation necessary in this area. Problems associated with cavernous or fractured bedrock, springs and seeps should be evaluated by backhoe or drilling methods.

Permeable valley bottoms and losing streams (those that lose water to the subsurface) are more widespread in the middle watershed area than in the upper. The water table, or level to which water moving vertically descends through the bedrock in the valley bottom, may be deep below the valley bottom. This base level or depth can usually be determined by visual observation. A thorough investigation upstream as well as downstream of the dam site is necessary to determine if the horizontal movement can be intercepted under the dam.

Lower Watershed (bedrock) Lakes

Lakes in the lower watersheds are usually in rugged, bedrock-lined valleys. Because the valleys are often narrow and the drainage areas large, spillways should be designed to accomodate large floods.

The valley slopes are usually vertical or very steep, with thin soil cover. The alluvial material in the valley bottom is coarse-grained and unsuitable for use in the central part of the dam. Thus, borrow material may be lacking in quantity as well as quality.

Because of the lack of impermeable soil, the core of the dam should be seated in bedrock. The permeability of the bedrock may be judged by surface observations, but test-drilling may be needed to determine if deep rock excavation or grouting of the rock is necessary.

Large caves, commonly associated with springs, often add to the complexity of lake-site evaluation in the lower watersheds. For example, spring outlets represent permeable horizons in the valley slopes. While a spring may add water to a lake, lake water may be lost into the permeable zone in the spring area.

WESTERN PLAINS AREA 3

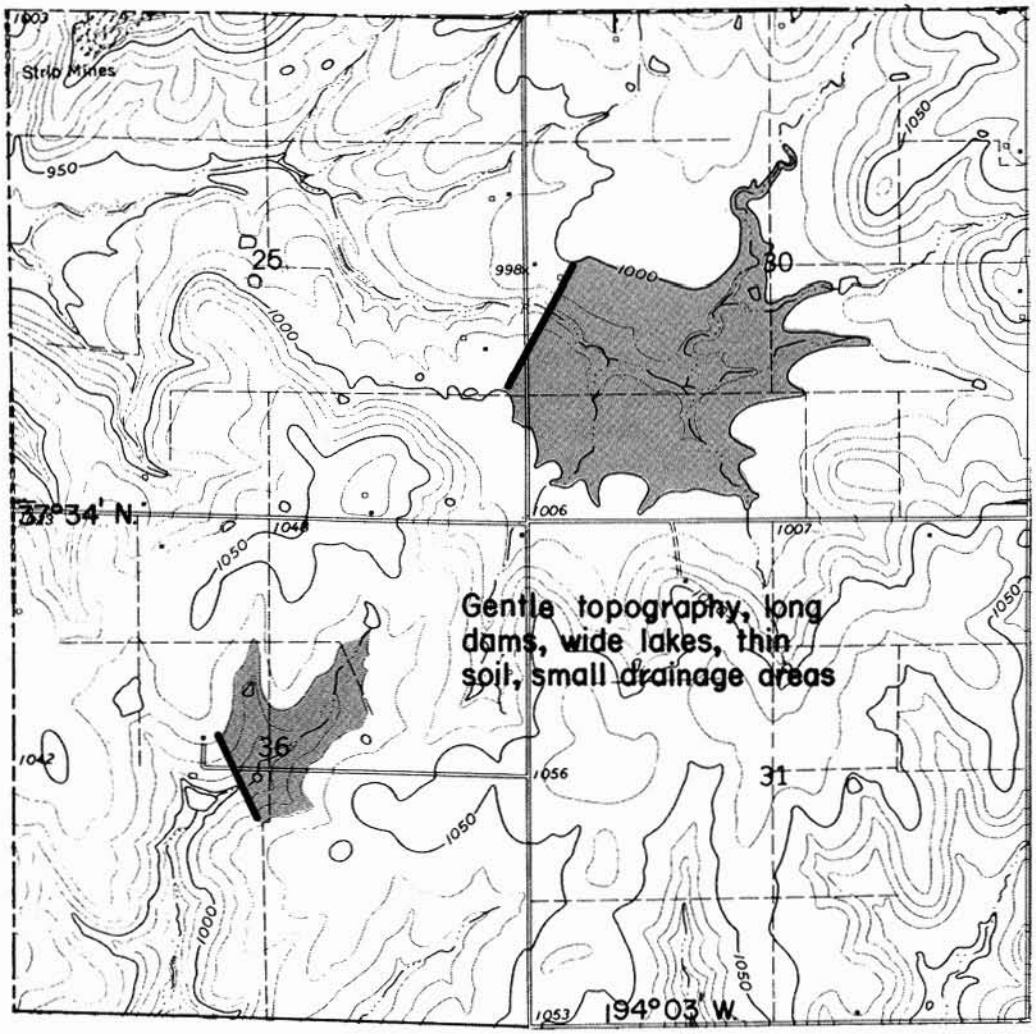
The western plains of Missouri are underlain by thin-bedded layers of shale, limestone, sandstone and coal. The shale is relatively impermeable, but the sandstone is usually permeable and can cause leakage problems. Thin soils are composed of a mixture of wind-deposited silts and clay-rich soil derived from weathering of the bedrock.

Area 3 has low relief, as the term "plains" indicates. Stream gradients may be relatively steep in the headwaters, but change rapidly to low gradients for most of the length of the stream. Lake settings mostly embrace the upper watershed features. Both upper and lower watershed lake settings will likely be associated with bedrock and generally thin soil cover.

Upper Watershed Lakes

A comparison of figure 7 with figure 6 shows that much wider lakes are created in the upper watersheds of the western plains than in the Ozark carbonate area because the valleys are wider, requiring longer dams. The lakes are short due to steep stream gradients; thus, lakes in this area are often as wide as they are long.

Thin soil covers layered bedrock composed of relatively impermeable limestone



Topography from U.S. Geological Survey, Jerico Springs 7½' quadrangle, 1962. Contour interval 10 feet (3.0 meters). Datum is mean sea level.

0 .5 MILE
0 .5 KILOMETER

Figure 7

Topographic map showing hypothetical upper watershed lakes in the Western Plains. Lower watershed lakes (not shown) are like those in figure 2.

or shale or permeable sandstone. Limestone ledges can be troublesome if solution-enlarged cracks exist. Padding the rock with soil and proper placement of the core of the dam can reduce leakage problems.

Lower Watershed Lakes

Lake sites in the lower watersheds have low stream gradients, similar to the example in figure 2, and are wide and flat bottomed. Large drainage areas, broad

valleys and relatively slow runoff make these sites ideal for large, shallow lakes.

Thick alluvial deposits in the valley bottom and thin soils on the valley slopes result in the need for deep core trenches in the valley bottom and rock excavation for core trenches in the valley slopes. Bedrock problems in the valley slopes are similar to those in the upper watersheds.

ST. FRANCOIS MOUNTAINS AREA 4

The St. Francois Mountains region, Area 4, has ridges and hills composed of igneous rock, with valleys and lower slopes underlain by massive carbonate rock and sandstone. Some igneous rock types are relatively impermeable but other types are fractured and jointed and can be very permeable. Most igneous rock has very little soil cover. Carbonate rock and sandstone in the valleys are weathered and may be permeable.

The St. Francois Mountains have high relief, with very steep valley slopes and high stream gradients. Lake settings are typically in the upper watersheds and in wide valleys of the lower watersheds, as shown in figure 8.

Upper Watershed (igneous bedrock) Lakes

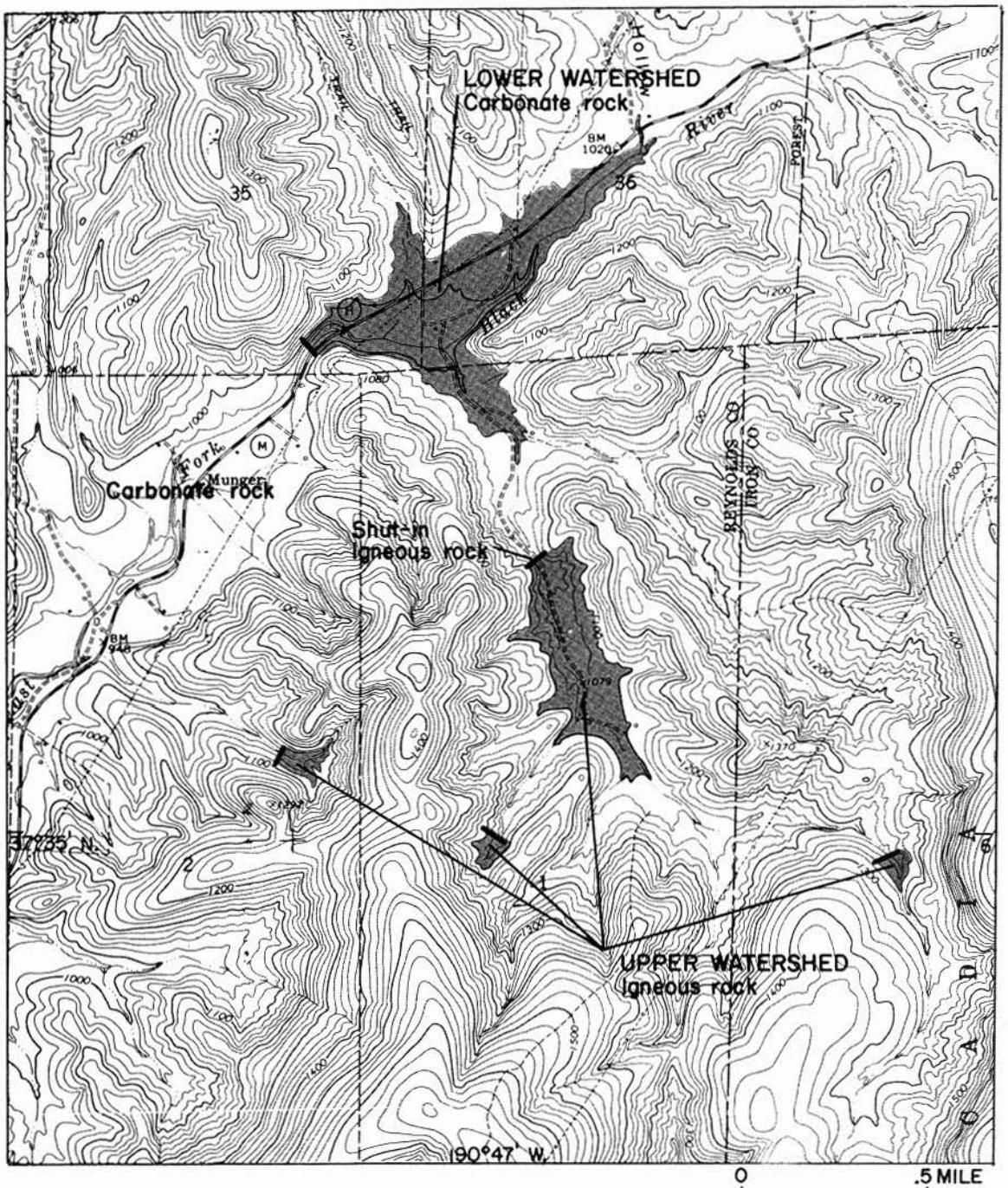
Construction of lakes in the upper valleys is hindered by a lack of readily available borrow material for an earthen dam. Most igneous rock does not weather rapidly; thus, very little soil accumulates on the outcrop. The bedrock is very hard, making excavation very expensive. Lakes tend to be small because of the steep stream gradients.

Many small hill areas between igneous peaks have thick soil over carbonate bedrock. These locations are favorable sites for small lakes, although valley size and drainage areas are usually small.

Lower Watershed (carbonate bedrock) Lakes

The lower watershed areas are topographically ideal for large lake sites. However, carbonate bedrock, masked by permeable alluvial soil, which is usually present in the broad valley bottoms, can make these sites geologically unsuitable.

Solution work along joints and bedding planes in the bedrock is generally extensive. In some areas weakening of the bedrock is extensive because the cementing agent between individual dolomite



Topography from U.S. Geological Survey, Johnson Shut-Ins 7½' quadrangle, 1968.
Contour interval 20 feet (6.1 meters). Datum is mean sea level.

Figure 8

Topographic map showing hypothetical upper and lower watershed lakes in the St. Francois Mountains.

grains has been removed, causing the dolomite to be friable (loose) like sand. Nevertheless, if these geologic problems can be corrected, the large drainage areas and large valleys with low gradients make the lower valleys desirable lake sites.

Shut-ins, which occur where valleys are constricted into narrow, steep gorges by resistent igneous (usually rhyolite) bedrock, exist in some of the lower valleys. The shut-ins provide natural dam sites and are highly desirable if the rock forming the shut-ins is not fractured, jointed or badly weathered, and if the valley is not floored by carbonate rock. However, there is usually very little soil available on the steep slopes of the shut-ins and most soil for construction must be transported from upstream and downstream areas.

SOUTHEASTERN LOWLANDS AREA 5

The Southeastern Lowlands, Area 5, is a province that is distinct in topographic and other physical characteristics. Deposits of sand, silt and clay mantle the Lowlands and silt, sand, clay, sandstone and shaly bedrock make up the hill regions. Most of the region is relatively flat, with some low, rolling hills and persistent terraces.

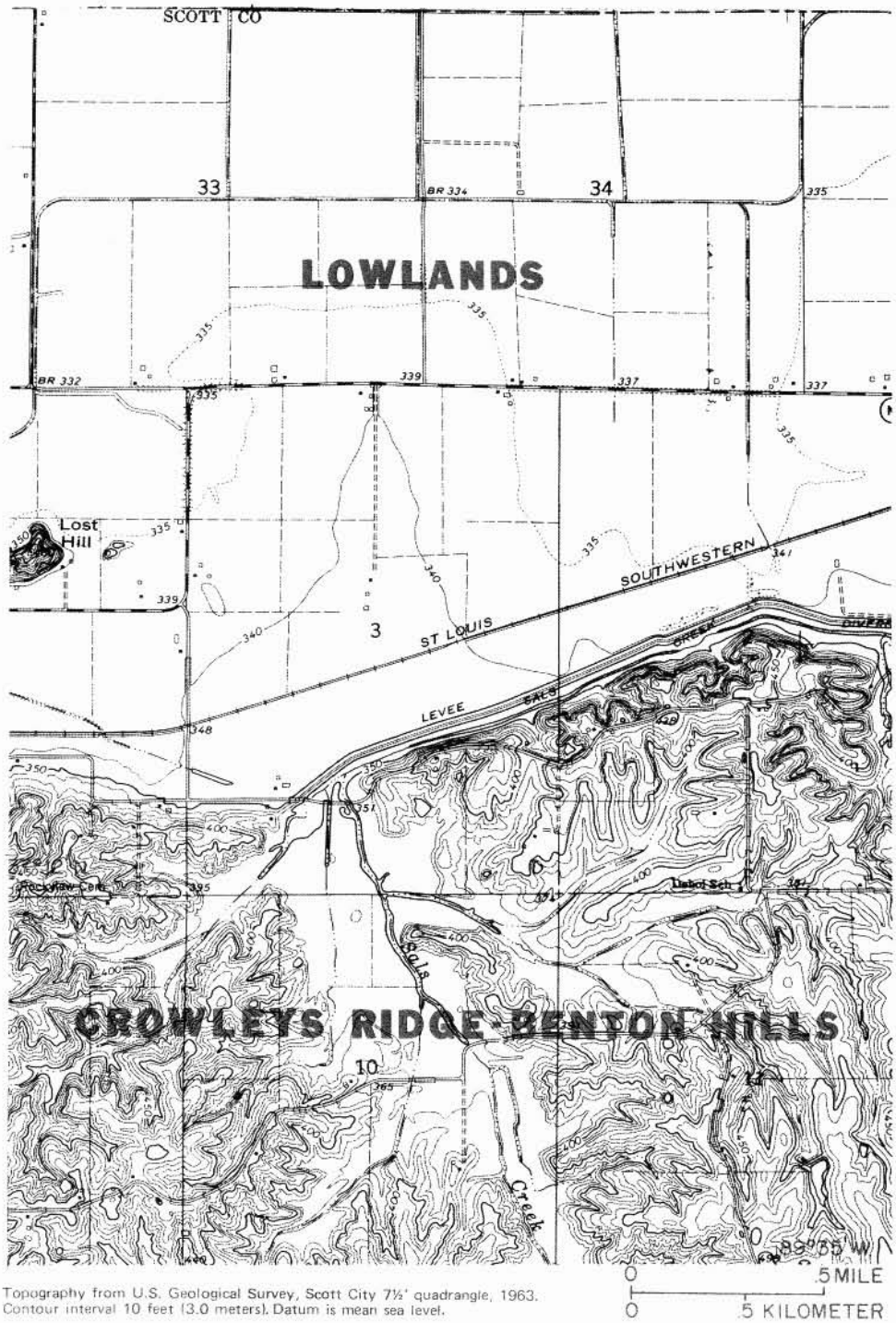
The Southeastern Lowlands has two topographic settings as far as the selection and performance of lake sites are concerned. These areas are the Crowleys Ridge-Benton Hills and the Lowlands as illustrated in figure 9.

Crowleys Ridge-Benton Hills Area

Bedrock is principally soft shale and sandstone. Thick soil, ranging from permeable sand and gravel to impermeable clay, exists in the upper parts of many of the hills. Clay-rich subsoils have developed where surface soil is thick.

Surficial soils in this area have low strength and moderate to high permeability. For the most part, they have been formed by wind deposition and are highly susceptible to erosion. Thickness of the windblown soil ranges from 10 to 30 feet (3 to 9 m).

The Crowleys Ridge-Benton Hills area has excellent settings for lake sites. Problems of water loss into bedrock are unlikely to occur because the predominant bedrock material is shale that is mostly impervious. However, seepage into silt-rich soil, as well as wave damage to dams made of silt-rich soil, have created some locally serious problems.



Topography from U.S. Geological Survey, Scott City 7½' quadrangle, 1963. Contour interval 10 feet (3.0 meters). Datum is mean sea level.

Figure 9

Topographic map showing the contrast in relief between the alluvial plains of the lowlands and the hilly topography of Crowleys Ridge–Benton Hills in the Southeastern Lowlands.

Lowlands

The Lowlands consist of mostly flat countryside, broken only by low relief. As noted, the soil materials range from permeable sand to impermeable clays. It is feasible to construct water impoundments much in the manner of a pond, by excavation with dragline into the water table in sandy areas. Typically, the water table is persistent at depths of 5 to 15 feet (2 to 5 m) below land surface; however, during periods of intense rainfall and flooding, water levels can be at or above the land surface. Problems associated with the creation of a water impoundment by dragline excavation include fluctuation of the water table, lack of stability of slopes adjoining the excavated lake and handling of the excavated material.

Where the soil materials are clay-rich, a lake can be constructed on the land surface. Rainfall will assist in filling and maintaining the lake. However, during seasons of low rainfall and high evaporation, pumping from wells will probably be necessary to maintain a stable waterline. In areas where parts of the proposed lake site have clay-rich soils and other segments have a somewhat permeable material, padding either with excavated clay soil or artificial sealants such as bentonite should be considered.

EVALUATION OF A POTENTIAL LAKE SITE

Examination of topographic maps is the first step in evaluating a potential lake site. Topographic maps can be used to determine the approximate size of the lake at a particular dam height, the drainage area for the lake, the gradient of the stream, the configuration of the valley, the steepness of slopes and the accessibility of the area. Local improvements such as pipelines, high tension lines, radio towers, roads, cleared land, open land, major fence lines, houses and other buildings are shown. Physical features such as streams, caves, springs and sinkholes can also be observed on topographic maps.

After an evaluation of the topographic setting, a geologic and hydrologic evalu-

ation of the proposed site should be made. The bedrock formations likely to be encountered can be determined from geologic maps, from well-log records and from publications. The surface geologic evaluation can usually be limited to a walk-through investigation to observe geologic conditions that are not evident from maps or reports of previous studies. At the same time, observations can be made of the presence or absence of springs or seeps, whether the stream is losing or gaining, the type and thickness of soil, and the characteristics of bedrock (jointing, solution features, pinnacles). Subsurface conditions at the dam or upstream can often be inferred by surface conditions downstream from the dam.

Where adverse geologic conditions exist at a proposed dam site, they can often be avoided by selecting another site a short distance upstream or downstream, thus getting well above or well below the problem. Grouting the rock or soil with chemicals or cement, padding (an earthen blanket) and proper placement of the core of the dam can often be used to offset adverse geologic conditions.

When potential problems associated with leakage and structural (lake bottom) collapse are suspected, but are not in evidence at the surface, holes can be drilled on the center line of the dam to determine the subsurface conditions. Geophysical surveys using seismic and electrical re-

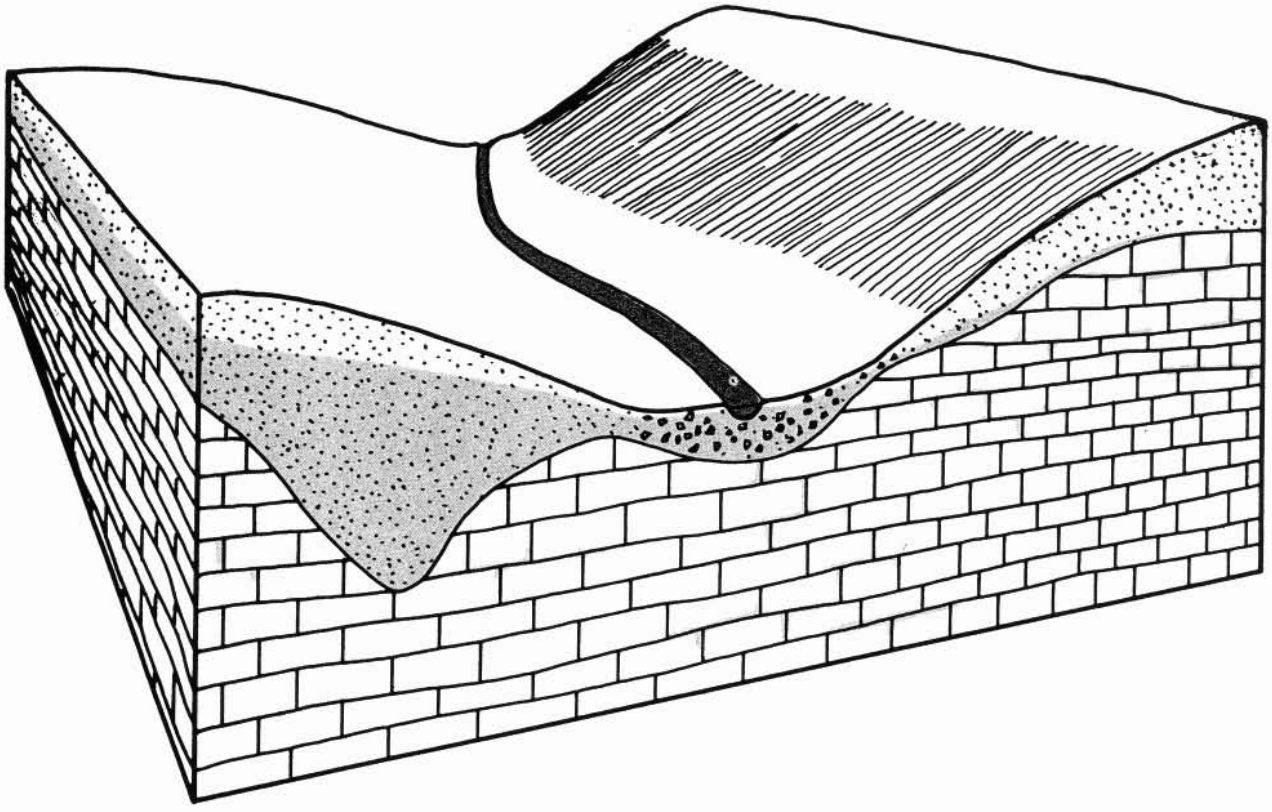


Figure 10

Schematic diagram of a valley cross section showing uneven bedrock surface.

sistivity methods may be used to complement the drilling program.

Exploration of the valley bottom to determine shallow subsurface conditions that cannot be prejudged from surface evidence (fig. 10) can often be done inexpensively with a tractor-mounted backhoe. Several holes can be excavated on the center line of the proposed dam to determine depth to bedrock, quality of material over bedrock, the presence of water, and estimate the cost of the core. Backhoe test pits can also be used to evaluate areas for borrow material for the earthen dam and core.

Very few proposed lake sites will have all the geologic and hydrologic conditions necessary to insure a successful water impoundment or, conversely, have all the conditions that indicate high risk. A combination of good and bad features is usually the case. From the economic standpoint a decision is reached by weighing the positive factors against the negative. Several sources of technical information and assistance are available to help evaluate these factors (appendix 1).

DESIRABLE GEOLOGIC AND HYDROLOGIC CONDITIONS

There are five geologic and hydrologic indicators of a desirable water impoundment site (fig. 11): 1) adequate drainage area, 2) well-defined stream channel, 3) springs or seeps in the headwater area, 4) high groundwater level, and 5) high clay content soils with impermeable bedrock.

Adequate Drainage Area

One of the most important considerations in selection of a lake site is the contributing stream flow and drainage area. In addition to the initial filling of a lake, the water level must be maintained for extended periods without rainfall. Annual evaporation and rainfall can be nearly equal for a large part of Missouri. Thus, evaporation plus normal seepage makes it most important to have an adequate water supply.

The desirable amount of drainage area or total water supply necessary to maintain a stable water level in a lake is difficult to determine. The runoff in a watershed is greatly affected by regional rainfall characteristics, topography, type and amount of vegetation, and soil and bedrock. Experience indicates that a minimum of 10 acres (4.0 ha) of drainage

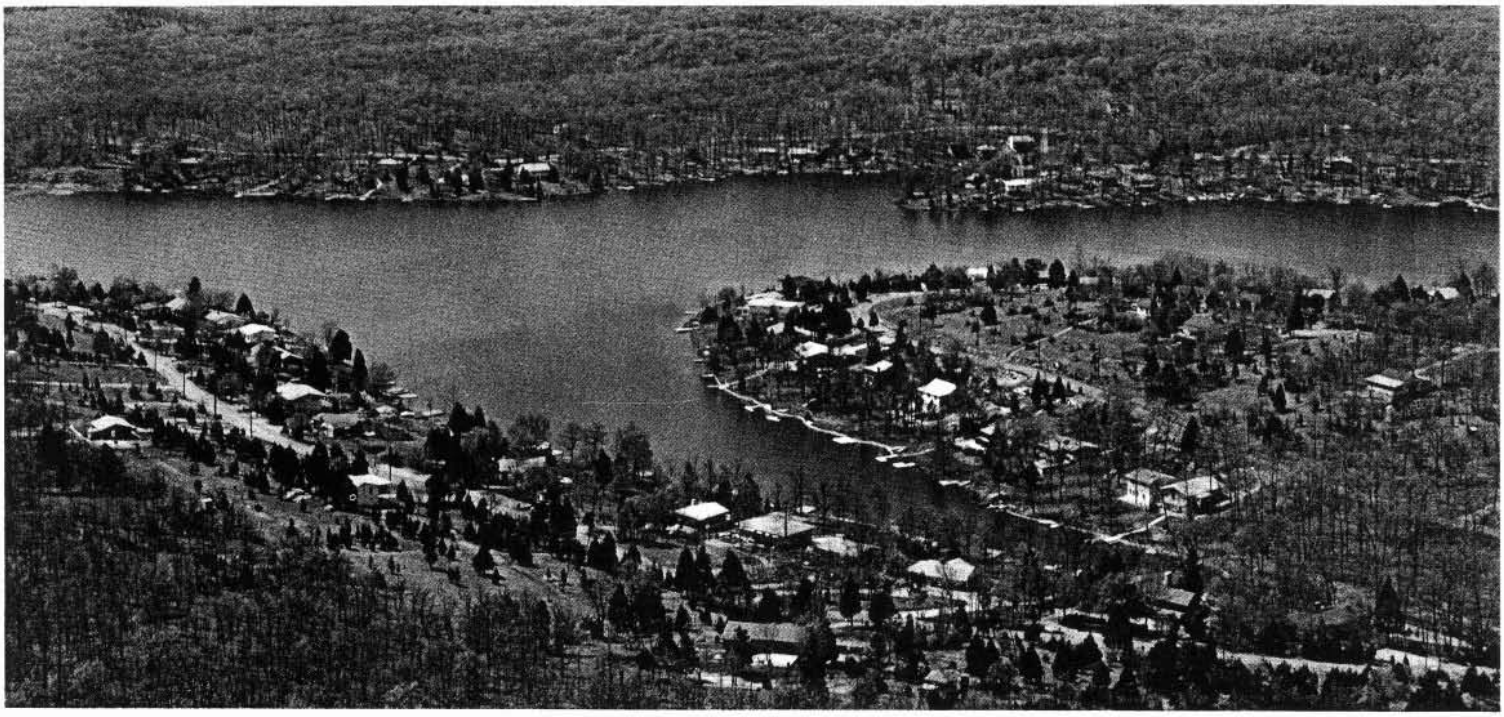


Figure 11

Successful lakes such as this, where recreation and housing developments revolve around the lake, involve a high investment. Photo by Jerry D. Vineyard.

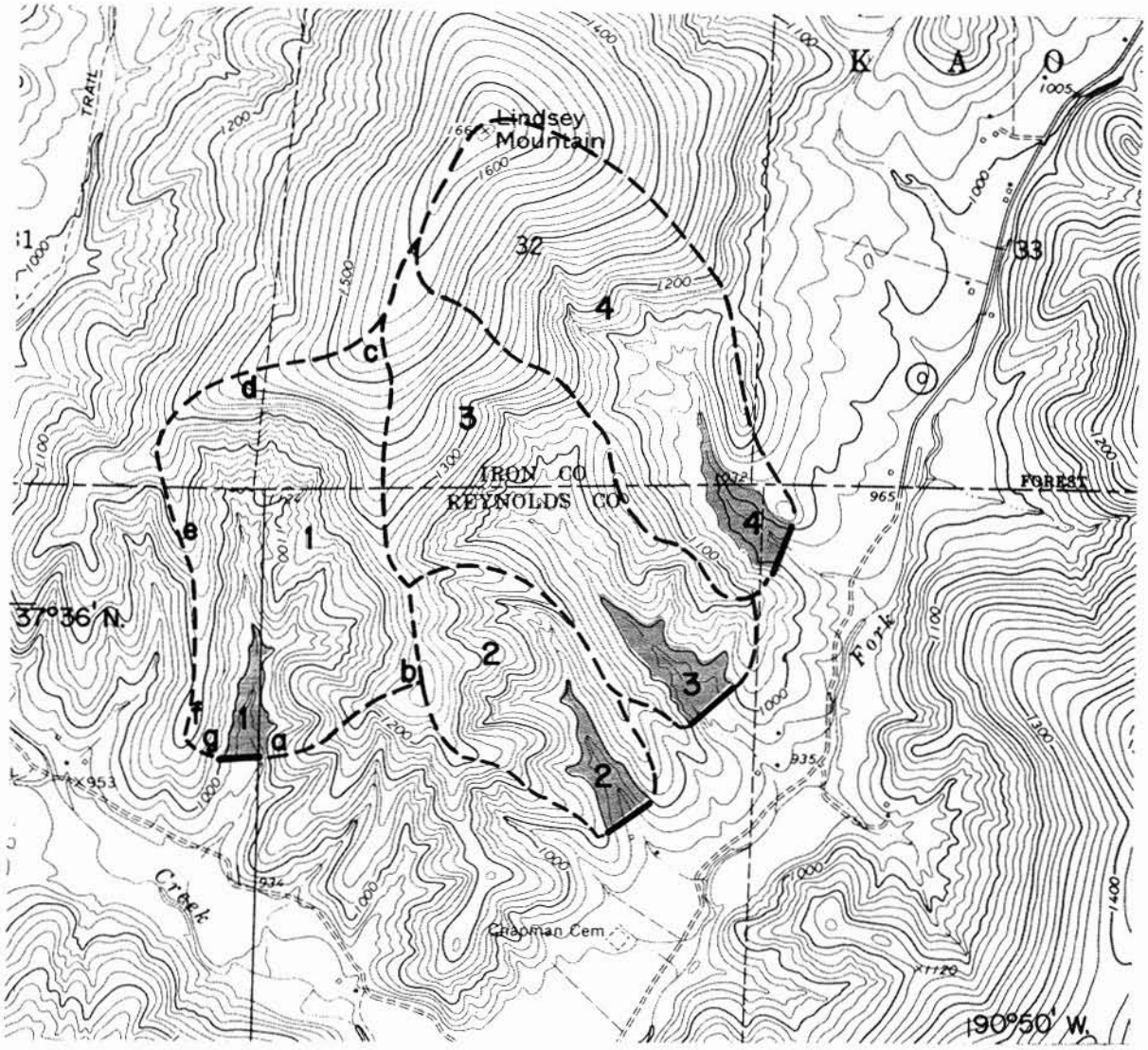
area to each acre (0.4 ha) of lake is desirable. As the drainage-area to lake-area ratio approaches 50:1, the storage capacity of the lake and spillway design become very important.

Drainage areas are easily computed on topographic maps, as shown in figure 12.

Well Defined Stream Channel With Few Abnormalities

A valley that develops normally by erosional processes is relatively narrow, has a steep gradient in the headwaters and progressively widens as the gradient decreases downstream. Resistant layers of rock or water-loss zones prevent the normal eroding or downcutting of a valley bottom. Abrupt changes in the valley width or stream gradient reflect these abnormalities, which can adversely affect the success of a lake.

A continuous flow of water is usually indicative of a relatively impermeable valley (lake) bottom. As shown in figure 13, absence of vegetation in the channel, well sorted or stratified sands and gravels, clay-rich soil zones, and terraces are indicators of a gaining reach of the stream even though the stream may be dry at the time of investigation due to climatic conditions or small drainage area. Many

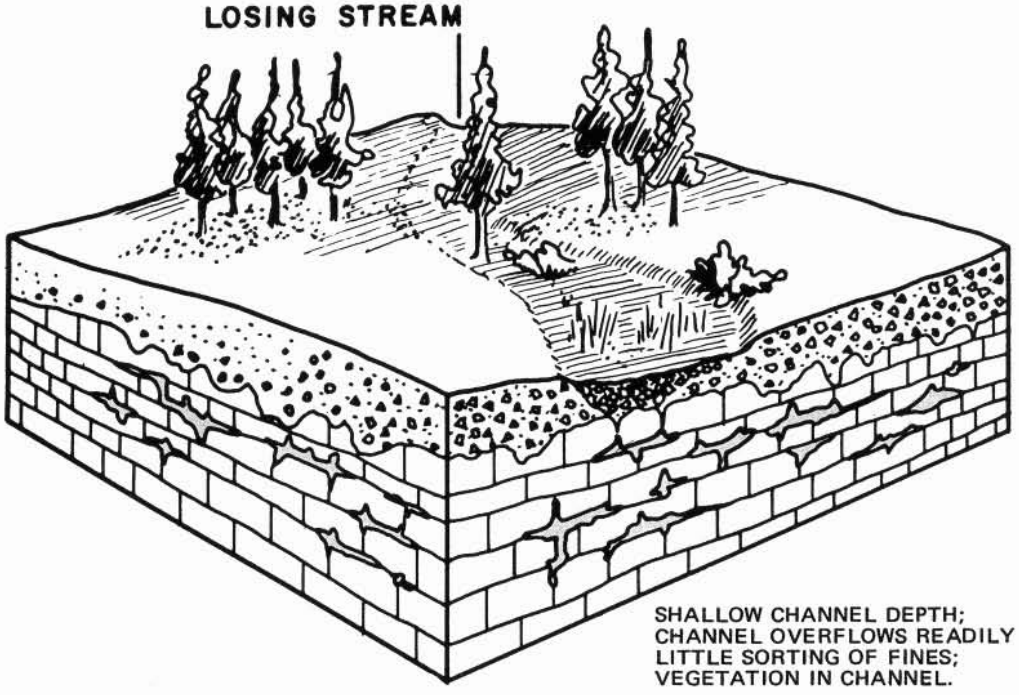


Topography from U.S. Geological Survey, Johnson Shut-Ins 7½' quadrangle, 1968. Contour interval 20 feet (6.1 meters). Datum is mean sea level.

Figure 12

Computing drainage areas on topographic maps. (Numbers 1, 2, 3, and 4 represent small lakes and their corresponding drainage areas.) To draw the drainage area for lake no. 1, start at the dam at point (a), go up the valley wall to the right to the ridgetop at point (b), then go up the ridge line to point (c), follow the ridge to the left through points (d, e, and f), then drop down the valley wall to point (g), the other end of the dam. You have followed the ridge line around the lake and have outlined the drainage area. Follow the same procedure for lakes 2, 3, and 4.

On this scale map, a grid pattern of squares 5/16 inch (7.9 mm) on each side divides the area into 10-acre plots. Drainage area no. 1 has approximately 23 squares or 230 acres of drainage; no. 2, 110 acres; no. 3, 210 acres; no. 4, 220 acres.



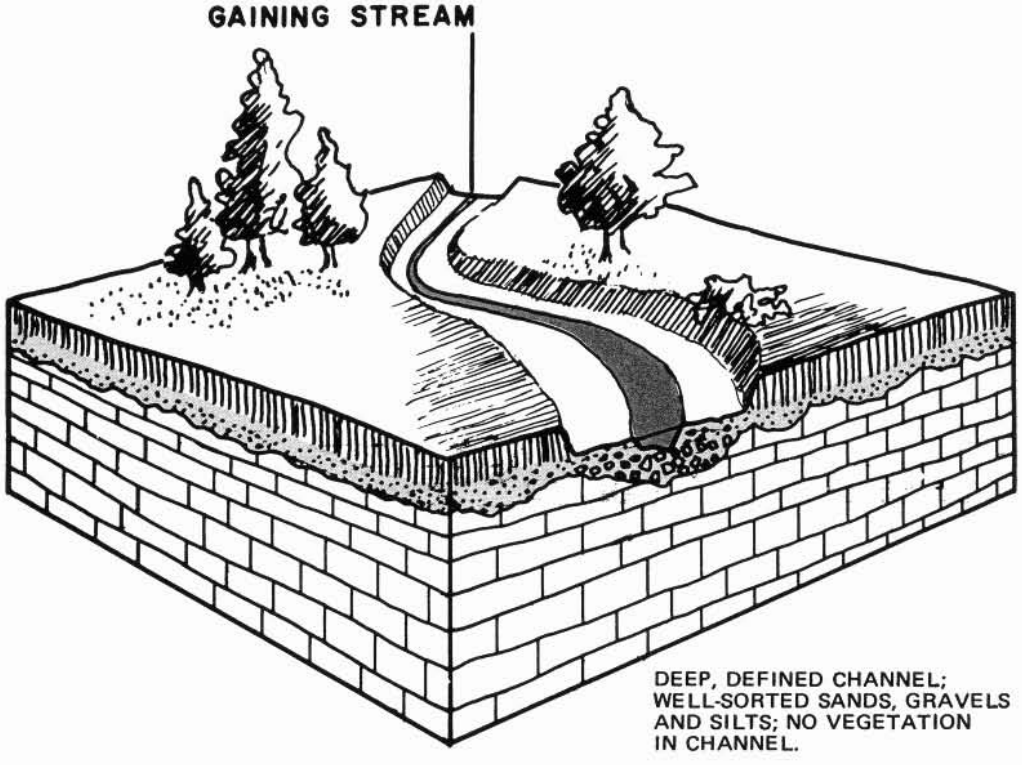


Figure 13

Schematic diagrams of valley cross sections showing a poorly defined channel (losing stream) and a well defined channel (gaining stream).

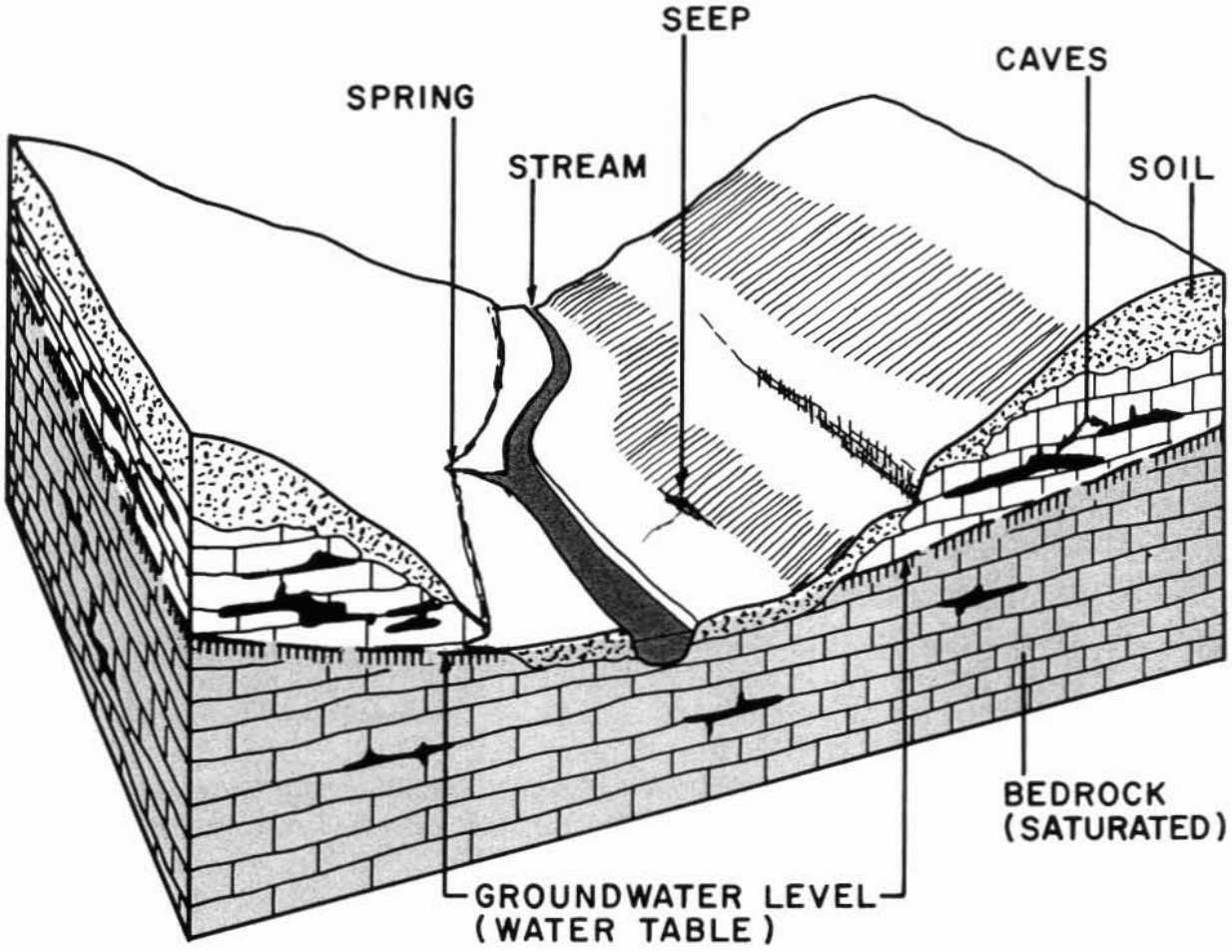


Figure 14

Schematic diagram of a valley which intersects the groundwater level.

other factors are considered in the evaluation of a stream channel, making the overall assessment one of observing many phenomena along the stream as well as within the watershed area.

Springs or Seeps in the Headwater Area

Springs and seeps upstream from the lake site are related to bedrock permeability. The surrounding countryside is discharging water to the valley (discharge area) instead of the valley discharging its water to the surrounding countryside (recharge area). The probability of the valley (lake) holding water is greatly enhanced by these features. If the stream is perennial, springs may be contributing to this flow. The absence of springs may indicate that water in the uplands is seeping into the ground and escaping down valley as underflow.

High Groundwater Level

Springs, seeps and perennial flow are evidence of a high water table level in many cases. A water table that is high enough to be intersected by a valley is likely to cause a perennial flow into the stream as shown in figure 14. Springs and seeps are ground water being discharged at the surface. Perennial flow caused by high water-table level does not always indicate impermeable bedrock in the valley bottom.

High Clay Content Soils With Impermeable Bedrock

Thick glacial till soils (Area 1), thick alluvial gumbo clays (Area 5 and flood plains of Area 2), and relatively impermeable shale bedrock (Areas 2 and 3) provide ideal lake sites, geologically. Residual clay soils (Area 2) vary considerably in their permeability, depending in part on their development history. A judgment of their relative water-holding capability must be carefully made and may require laboratory testing procedures.

Glacial till varies in consistency from sandy, silty clay to gravel and boulder clay. Most tills can be considered impermeable unless large pockets of sand or gravel are present.

Thick gumbo clays (Area 5) are impermeable and provide excellent material for lake construction where topography is suitable. The lateral persistence of the clay should be verified prior to construction, as permeable beds or pockets of sand can be associated with the clay.

The shale bedrock of Areas 2 and 3 makes excellent lake bottoms. The vertical and horizontal permeabilities of the shale are very low. Limestone bedrock, usually associated with the shale, is commonly fractured and can transmit water horizontally.

UNDESIRABLE GEOLOGIC AND HYDROLOGIC CONDITIONS

There are many geologic and hydrologic conditions that are indicators of undesirable water impoundment sites. Most of these are related to: 1) dry, poorly defined stream channel, 2) low groundwater level, 3) karst topography, 4) pinnacled bedrock, 5) severe jointing, 6) springs downstream from the dam site, and 7) coarse textured material in the valley bottom and slopes (fig. 15).

Dry, Poorly Defined Stream Channel (losing stream)

Generally, a dry, poorly defined stream channel, as shown in figure 13, is

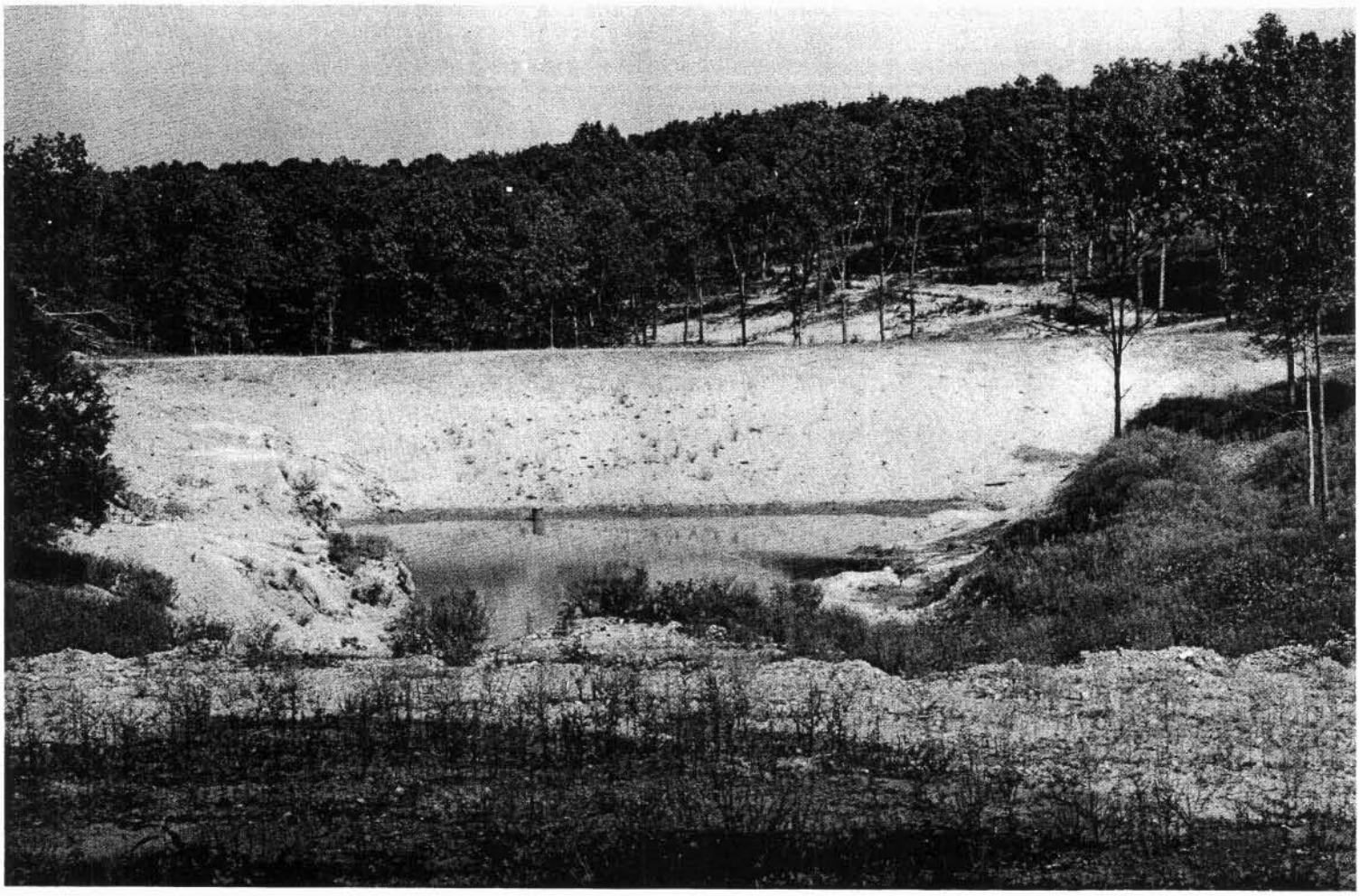


Figure 15

This obviously unsuccessful lake should never have been constructed in this location because of adverse geologic conditions. It would be uneconomical to repair. Photo by David Hoffman.

an indicator of a losing stream. Vegetation growing in the stream channel; unsorted alluvial material with boulders and gravel; and a very small channel in relation to the size of the drainage area are all characteristics of a losing stream. Absence of terraces, angular topographic profiles and a host of other surface features aid in the identification of losing streams. When water from rainfall enters the valley, it seeps underground into thick gravels or into bedrock openings. In the absence of surface flow the gravels and sand (alluvium) are not carried away and little sorting of the alluvium takes place. Vegetation grows in the channel and the streambed is not always clearly defined.

Investigation downstream may reveal how deep the lost water goes before it starts moving horizontally. If the water

reappears a short distance downstream from the proposed dam, the water-loss zone may be shallow and can be intercepted by the core of the dam. If no reappearance is noted downstream, the lost water might be going very deep or possibly leaving the valley under the valley walls. In this case, the lake site would be considered unfavorable for water impoundment.

Low Groundwater Levels

A low groundwater level has many causes, but generally it reflects conditions that are undesirable for lake sites, For example, a site underlain by cavernous bedrock with a low groundwater level would make a poor setting for a lake.

Information on groundwater levels can be obtained from nearby water wells or well logs. If wells indicate a low groundwater level and the valley and its stream have not developed normally, the basin is probably very permeable and would not hold water.

Karst Topography (Sinkholes and Caves)

Karst topography is characterized by the presence of numerous sinkholes and caves which indicate very high permeabilities in the soil and underlying bedrock. As shown in figure 16, a sinkhole is simply an area where the roof of a cave has collapsed. Water moving in the cave carries away the fallen debris and the sink enlarges itself until it is stable, usually resulting in an inverted cone-shaped depression. The depth of sinkholes varies considerably from place to place, but in Missouri a depth of from 70 to 80 feet (21 to 24 m) is not uncommon. This depth may well put the cave at or below the valley bottom.

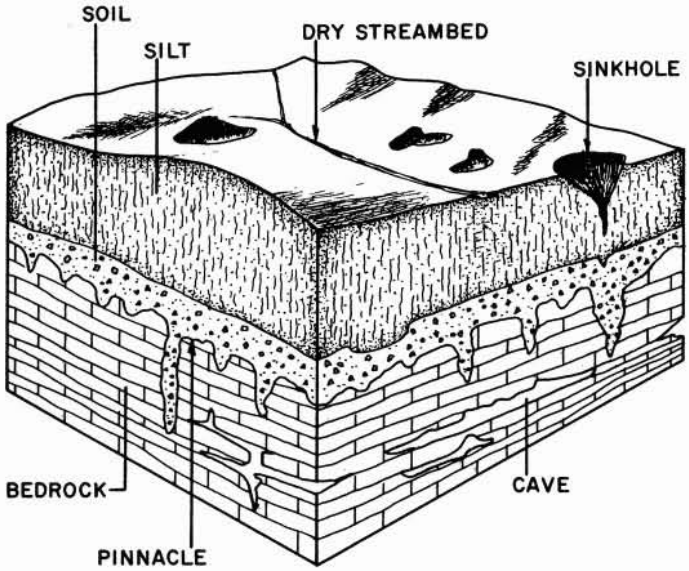
The orientation of the cave and its relationship to the valley cannot always be determined. The cave may parallel the valley, be at right angles to it, be above the valley bottom, or well below it. Caves are natural outlets for water, so where sinkholes exist at or near a proposed lake, the site is considered geologically unsuitable.

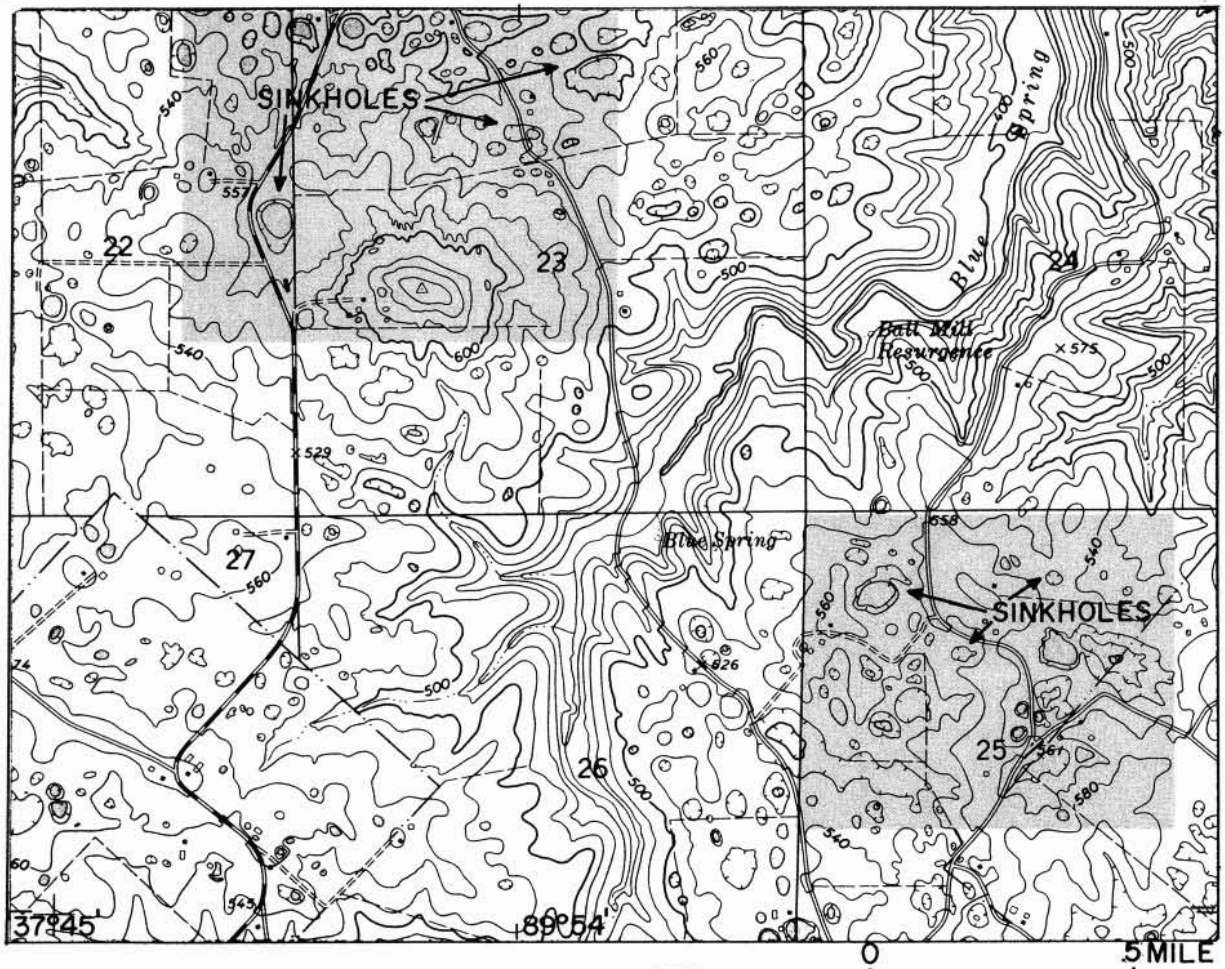
Pinnacled Bedrock

Pinnacles (spire-shaped pillars of rock) are formed by solution along joints or cracks in the bedrock, or by differential weathering caused by abnormalities present in the rock. This phenomenon is not too unlike the sinkhole-cave relationship. The space between the pinnacles is not expressed on the surface as a depression, but rather as a filled depression (fig. 16). Thus, there may be no surface evidence of the problem. Bedrock may be present at the surface at one point, but 20 to 30 feet (6 to 9 m) away the soil may be many feet thick. The thick soil filling the crevice between the pinnacles is usually very permeable and may result in serious water loss from the lake (fig. 17).

Severe Jointing

All bedrock is fractured or jointed to some degree, but most joints are very small and cannot be seen except on close examination. These cracks are generally of little concern. Large joints, however, can cut entirely through a hill or





Topography from U.S. Geological Survey, Lithium 7½' quadrangle, 1970
Contour interval 20 feet (6.1 meters) Datum is mean sea level

Figure 16

Schematic diagram showing karst features (including sinkholes) and solution work in joints and bedding planes. The topographic map shows karst features.

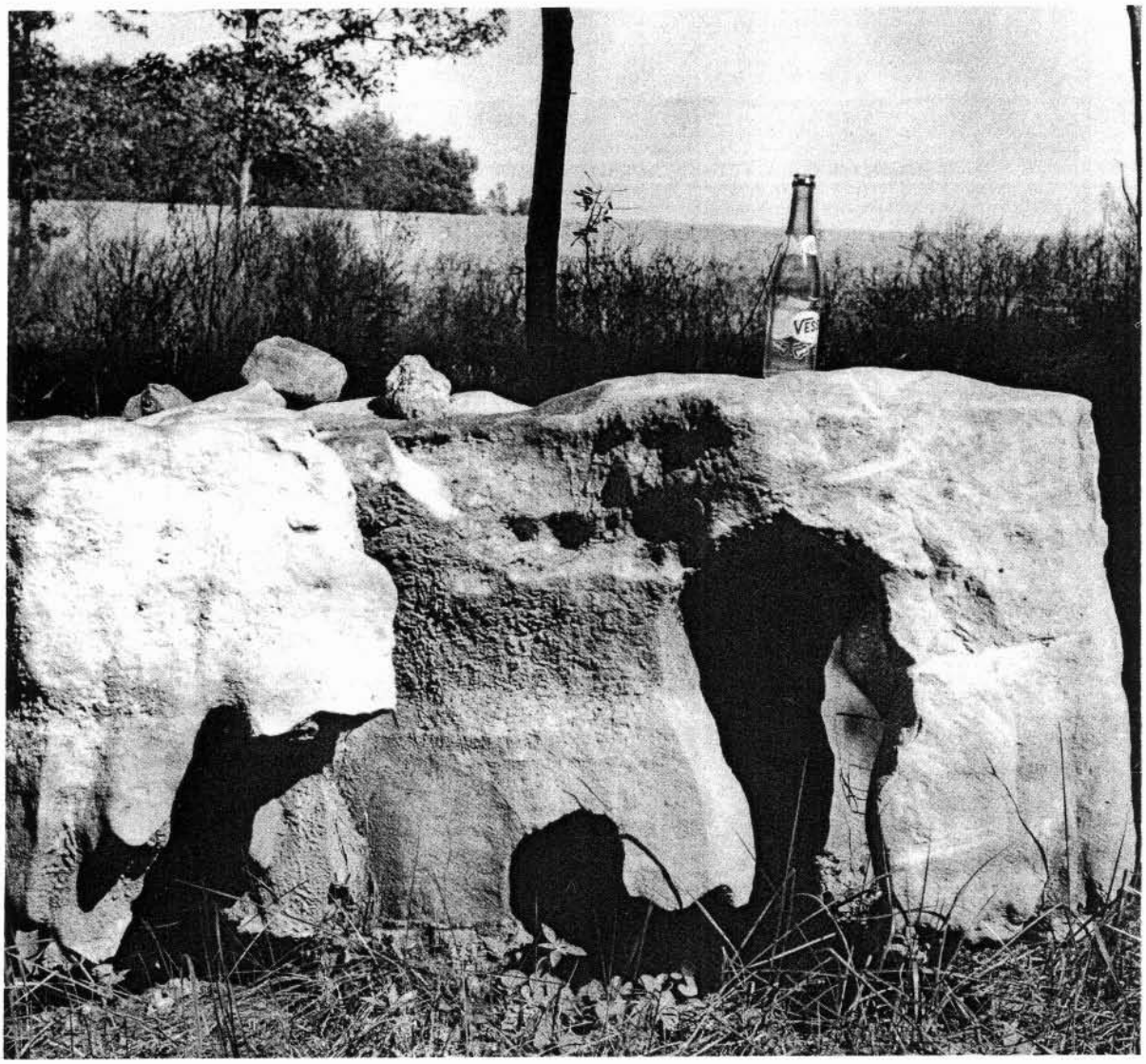


Figure 17

Solution work caused by running water makes for a permeable lake bottom. Photo by Jerry D. Vineyard.

ridge and become natural outlets for water. Slumping of large blocks of rock downhill may cause the joints to open up to crevices of several inches to several feet in width. Severe jointing, like pinnacled bedrock, is not readily noticeable from the land surface, but can usually be suspected from joint development in nearby bedrock exposures. Where soil cover is uniform, however, the problem may be overlooked unless subsurface exploration is conducted.

Springs Downstream from the Dam Site

Springs downstream from the dam site are indicators of a geologic condition

that has contributed to the failure of numerous lake projects. The spring is a natural outlet discharging water collected from several small underground feeder systems. Hence, the chance of impounded water in the lake finding its way into one of these systems and from there into the main channel of the spring is very great.

There are generally two types of downstream springs. One is the alluvial spring in which water is lost from the stream into the alluvium upstream, flows at shallow depths through the alluvium and reappears downstream. The other is the bedrock or bedding-plane spring in which water moves vertically into the alluvium and bedrock, then horizontally through the bedrock and emerges at an outlet down-stream. In an alluvial spring the water can usually be intercepted with a properly designed core under the dam. However, water moves at much greater depths in a bedrock spring system and is often difficult or impossible to intercept. Therefore, the dam should be placed well below or downstream from a bedrock spring outlet.

Coarse Textured Material in the Valley Bottom and Slopes

Most valley slopes in bedrock areas have a natural clayey soil cover if the slopes are gentle enough so that erosion does not remove the soil as fast as it forms. In the valley of a losing stream the floodplain normally has a coarse textured soil composed of silts, sands and gravels overlying bedrock. If both the slope soils and alluvial soils are coarse grained sands and gravels, leakage problems are common. The sorting of slope and alluvial soils assists in determining the classification (losing or gaining) of the stream, as mentioned previously.

Glacial soils (Area 1) have pockets or lenses of sand and gravel, as shown in figure 18, which cannot always be predicted from surface evidence. These coarse textured materials create serious leakage problems where they are located in the valley slopes or lake bottoms.

The best assurance against water loss from a lake, whether it is rapid flow or slow seepage that affects the waterline in dry weather, is a fine grained, plastic clayey soil 4 to 5 feet (1 to 2 m) in thickness covering the bedrock or sand and gravel deposits on the valley slopes and bottom. This pad of material would help prevent water from entering the permeable bedrock to be transmitted around or under the dam, or through the hill to the next valley.

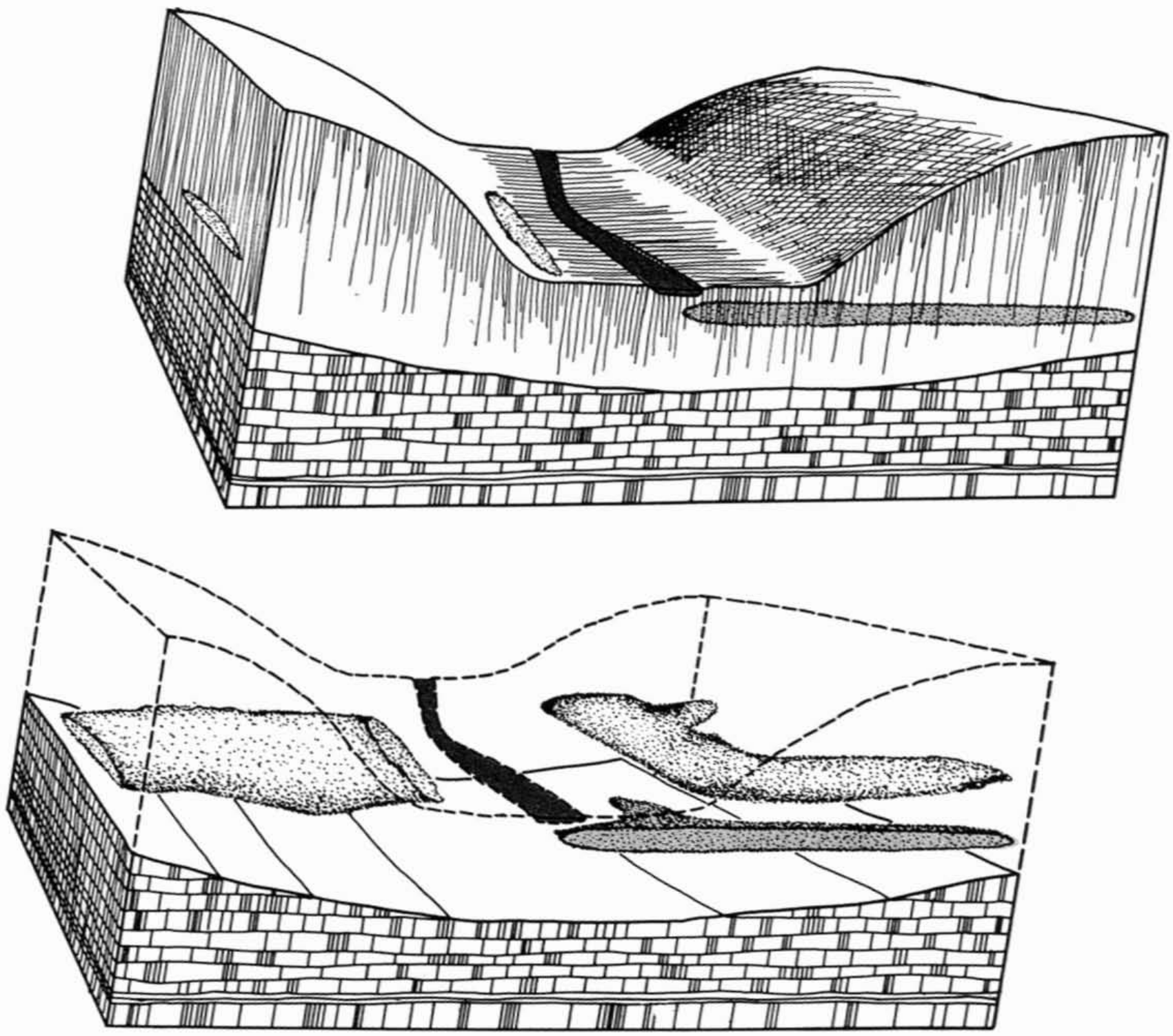


Figure 18

Schematic diagram of a valley cross section with sand pockets in glacial till and deep alluvium.

CONSTRUCTION CONSIDERATIONS

Specifications concerning dam construction are numerous and varied, but most concern the stability of the dam and its ability to impound water. Two important details relating to the prevention of leakage should be considered. The first is the construction of the core of the dam, and the second is the source of the borrow material to be used for the earthen dam. Inadequate location, excavation, and placement of the core may be the most important cause of the failure of water impoundments.

THE CORE AND CORE TRENCH

The core or impermeable central part of the dam (fig. 19) is extended downward to provide an underground barrier to water movement. Its purpose is to intercept water that would normally go under or around the dam. If a dam is constructed on top of alluvial material in the valley bottom, and the ends of the dam are constructed on colluvial soils on the valley slopes, water will probably flow around and under the dam through these permeable materials.

The core trench is constructed across the valley bottom to a depth at which it is seated in a relatively impermeable layer of clay or bedrock. In general, 5 or more feet (2 or more m) of clay overlying bedrock in the valley bottom is necessary to prevent vertical percolation of lake water into the bedrock. This, of course, varies with the depth of the lake and type of clayey material. The core should be seated several feet into the clay layer. Water which penetrates the upper alluvial sands and gravels will travel laterally on the surface of the clay layer, and be cut off or intercepted by the core under the dam.

If a clay layer does not exist and permeable sand and gravel extend to weathered bedrock, it is necessary to seat the

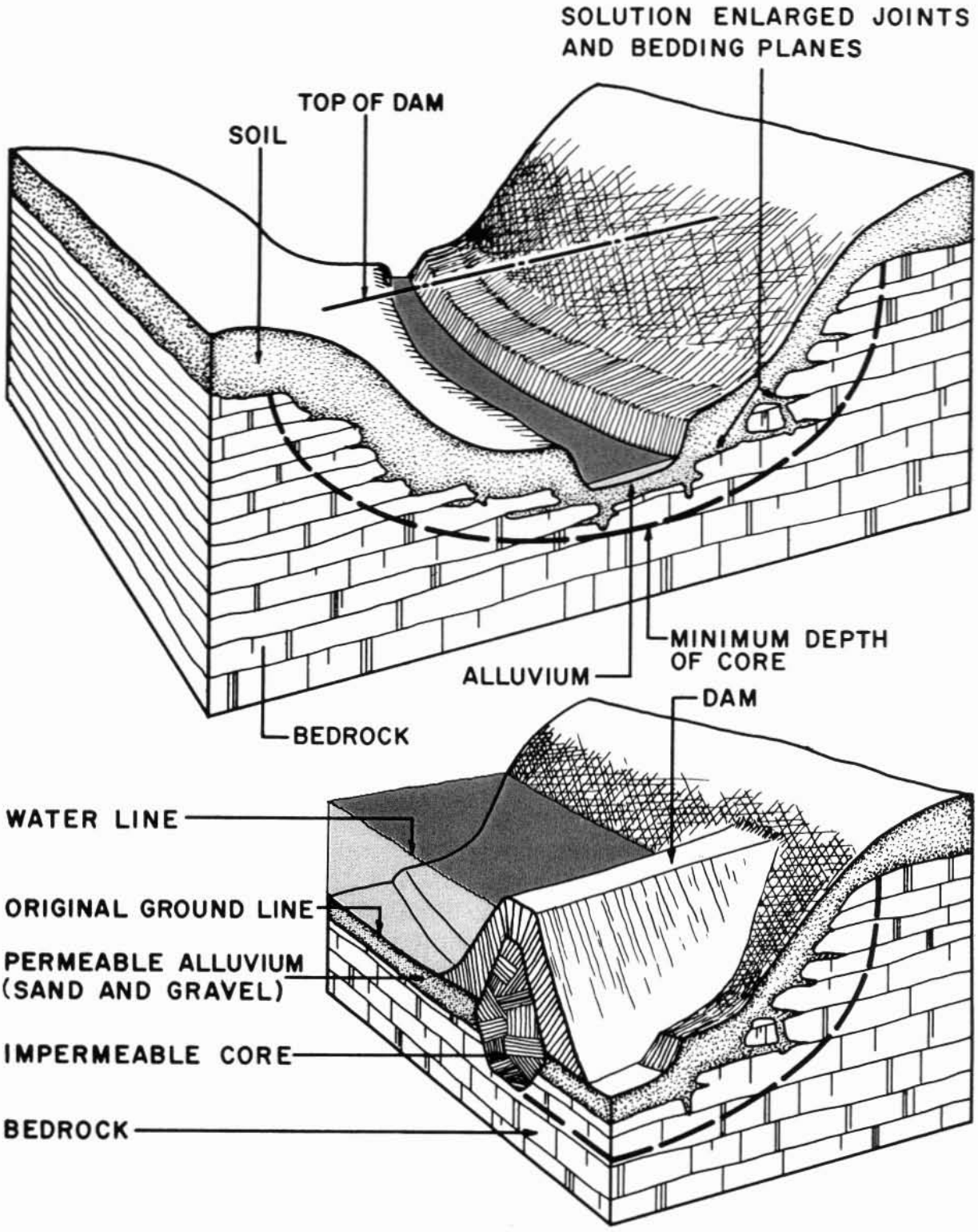


Figure 19

Schematic diagram of the core of a dam.

core into unweathered bedrock to a depth of several feet. The upper 2-6 feet (1-2 m) or more of bedrock in the valley bottom is usually very weathered and allows large quantities of water to flow through solution-enlarged openings between rock layers. The core must penetrate deep enough to intercept this water.

The first rock encountered below the alluvium may be a layer of hard erosion-resistant rock. The stream, in its perpetual quest to cut the valley deeper, will have little effect on that hard rock layer, but will erode the rock layer underneath if it is softer or more soluble. If the subsurface erosion progresses far enough, the stream will flow through the underground openings and the surface stream channel will be dry. If the underground flow reappears downstream, it is possible that it can be intercepted by a properly placed core, thus eliminating the earlier mentioned problem of a losing stream. However, it may be more practical to select a new dam site downstream from the resurgence than to create an artificial barrier in the form of a deep core.

The core in the abutment areas (valley slopes) is constructed similarly to the core in the valley bottom because it serves the same purpose. The exposed bedrock is typically weathered 2 to 4 feet (about 1 m) back into the valley slopes. Whenever a clay layer 5 feet (2 m) or more in thickness does not cover the bedrock on the valley slopes the core should extend several feet into the bedrock because water might enter the rock somewhere within the lake basin and flow around the dam. Excavation should proceed until the individual thin beds of rock become indistinct and the rock appears massive. Clay for the core is then packed on firm, fresh rock.

An impervious core is useful for all dams, but is especially useful to prevent most leakage problems caused by geologic deficiencies present in the valley bottom and slopes.

SOURCE OF BORROW MATERIAL FOR THE CORE AND DAM

After the core trench has been excavated to the proper depth, it is backfilled and compacted with the best-quality clay-rich soil available. A relatively large amount of soil is also needed for the construction of the earthen dam.

If possible, borrow material for the core and dam should be obtained from sites above the potential waterline of the lake. Clayey soils present on the lower slopes and valley bottom should not be disturbed because they act as a natural

pad or barrier that prevents water from entering the weathered bedrock. To make the natural pad more effective the stream channel, which is usually devoid of clay material, should be filled to general flood-plain elevation with borrow material. This gives added protection to the core in the deep water part of the lake. The slopes above the waterline, the shallow water area of the upper end of the lake, and the ridge areas usually will provide adequate quantities of borrow material.

Figure 20

Extensively weathered areas resulting in extremely permeable bedrock (where caves and sinkholes are likely) are not good water impoundment settings. Photo by David Rath.

PHYSICAL FACTORS THAT AFFECT CONSTRUCTION COSTS

The decision to build a lake is usually made after comparing the cost of impounding water with the benefits to be gained from the impoundment. Construction costs are a major consideration, especially if factors are present which substantially increase the costs.

The expenses incurred during lake site evaluation may be significant if test drilling is done. However, these costs are considered a necessary investment because the evaluation determines the suitability of the site and reveals factors which influence construction costs.

In areas of low relief, such as in the Western Plains, the valleys are wide and require long dams which increase the cost per acre of water.

Whenever a dam is constructed across a valley where bedrock is at or near the surface, rock excavation is needed to seat the core of the dam in unweathered bedrock. Conversely, if a dam is constructed over thick, permeable alluvial material, the core has to extend to considerable depth to prevent water from flowing under the dam. In either instance, costs will increase considerably with the amount of excavation that has to be done.

Another factor which affects construction costs is the proximity of borrow material for construction of the core and dam. In some instances impermeable materials may have to be hauled long distances because available material is either too permeable or lacking in quantity (fig. 20).

Considerable expense may be involved in recording, grouting, or padding that is done to prepare a site for water impoundment or to repair a leaky impoundment.

Some types of bedrock and soil materials are unusually abrasive to construction equipment, particularly tires and cutting blades. Examples of such materials are the hard igneous rocks in the St. Francois Mountains and alluvial deposits with a high percentage of gravels and boulders in some parts of the Ozarks. Where these conditions exist, higher construction costs are necessary to offset the increased costs of maintenance on equipment.

REPAIRING LEAKING IMPOUNDMENTS

If leakage from a lake occurs, several remedial measures are available. Recoring if the water loss is shallow, grouting if the loss is deep or not precisely known, and padding if the lake is very small, or a combination of the three are the most effective methods of repairing leaky impoundments. Repair work may be totally in vain, especially if the conditions causing the leakage are not fully understood.

RECORING THE DAM

If a dam is built without a core or the core is ineffective, recoring may be the most effective method of repair (fig. 21). Water loss around or under the dam may be cut off or intercepted by placing a new core near the upstream toe or the downstream toe of the dam if the water loss zones can be located. If possible, the core should be on the upstream toe because downstream cores can lead to severe piping of water through the dam and possible catastrophic failure at a later date.

GROUTING

If the area of water loss cannot be precisely located and recoring is infeasible because of recurring rainfall, depth of leakage or other physical construction problems, grouting may be the most practical solution. In grouting a leaky dam,

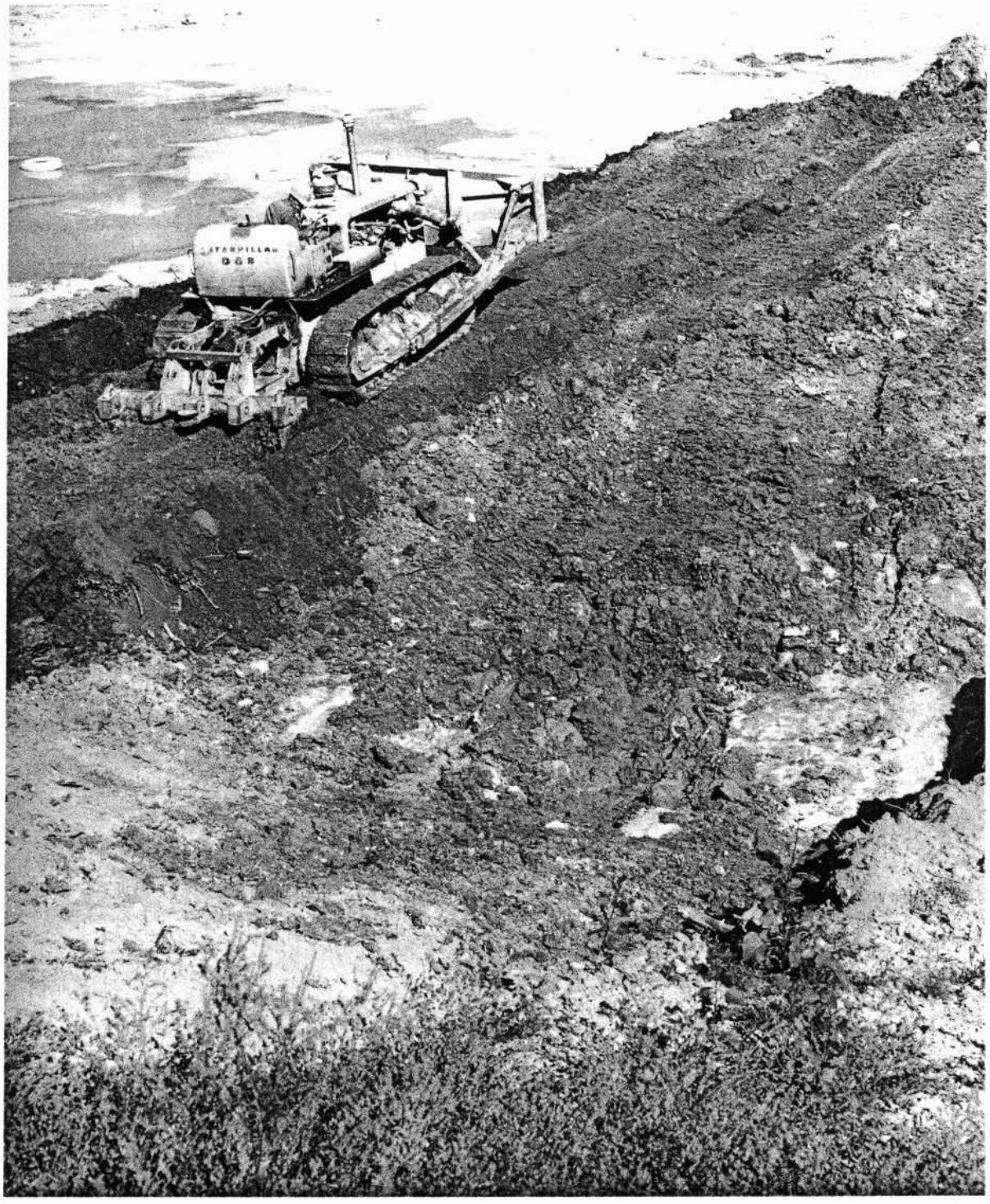


Figure 21

A leaky lake can sometimes be repaired by sealing the permeable limestone rock in the lake bottom. Photo by Jerry D. Vineyard.

holes are drilled into the dam and/or abutment areas and cement or chemical grout is pumped down the holes. The liquid grout moves as water does through the interconnected voids in the rock or soil and, when it hardens, providing a grout curtain or core.

PADDING

If the water loss zone within the lake basin can be located, an impermeable earthen blanket or pad compacted over the zone of seepage can be effective in preventing water from entering the bedrock. Padding is used mainly in very small lakes where the entire basin below the waterline can be covered (fig. 22).

Figure 22

To prevent leakage under a dam, a clay pad can be put in the lake bottom. Photo by Jerry D. Vineyard.

PROBLEMS IN LAKE DEVELOPMENT OTHER THAN LEAKAGE

Once a lake is full of water for a period of time, several changes take place in the surrounding area that can affect the lake. The soil and rock on the valley slopes and under the dam become water saturated, the valley is restricted because of the dam, and the lake traps sediment and nutrients. Problems related to these changes include the collapse of the lake bottom, collapse of the dam, landslides into the reservoir, eutrophication and siltation of the lake.

COLLAPSE OF THE LAKE BOTTOM

The collapse of a lake bottom is a sudden event. The collapse is usually caused by a change in the water level in the shallow subsurface. If a cave or other void exists in the soil or bedrock at a shallow depth below the lake, saturation of the roof of the void may weaken it to the point where it cannot support itself and collapse takes place. Such collapses can usually be predicted by geologic investigations before lakes are constructed (fig. 23).

DAM FAILURE

Overtopping of a dam during intense rainfall is perhaps the greatest cause of dam failure. Inadequate spillways, lack of adequate storage in the lake, and too-large drainage areas are the principal causes. Once the capacity of the spillway

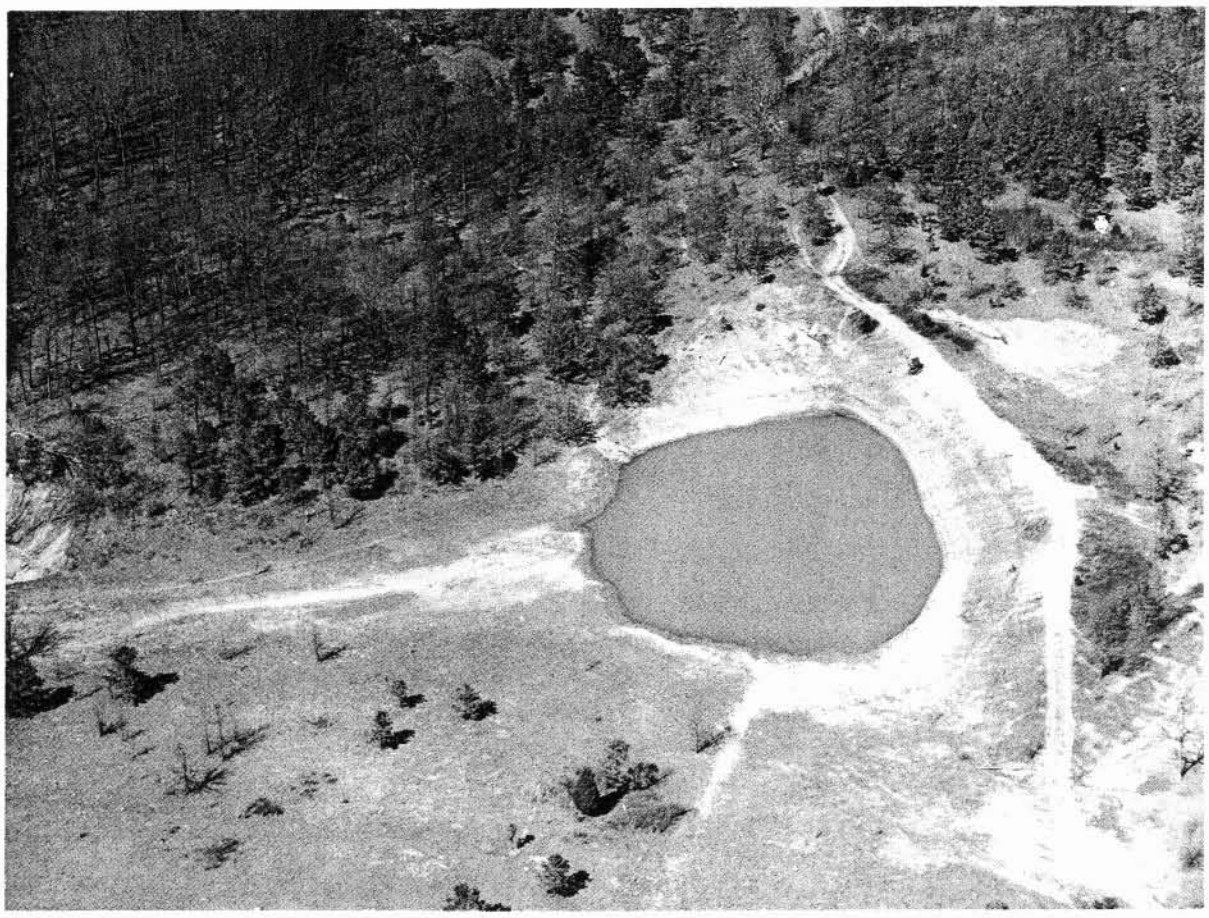


Figure 23

The potential for collapse of the bottom of this lake could probably have been predicted by a preconstruction investigation. Photo by Jerry D. Vineyard.

is exceeded, water flows over the earthen dam and can cause severe erosion. If the erosion progresses below spillway elevation, the dam may be destroyed due to further downcutting by lake water. If the water level in the lake is lowered fast enough, the saturated dam can collapse under its own weight.

Building a dam with slopes that are too steep can cause severe problems at a later date. After the dam becomes saturated, the steep slopes lose their strength, and sliding or flowing of the soil takes place. This action steepens the slope even more and further sliding can be expected. Continuation of the sliding can cause dam failure. When a dam is in this condition, overtopping can be disasterous.

Cracks that form on and within a dam from sliding and settlement are natural channels for the flow of water. Enlargement of the cracks by erosion contributes to an already weakened condition of the dam.

LANDSLIDES INTO THE RESERVOIR

Soils on valley slopes are usually relatively stable. However, when a lake is built the soil at and below lake level becomes saturated, effectively reducing its weight by the bouyant effect of the water. This can cause the soil to become unstable and slide downslope either slowly or rapidly to fill or partly fill the reservoir. If the slide is rapid, the waves that are generated can overtop the dam.

The thick, clayey tills, soft shales and deposits of loess in the northern part of the state are particularly subject to this phenomenon.

EUTROPHICATION

Lakes are dynamic systems constantly undergoing change. Eutrophication, the natural process of aging or maturing of a lake, occurs in all lakes, and under natural conditions progresses very slowly. Nutrient enrichment and sedimentation are the primary contributors to the aging process. A lake which is rich in nutrients produces large amounts of aquatic plants. Dead plants and sediment accumulate on the bottom. Encroachment by shoreline vegetation reduces the lake size, and the lake finally becomes completely filled.

Artificial enrichment due to man's activities may reduce the life of a lake by greatly accelerating the rate of eutrophication.

Rapid nutrient enrichment may render a lake unsuitable for its intended purpose. For instance, dense algal growths appear when a lake is excessively enriched. Dead algal cells give the water a brownish color and may impart disagreeable odors. As the algae are decomposed, oxygen depletion occurs and the oxygen levels may decline enough to disrupt lake ecology or, in severe cases, cause fish kills.

A lake acts as a nutrient trap. In addition to the incoming supply, large amounts of nutrients are released from decaying plants, compounding the problem.

An excess of nutrients is most commonly leached into a lake from domestic sewage, livestock wastes, and fertilizers. Domestic sewage, even when given secondary treatment, contains large amounts of plant nutrients and is a source of lake enrichment, especially in real-estate developments. Leachate from septic tanks and leaking sewer lines can quickly

cause prolific growths of algae. Livestock wastes can also be a major cause of enrichment, especially when feed lots exist in a lake's watershed. Fertilizers applied to lawns, golf courses and farms are a constant source of smaller amounts of nutrients.

Accelerated eutrophication is difficult to control without causing serious damage to the ecology of a lake. Even when nutrient sources are brought under control, nutrients already trapped in a lake can remain available for several years.

Possible sources of nutrients resulting from man's activities should be investigated before a lake is constructed. If possible, nutrient sources in a lake's watershed should be controlled before the dam is closed and the lake begins to receive runoff from the watershed. If lake development includes plans for housing, the plans should include a sewage system designed to keep sewage leachate out of the lake. Fertilizing of lawns, golf courses, and fields should be minimized.

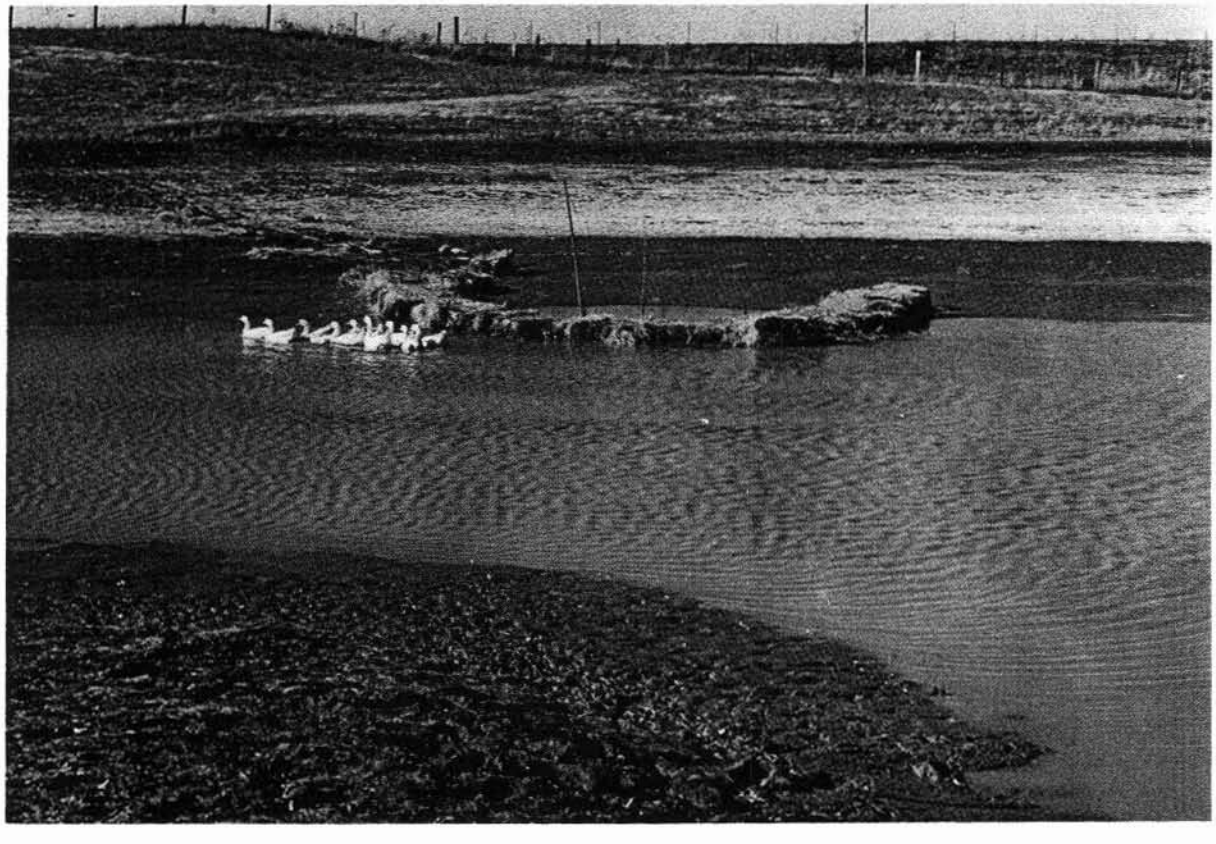


Figure 24

Siltation of a lake can quickly destroy its usefulness. Photo by Jerry D. Vineyard.

SILTATION

Intense rainfall in areas of erodible soil can cause the filling of a lake with sediment in a very short period of time. While erosion is a problem in the Ozarks, more severe conditions exist in the northern and western parts of the State and on Crowleys Ridge in the Southeastern Lowlands.

Denuding of the ground surface during farming operations and construction are the principal causes of severe siltation (fig. 24). Placing siltation basins or traps upstream from the lake and keeping vegetation in the watershed help prevent sediment from entering the water. A grass filter at least 100 feet (30 m) wide should be left around the edge of a lake. It is even more preferable to leave the entire watershed in grass or timber.

SUMMARY AND CONCLUSIONS

Missouri has a variety of topographic and geologic settings in which small lakes can be constructed. A variety of geologic and hydrologic problems also exist, which makes proper planning and management very important for successful lake development. Early recognition of potential problems and assessment of their severity are necessary in order to judge the quality of a lake site and accurately estimate construction costs. The advice and guidance of experts are often required.

A thorough evaluation of each lake site is very important, because rarely is a site free of all undesirable geologic and hydrologic conditions. Topographic maps and field reconnaissance can be used to locate most undesirable as well as desirable conditions. Drilling, although costly, may be needed to investigate subsurface conditions. Even poor lake sites can usually be made to hold water if sufficient funds are available to correct the problems. However, the economic feasibility of lake development must usually be decided by weighing the benefits to be derived from the lake against correcting the undesirable conditions.

Two important considerations in the construction of a dam are the core and the source of borrow material for the core and earthen dam. The core is designed to intercept water that would normally go through, under, or around the

dam. Its proper location, excavation and placement are often the most important factors in successful water impoundment. Clayey soils present on the lower slopes and valley bottoms should not be used as borrow material because they act as a natural barrier to water loss. Borrow material should be obtained from above the waterline of the lake.

Recoring the dam, grouting and padding are remedial methods commonly used to repair leaking impoundments. However, remedial methods should not be depended on to make an unsuitable site work because they are costly and often fail unless the problems associated with leakage are fully understood. It should be emphasized that proper location and construction of the core and dam and proper source of borrow material will often eliminate the need for any remedial work.

Whenever a dam is built and water is impounded for a period of time, changes take place in the surrounding area which can result in problems other than leakage. Collapse of the lake bottom, collapse of the dam, landslides into the reservoir, accelerated eutrophication, and siltation are problems which can occur after a lake is filled, but should be considered before a lake site is selected.

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APPENDIX I

SOURCES OF TECHNICAL INFORMATION AND ASSISTANCE

Several state and federal agencies in Missouri assist landowners, governmental bodies and other agencies through various programs. Although most aid is in the form of technical assistance, some financial help is available through various cooperative programs.

Information on proposed lake site geologic evaluation, dam design assistance, fish stocking and management, weed control, pollution control, water well development design and other information relating to lake development can be obtained from the following agencies:

Geology, Ground Water and Surface Water

Missouri Dept. of Natural Resources
Division of Geology and Land Survey
P. O. Box 250
Rolla, Missouri 65401

U. S. Geological Survey
Water Resources Division
1400 Independence Road
Rolla, Missouri 65401

Solid and Liquid Waste

Missouri Dept. of Natural Resources
Division of Environmental Quality
P. O. Box 176
Jefferson City, Missouri 65101

Design and Planning

Missouri Society of
Professional Engineers
210 Monroe Street
P. O. Box 365
Jefferson City, Missouri 65101

All Aspects

Missouri Department of Conservation
Jefferson City, Missouri 65101

Soil Conservation Service
U. S. Dept. of Agriculture
P. O. Box 459
Columbia, Missouri 65201

U. S. Army Corps of Engineers
Kansas City District
700 Federal Building
Kansas City, Missouri 64106

U. S. Army Corps of Engineers
St. Louis District
210 N. 12th Street
St. Louis, Missouri 63101

Extension Division
University of Missouri-Columbia
Columbia, Missouri 65201

Mark Twain National Forest
Fairgrounds Road
P. O. Box 937
Rolla, Missouri 65401

APPENDIX II

GLOSSARY

Abutment - The contact area where a dam is seated against the valley slope; common terms are dam abutment and slope abutment.

Alluvium - Stream deposits in valley bottoms composed of gravel, sand silt and clay in any combination.

Artificial lake - Lake created by damming a valley or by excavation, in contrast to naturally occurring lakes.

Artificial sealants - Chemicals or processed earth products used to reduce permeabilities in soils; those commonly used are bentonite and soda ash.

Bed; bedding plane - A layer of rock that can be measured in inches or feet; the surface between two beds is a bedding plane.

Bedrock - The solid rock underlying surface material.

Carbonate bedrock - Limestone or dolomite.

Catchment area - A part of the surface of the earth that is occupied by a drainage system.

Cave - A natural underground chamber caused by solution or erosion; can be in soil or rock and can vary in size from very small to very large.

Channel - The course of the stream, usually the deepest route.

Core - Usually the central part of the dam, an impermeable barrier of compacted clay extended downward below the dam to intercept water and provide an "underground dam".

Discharge area - An area that is discharging ground water through seeps and springs.

Drainage area - The drainage area of a stream at a specified location is that area, measured in a horizontal plane, which is enclosed by a drainage divide (a ridge that separates drainage systems).

Eutrophication - The aging and eventual filling of a lake by natural processes.

Fractures and joints - A naturally occurring crack or break, common in most bedrock; openings range in width from hairline to many inches.

Freeboard - The vertical distance between the designed high-water level of the lake and the top of the dam.

Gaining stream or watershed - A stream or watershed that receives water from the subsurface and has a progressively greater flow of water as it advances downstream;

in dry weather, the upstream part dries up before the downstream part, with the mouth of the valley being the last to go dry.

Geologic deficiency - A naturally occurring geologic feature that can be detrimental to a particular project.

Gradient - The slope of a stream measured in feet per mile.

Groundwater level - The level below which soil or rock is saturated with water.

Gumbo clay - A clay soil that becomes sticky or putty-like when wet.

Igneous rock - Rock formed by solidification from a molten or partly molten state.

Impermeable rock or soil - Rock or soil whose ability to transmit water is very low; all rock and soil are permeable to some degree.

Karst, karst features - A carbonate (limestone or dolomite) area marked by sinkholes, caves and other solution features caused by dissolving of the rock by water.

Landslide - Movement of soil or rock downhill; it can be rapid or slow, and can affect small or large areas. If the affected area is very small, the movement is called soil slumping and if the movement is slow, it is referred to as soil creep.

Loess - A homogeneous nonstratified permeable deposit of soil consisting mostly of silt deposited mostly by wind.

Losing stream or watershed - A stream or watershed which contributes water to the subsurface; in dry weather, the downstream part will usually have less water flow or go dry quicker than the upstream part.

Massive rock - Rock occurring in thick beds that is free of obvious bedding planes.

Outcrops; crop out - A bed or layer of rock that is exposed at the surface.

Perennial stream - A stream that flows continuously.

Pinnacle - A high point or spire of rock bounded on the sides by soil; in this report, pinnacles are the result of solution work in soluble rock.

Recharge area - An area where surface water goes underground through soil and bedrock, replenishing the groundwater, and/or springs downstream.

Reconnaissance - A preliminary survey to gain information, usually by a walk-through investigation.

Relief - Difference in elevation between the highest point and the

lowest point of an area.

Residual soil - Soil formed in place from weathering or breakdown of bedrock.

Resurgence - Where water, lost to the subsurface, reappears in a spring or seep.

Runoff - That part of precipitation that appears in surface streams.

Sandstone - Bedrock composed mainly of quartz grains cemented together by various cementing agents.

Shale - A thinly laminated (layered) bedrock composed principally of clay-sized particles.

Shut-in - When a valley is restricted and then widens out to its former width, the restriction is called a shut-in; the term is used in the St. Francois Mountains area.

Sinkhole - When soluble rocks dissolve in the subsurface, the surface soil or rocks sink or fall into the opening, causing a cone or cup-shaped depression called a sink or sinkhole.

Soil - (In this report.) All the unconsolidated material above bedrock, regardless of its origin or mode of deposition.

Sorting - Mechanical action by wind or water that separates materials according to size and/or weight.

Spillway - A primary spillway, usually a steel pipe or concrete conduit, discharges excess water from normal rainfall that is sufficient to raise the lake level; an emergency spillway discharges water flow that exceeds the capacity of the primary spillway.

Spring - Water that issues from the ground through a natural opening either from soil or rock.

Stratification - In alluvial material, the sands, gravels and clays that are sorted and deposited in layers or lenses by water flow.

Stream gradient - The slope of the stream in a downstream direction; usually measured in feet per mile.

Terrace - A flat surface above general floodplain elevation; usually a remnant of a floodplain that existed when the stream was at a higher elevation.

Till or clay till - Soil consisting of clay, sand, gravel and boulders that was deposited by glacial processes.

Watershed - Part of the surface of the earth that is occupied by a drainage system.

Weathering - Process whereby chemical and mechanical action on rock causes it to break down or decay, eventually changing it to soil.

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