AN ENGINEERING GEOLOGIC APPROACH TO EVALUATING GROUNDWATER AND SURFACE WATER CONTAMINATION POTENTIAL AT LAKE OF THE OZARKS, MISSOURI

by

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INTRODUCTION

The striking natural beauty and economic health of the Lake of the Ozarks region are founded on the high-quality water resources of the area. Unfortunately, the geologic conditions that created the rugged hills and the deep, winding valleys render the water resources of the region vulnerable to the effects of development.

Before construction of Bagnell Dam, the study area was sparsely populated and had abundant groundwater resources. Wells and springs were relied on for private water supplies. Development eventually followed creation of the lake, and today, private homes, resorts, businesses, and vacation cabins occupy much of the shoreline. There are still large undeveloped areas in many places, but near the lake, for many miles upstream from Bagnell Dam, development is intense. Many homes near the lake are built on steep terrain.

Soil cover in the vicinity of the Lake of the Ozarks is typically thin or extremely stony, proving to be poorly suited for many of the most common on-site and centralized methods of waste treatment. Highly permeable bedrock allows rapid transport of poorly treated waste into the groundwater system and into the lake itself. In addition, most homes built around the lake get water from private wells, most of which are inadequately cased. Many wells with adequate casing are subject to contamination, because the casings are improperly sealed.

STUDY AREA AND PURPOSE

The purpose of this report is to describe and classify groundwater resources and engineering characteristics of area soils and bedrock, with respect to land development and waste disposal. The study concentrates on eight 7.5-minute quadrangles, Bollinger Creek, Sunrise Beach, Lake Ozark, Bagnell, Barnumton, Green Bay Terrace, Camdenton, and Toronto (fig. 1), which are primarily in Camden County but also include parts of Miller and Morgan Counties. Though the study area does not include all of the Lake of the Ozarks, geologic and hydrologic conditions in the rest of the lake area are quite similar to those of the study area. Conclusions in this report apply to Lake of the Ozarks outside the study area.

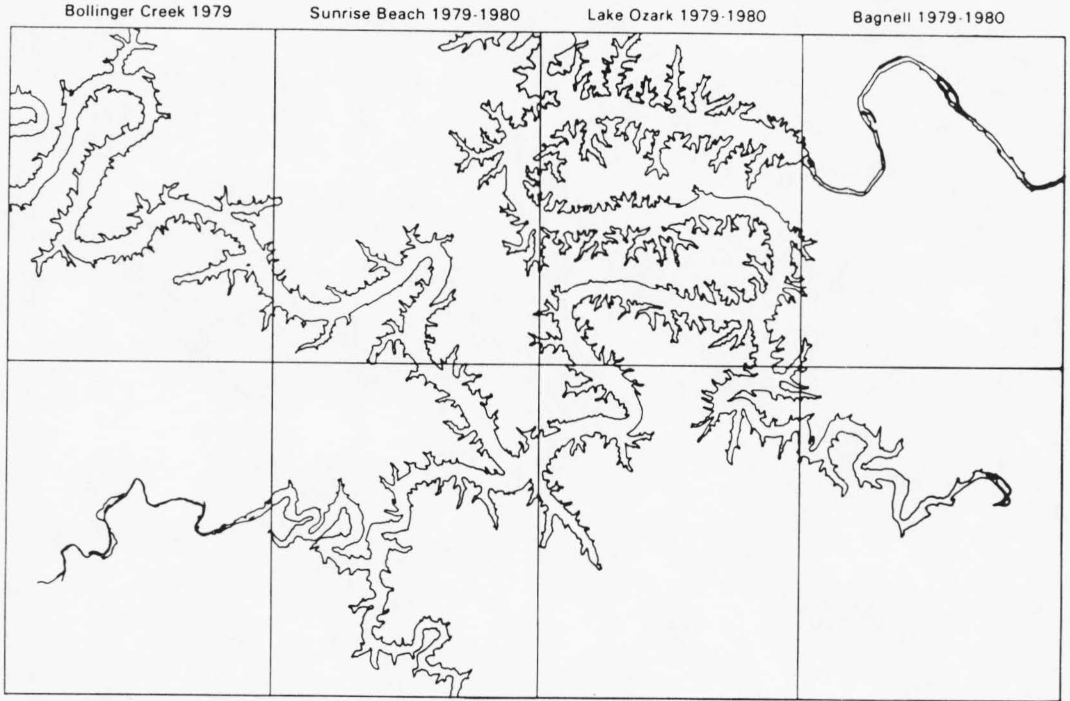

Figure 1 — Eight quadrangles in the Lake of the Ozarks study area.

AREAL GEOLOGY

Bedrock underlying the study area comprises Cambrian and Ordovician dolomite, cherty dolomite, and sandstone. Minor Pennsylvanian sediments occur in parts of the area.

Dolomite, a calcium-magnesium carbonate similar to limestone (calcium carbonate), is the predominant rock type in the area. The major bedrock units in the area are mainly dolomite: Eminence Dolomite, Gasconade Dolomite, Jefferson City-Cotter Dolomite. They are not entirely dolomite, but also contain appreciable amounts of chert and small amounts of other minerals. Chert, or flint, is silicon dioxide, and is much more resistant to weathering than dolomite. As bedrock weathers, dolomite is dissolved, but the chert remains with other insoluble products to form residual soil materials. Only two bedrock units in the study area contain appreciable sandstone, a rock formed by the accumulation and cementing of sand: the Roubidoux Formation and the Gunter Sandstone Member of the Gasconade Dolomite.

Sedimentary bedrock formations in the study area are widely recognized units identifiable throughout southern Missouri. They differ in appearance, composition, and physical characteristics.

Little detailed geologic mapping is available for the study area. The geologic map included in this report (pl. 1) was compiled from regional geologic maps, outcrop maps, and well logs filed at the Missouri Geological Survey, supplemented with some field geologic mapping.

Eminence Dolomite

The Eminence Dolomite, an upper Cambrian dolomite containing minor chert beds, and the oldest unit exposed in the area, is at the bottom of the exposed bedrock sequence; hence, outcrops of this unit are limited to the lake shore. Because the beds dip eastward, the Eminence is exposed only in the western part of the study area. Although residual soil developed on the Eminence typically has a low chert content, the soil generally overlying the Eminence contains abundant chert boulders and fragments that have moved downslope from the weathering of the overlying Gasconade Dolomite. Only about the upper 50 ft of the Eminence is exposed in the area.

Gasconade Dolomite

The Gasconade Dolomite is relatively chert free in the upper part, to very cherty in the lower. A persistent sandstone unit, the Gunter Sandstone Member, forms the base of the Gasconade, which is best exposed along the lake and often forms vertical bluffs. Total thickness of the unit varies from about 280 to 360 ft. On hillslopes, hard, resistant Gasconade chert and dolomite form flat benches, on which the soil is typically stony and less than about 2 ft thick. Residual soil developed from the Gasconade consists of layers of silty clay interbedded with resistant chert beds and boulders.

The Gunter Sandstone Member consists of thinly bedded sandstone 15 to 20 ft thick. It occasionally forms bluffs, and weathered boulders of it often cover slopes. Soil derived from weathered Gunter is very sandy.

Roubidoux Formation

The Roubidoux Formation in the study area is composed of cherty dolomite and sandstone. In some areas, the virtual absence of sandstone makes it difficult to distinguish the Roubidoux from the underlying Gasconade. The formation generally forms the bedrock surface in the upland areas on the west side of the study area, but because the bedrock surface is tilted, the formation is much lower on the east side. Maximum thickness is about 150 ft.

Residual soil developed on the Roubidoux is a variable mixture of chert and sandstone cobbles and boulders, and sandy to silty clay; it varies from extremely thin on steep slopes, to thick in upland areas. Soil formed from weathered Roubidoux is extremely permeable; water passes through it relatively easily.

Jefferson City-Cotter Dolomite

Outcrops of Jefferson City Dolomite and Cotter Dolomite are limited to a few high ridgetops in the eastern part of the study area. Because these two units are similar and difficult to distinguish from each other in the field, they are often referred to as a single unit, the Jefferson City-Cotter Dolomite, a predominantly silty to slightly cherty dolomite containing minor sandstone and shale beds. Residual soil developed on the unit is generally less cherty and more clay rich than soil developed from other bedrock units in the area.

Undifferentiated Pennsylvanian Deposits

Sandstone, shale, clay, and minor coal seams are scattered throughout the uplands across the area. These Pennsylvanian sediments were deposited in sinkholes developed in the underlying Ordovician bedrock. The nature of deposition accounts for their limited and discontinuous presence.

Structural Geology

Bedrock structure of the study area is generally characterized by broad, gentle folding. The amount of tilting, or dip, of the bedrock ranges from less than 1°, to as much as 30° locally. Steeper dips are frequently associated with faulting or solution-induced collapse structures. Mapping of faults in the area is based on natural linear features (lineaments) observed on aerial photographs and topographic maps, and from changes in bedrock contact elevations recorded in logs of adjacent wells. On aerial photographs and well logs, some features that appear to indicate faulting may actually represent folded strata or fracture zones in the bedrock where no actual fault movement has taken place.

Bedrock Weathering and Karst Features

Bedrock in the study area is composed primarily of dolomite which has been weathered to varying degrees. The effects of weathering are most apparent on the land surface where soil has formed by physical and chemical decomposition of bedrock. Subsurface weathering, which is less apparent, has resulted in solution-enlarged openings in the bedrock along fractures and bedding planes. These openings allow precipitation to recharge groundwater rapidly in the area, but, unfortunately, they also allow pollutants to be carried into the subsurface. Karst development in the study area is exemplifed by numerous caves, sinkholes, and losing streams. Many caves and springs were inundated when Bagnell Dam was constructed. Losing streams, those which channel much or all of their flow into the subsurface, are common in the study area.

SURFICIAL GEOLOGY

Site suitability for waste treatment or disposal depends heavily on the characteristics of the surficial materials indigenous to the area. Surficial materials, the unconsolidated materials lying on bedrock, are variable in nature in the study area; their characteristics may vary drastically over short lateral and vertical distances. For purposes of this report, surficial materials are classified into four units that are easily recognizable in the field and have different engineering characteristics: alluvium, residuum-loess (gentle slopes), residuum-loess (steep slopes), and residuum-colluvium-bedrock. Plates 2a through 2g are surficial materials maps of the study area, and contain block diagrams showing general characteristics and topographic relationships of surficial-material units.

Unit A: Alluvium

Alluvium is a general term applied to clastic, or granular, materials deposited by modern rivers on their flood plains. Alluvium in large river valleys, such as those of the Osage and Niangua, typically consists of up to about 50 ft of clay, silt, sand, and gravel. The material is finer grained near the surface; grain size increases with depth. Flood plains are characterized by low topographic relief and are subject to periodic flooding. Alluvium associated with small creeks and wet-weather streams is usually less than 3 ft thick and mostly comprises poorly sorted chert gravel and cobbles, with lesser amounts of clay and silt. Bedrock outcrops are common in the creek channels.

Unit B: Residuum-Loess, Gentle Slopes

Residuum is a broad term applied to all materials that are derived from weathering of bedrock but have undergone little or no transportation. Loess is generally believed to be Pleistocene ("Ice Age") windblown silt derived from ancient flood plain and glacial outwash deposits. Wind carried this material from outwash plains and major river valleys and deposited it on upland surfaces. Unit B, which occupies flat to gently rolling upland prairies and broad ridgetops where slopes are generally less than 8 percent (8 ft vertically per 100 ft horizontally), comprises a thick stony residuum capped by up to 3 ft of clayey silt; the total thickness ranges up to 13 ft. Weathering of bedrock has produced a stony residuum composed of stratified layers of broken chert and sandstone fragments, separated by thin layers of red silty clay. Stone content in the residuum is 10 to 50 percent. Stone fragments are 0.25 to 3 in. in diameter. A dense stone line composed of 20 to over 50 percent rock or chert fragments rests on the residuum.

Unit C: Residuum-Loess, Steep Slopes

Unit C, which occupies ridgetops and moderate to steep hillsides with slopes of 8 to 15 percent, comprises a stony residuum, 3 to 9 ft thick, developed from the weathering of cherty dolomite and sandstone, and capped in places by a thin layer of loess. The residuum consists of stratified beds of hard, broken chert and red silty clay with occasional layers of sandstone. Beds of massive chert boulders, some over 3 ft in diameter, are not uncommon. The residuum is usually quite stony, containing 15 to 65 percent chert and sandstone fragments, which are 0.25 to 3 in. in diameter. In places on ridgetops, a thin layer of clayey silt, 3 ft or less thick, overlies the stony residuum. Bedrock outcrops and glade areas are common on ridgetop knolls. (A glade is an area of low relief where essentially no surfical material is present and bedrock forms the land surface.)

Unit D: Residuum-Colluvium-Bedrock

This unit comprises extensive dolomite, chert, and sandstone outcrops on bluffs and hillsides having slopes greater than 15 percent. On most slopes there is a thin covering of stony residuum or colluvium less than 3 ft thick. (Colluvium is a general term for loose material deposited at the base of a slope or cliff and brought there chiefly by gravity.) Surficial materials eroded from the slopes and transported downslope have created a poorly sorted deposit of clay, gravel, and cobbles in valleys at the base of the hills. Stream channels in the upper reaches of these valleys contain an assortment of chert, sandstone, and dolomite fragments. Further downstream, in the larger creeks and rivers, stratified layers of silt, sand, and gravel are present in the alluvium.

GROUNDWATER RESOURCES

Good-quality groundwater is readily available in the study area. Wells drilled to suitable depths will provide enough water for private use. Deeper wells will yield ample water for public water supplies. There appear to be no problems with excessive groundwater withdrawals in the area; none are anticipated in the near future.

All bedrock units in the study area will yield water to some degree. Wells drilled for private water supplies are typically 150 to 400 ft deep and are designed to yield 10 to 15 gallons per minute (gpm). Wells drilled for public water supplies are generally 500 to 1000 ft deep and can yield up to approximately 250 gpm.

Roubidoux Formation

The Roubidoux Formation is only a minor aquifer in the study area, where it forms the bedrock surface in most places, but has insufficient saturated thickness to yield appreciable groundwater. The Roubidoux often contains well developed solution-enlarged fractures that allow rapid downward water movement. The unit is important for groundwater recharge, but also can allow the downward movement of contaminants; therefore, wells that penetrate the Roubidoux, but produce from deeper formations, should be cased and sealed through the Roubidoux to protect the wells from local contamination.

Gasconade Dolomite

The formation most commonly used for private water supply in the study area is the Gasconade Dolomite. The upper Gasconade, a dolomite with low chert content, produces little water, but the lower Gasconade, a more cherty dolomite, and the Gunter Sandstone Member yield sufficient water for private water supplies in most of the area. Well yields for the Gasconade are approximately 10 gpm to about 50 gpm.

Eminence and Potosi Dolomites

The Eminence Dolomite, the oldest bedrock unit exposed in the study area, has a low to moderate chert content. The Potosi Dolomite underlies the Eminence. Both units are used for public water supply in the area. Wells fully penetrating them can produce up to about 250 gpm.

GROUNDWATER RECHARGE

Groundwater in the study area is recharged through two different processes. Shallow bedrock formations are recharged primarily by precipitation. Some of this water moves down gradient, generally toward the lake, and emerges as spring flow; some also moves downward to recharge deeper bedrock formations. The second recharge source is groundwater from outside the area, moving down gradient to recharge the deeper local bedrock forma tions. General directions of groundwater movement are best shown using a potentiometric map, a contour map constructed from water-surface elevation measurements in wells. The nature of the aquifers in the study area is such that shallow and deep wells will have different water-surface elevations. The potentiometric map in this report (pl. 3) was constructed using only data from deep, high-yield (50 gpm+) wells, most of them containing pressure-grouted casing that excludes shallow groundwater from the wells. The map shows deep groundwater movement from the north, west, and south, toward the Osage River. A potentiometric map of the shallow aquifer was not constructed, but shallow groundwater movement is generally toward the lake.

The Lake of the Ozarks probably recharges shallow groundwater locally. Due to this interchange of water between the lake and the shallow aquifer, it is prudent to case wells close to the lake fairly deeply to exclude lake water from them.

GROUNDWATER CONTAMINATION

The nature of the carbonate aquifer in the study area is such that any activity on the surface will have some effect on the groundwater system. Improper waste disposal is likely to cause at least local groundwater contamination. The single greatest threat to shallow groundwater quality is waste effluent from private homes, entering the groundwater system through improperly constructed private wells. Throughout much of the study area, the lake shore is lined by houses, most of which have individual wells and septic tanks on the same lot. Nearly all these home sites exhibit severe geologic limitations with respect to on-site waste-disposal methods, such as septic tanks and tile fields. The effluent either surfaces and flows into the lake, seeps downward through the thin soil and enters the lake downslope, or recharges groundwater through poorly constructed private wells or permeable bedrock. Fortunately, the potential for regional contamination from septic effluent is low. Most of the waste moves into the lake through shallow groundwater and becomes a surface-water problem. Typically, the source of pollutants in an individual well is the well owner's disposal field or a nearby disposal field.

Development on upland areas away from the lake can cause similar problems, but these areas typically have thicker soil materials, less rugged topography, and are less densely developed. Houses are usually on lots larger than those near the lake. As a result, there is less chance for contamination of private wells.

A study by Consulting Analytical Services International (CaSi, circa 1981), for the City of Osage Beach and the Missouri Department of Natural Resources, found that shallow groundwater contamination is a serious problem around the lake. Of 55 wells sampled in the Osage Beach-Turkey Bend area, 35 percent contained bacteria; 38 percent contained more than 1 milligram per liter (mg/l) nitrate as nitrogen. Natural-background nitrate-nitrogen in the area is probably less than 0.1 mg/l. Most of the intensely developed areas of the lake probably have similar contamination problems. The recommended maximum nitrate concentration in drinking water is 10 mg/l as nitrogen. Though most of the wells sampled contain less than 10 mg/l nitrate, the presence of nitrate above natural background levels shows that private wells are usually improperly sealed, and that a significant pollution potential exists in the area.

THE EFFECTS OF DEVELOPMENT ON LAKE WATER QUALITY

Since construction of Bagnell Dam, there has been nearly continuous development around Lake of the Ozarks. The economics of the area heavily depends on tourism generated by the lake. Water related recreational activities attract thousands of people annually, many of whom now live along the lake, spend vacations at resorts, or own weekend homes around the lake. With people come businesses that provide services to the large seasonal population.

Each home, business, and resort produces waste water that must be disposed of. Larger communities and businesses generally use lagoons or mechanical treatment systems for disposal of liquid waste. Smaller businesses and private homes usually depend on septic tanks and tile fields for sewage treatment and disposal.

Each method of waste disposal ultimately discharges treated waste water into the watershed of Lake of the Ozarks. As discussed earlier, much of the land adjacent to the lake has moderate to severe geologic limitations with respect to on-site waste-disposal methods. As a result, many disposal methods do not provide adequate treatment; poorly treated waste water is discharged, via soil, bedrock, and overland flow, into the watershed of Lake of the Ozarks.

Development intensity is directly related to the amount of waste water produced. To determine potential surface-water- and groundwater-quality problem areas, development-intensity maps of Lake of the Ozarks shoreline in the study area were constructed. They graphically depict four classes of development intensity: intense, moderate, slight, and undeveloped. Development-intensity classes are based on average spacing between buildings shown on topographic maps of the study area. Average building spacing is less than 100 ft in intensely developed areas, 100 to 600 ft in moderately developed areas, 600 to 1000 ft in slightly developed areas, and greater than 1000 ft in undeveloped areas.

Approximately 605 miles of lake shore were evaluated. Development intensity was determined using the most recent U.S. Geological Survey 7.5-minute topographic maps made from aerial photographs taken from 1979 to 1981. Buildings less than about 500 ft from the shoreline were included, but most intense development is within 200 ft of the lake. Shorelines were measured using a Numonics electronic graphics calculator. Approximately 45 percent (275 mi) of the shoreline is intensely developed, approximately 14 percent (82.33 mi) is moderately developed, only 4 percent (23.83 mi) is slightly developed, and 37 percent (224.04 mi) is undeveloped. A sizeable portion of the undeveloped shoreline, including bluffs, steep slopes, low-lying areas where streams enter the lake, and government-owned land, is probably not suitable or available for development. It was beyond the scope of the study to determine the types of buildings being evaluated. Plate 4 shows shoreline-development intensity, and table 1 summarizes shoreline-development measurements.

At normal pool level, Lake of the Ozarks contains approximately 1,280,000 acre-feet of water. If all waste products that enter the lake were evenly distributed, there

TABLE 1

Shoreline-development intensity for eight quadrangles in the Lake of the Ozarks area†

Quadrangle	Shoreline development intensity by quadrangle							
	Intense*		Moderate**		Slight***		Undeveloped****	
	miles	(% total)	miles	(% total)	miles	(% total)	miles	(% total)
Bagnell	0.07	(13)	0.26	(47)	0	(0)	0.22	(40)
Toronto	2.70	(8)	3.37	(10)	0.52	(2)	26.46	(80)
Lake Ozark	103.78	(49)	34.08	(16)	9.13	(4)	63.47	(31)
Camdenton	19.68	(29)	9.90	(15)	3.74	(5)	34.98	(51)
Sunrise Beach	54.72	(60)	11.41	(12)	5.88	(7)	18.92	(21)
Green Bay Terrace	47.10	(48)	17.20	(17)	0.90	(1)	33.37	(34)
Bollinger Creek	46.08	(48)	5.27	(5)	2.54	(3)	42.47	(44)
Barnumton	0.87	(12)	0.84	(12)	1.12	(16)	4.15	(60)
Totals	**275.00**	**(45)**	**82.33**	**(14)**	**23.83**	**(4)**	**224.04**	**(37)**

* Buildings average less than 100 ft apart
**Buildings average 100-600 ft apart
*** Buildings average 600-1000 ft apart
****Buildings greater than 1000 ft apart

†For quadrangle locations refer to figure 1 (p. 2).

would probably be no water-quality problem. Unfortunately, much of the development around Lake of the Ozarks is concentrated around small coves that have limited circulation with the rest of the lake.

The 1981 CaSi study found lake water quality in undeveloped coves to be generally superior to that of developed coves. Sources of contamination such as surface discharges from lagoons or mechanical-treatment systems are easily recognized. Non-point source discharges such as those from septic tank tile-field systems are not as easily identified. Using a device that compared the background fluorescence and conductivity of lake water against those of a local waste water effluent, CaSi was able to define areas where plumes of waste water were entering the lake from non-point sources such as septic tank tile-field systems. Using this method, dozens of effluent plumes were located along a relatively short reach of shoreline in a developed cove.

Many factors affect the water quality of the lake. These include the amount, type, location, and density of development; temperature; precipitation amounts and patterns; degree of waste treatment; lake stage and fluctuation; sunlight duration; and wind velocity and direction. Of the above factors, only the amount, type, location, and density of development, and the degree of waste treatment can be readily controlled. Surface-water quality will continue to decline at Lake of the Ozarks unless steps are taken to control those factors that can be controlled.

LIMITATIONS CONCEPT

For purposes of this report, four basic soil-bedrock units have been designated. Each has certain inherent characteristics with respect to various waste-disposal methods and has been evaluated for its general suitability for waste disposal and assigned a slight, moderate, or severe limitation rating for each waste-treatment and disposal method.

The slight, moderate, and severe ratings are general evaluations of geologic conditions associated with the units. Conditions within each unit will vary somewhat and on-site exploration is essential before the appropriate waste-disposal methods can be determined. <u>The slight, moderate, and severe ratings are intended only as a guide for planning purposes</u>. Site-specific exploration may reveal a site rated as severe to have only slight or moderate limitations, whereas a site rated slight may have greater limitations.

Slight Limitations

Slight limitations indicate the site should create little danger of groundwater or surface-water contamination as the result of properly designed and maintained conventional waste-treatment and disposal methods.

Moderate Limitations

Significant danger exists of groundwater or surface-water pollution associated with conventional waste-treatment and disposal methods. Problems can generally be overcome with established engineering procedures but will entail substantial cost increases. Proper design, installation, and maintenance are paramount.

Severe Limitations

Contamination of surface water or regional groundwater is likely. Hazards are so severe that elaborate and costly engineering designs and procedures may not be totally successful in alleviating the problem. Development should be allowed only if there is a unified sewage-collection and treatment system.

Unit A: Alluvium

Septic tanks and tile fields on flood plains of larger streams with well-graded alluvium will normally encounter slight geologic limitations. A high water table may cause surfacing of effluent. In smaller stream valleys and losing stream valleys with very coarse alluvium, the possibility of rapid movement of effluent into surface water or groundwater presents severe limitations. Soil at the base of slopes on the edge of smaller flood plains is usually finer grained and can be better used for septic tank soil-absorption systems.

Limitations on lagoons in this environment are moderate to severe. The silty, sandy, and gravelly nature of most flood plain soils in the area make infiltration from lagoons a severe problem. The finer grained soil of larger stream flood plains and terraces are frequently better suited for lagoons.

Flooding, fluctuating water-table levels, and permeable soil severely limit this unit for sanitary landfills.

Unit B: Residuum-Loess, Gentle Slopes

Because of fractured bedrock and permeable residuum, there is a high potential for groundwater contamination from septic systems constructed in this unit. If lots are fairly large, generally 1 to 3 acres, and the area is served by public water, the limitations are moderate. Smaller lots with individual wells can fall into the severe limitations category.

During lagoon excavations, the encountering of stony residual-clay soils and relict bedded cherts in the residuum will frequently result in severe leakage problems. Expensive artificial liners may be required to reduce leakage. Thin soil over permeable bedrock greatly limits the number of acceptable landfill sites. Sites on broad upland surfaces where exploration reveals an acceptable soil thickness may be worth consideration.

Unit C: Residuum-Loess, Steep Slopes

Steep slopes and thin soil cover severely limit septic tanks and severely restrict lagoon development and landfills in this unit. All types of waste disposal are also severely limited.

Unit D: Residuum-Colluvium-Bedrock

Thin soil cover and steep slopes severely limit Unit D for septic tanks, lagoons, and landfills.

CONCLUSIONS

In densely developed areas around Lake of the Ozarks, improper disposal of liquid wastes are causing groundwater contamination problems that are due to four factors:

1. Most intensely developed portions of the study area exhibit moderate to severe geologic limitations with respect to on-site waste-disposal systems.
2. Deeply weathered carbonate bedrock, which allows easy migration of contaminants from the soil horizon to the groundwater system.
3. Steep slopes in the more desirable development areas.
4. Improper well construction that allows contaminants to enter groundwater through poorly sealed well casings.

Surface-water contamination of the Lake of the Ozarks, resulting from on-site waste treatment and disposal, is primarily due to thin soil and steep slopes on most sites, which allow surface runoff and seepage of effluent through permeable bedrock into the lake.

Runoff and seepage of effluent will continue if changes are not made. In terms of public health, development of public water-supply districts to supply rural lake-area residents with a safe source of water would eliminate some problems but pollutants would still be present and would continue to degrade shallow groundwater and surface water. More strict attention to the development plan of lots where individual waste-treatment systems will be used would also mitigate some of the contamination problems. Such improved planning would include restrictions on lot size and arrangement relative to geologic conditions. A more permanent and effective but more costly approach would be the development of centralized sewage-disposal districts. If sewage were piped to central locations, where treatment could be more complete and the effluent disposed of properly, two things would result. First, with the source of contamination removed, shallow-groundwater quality would begin improving; eventually, water quality would return to more normal background conditions. Secondly, with the groundwater quality improved, shallow groundwater entering the lake would be of better chemical and bacteriological quality, and contaminants in shallow groundwater would no longer be transferred to the lake by groundwater movement.

Other steps would need to be taken, including ensuring all resorts, businesses, and other facilities around the lake that use centralized waste-treatment systems comply with clean-water laws.

Until any of these recommendations can be implemented, steps should be taken to prevent increased contamination. New development, including private homes, should take into account geologic conditions and engineering-related constraints of sites. These new developments should be required to use waste-disposal techniques that eliminate or at least significantly reduce pollutants from entering the lake or the groundwater system. Private wells should contain properly sealed casing, to prevent contaminants from entering them and degrading local shallow-groundwater quality. These steps are needed to prevent further surface-water and groundwater degradation and, it is hoped, to pave the way for a concerted effort to improve the groundwater quality and the quality of Lake of the Ozarks.

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