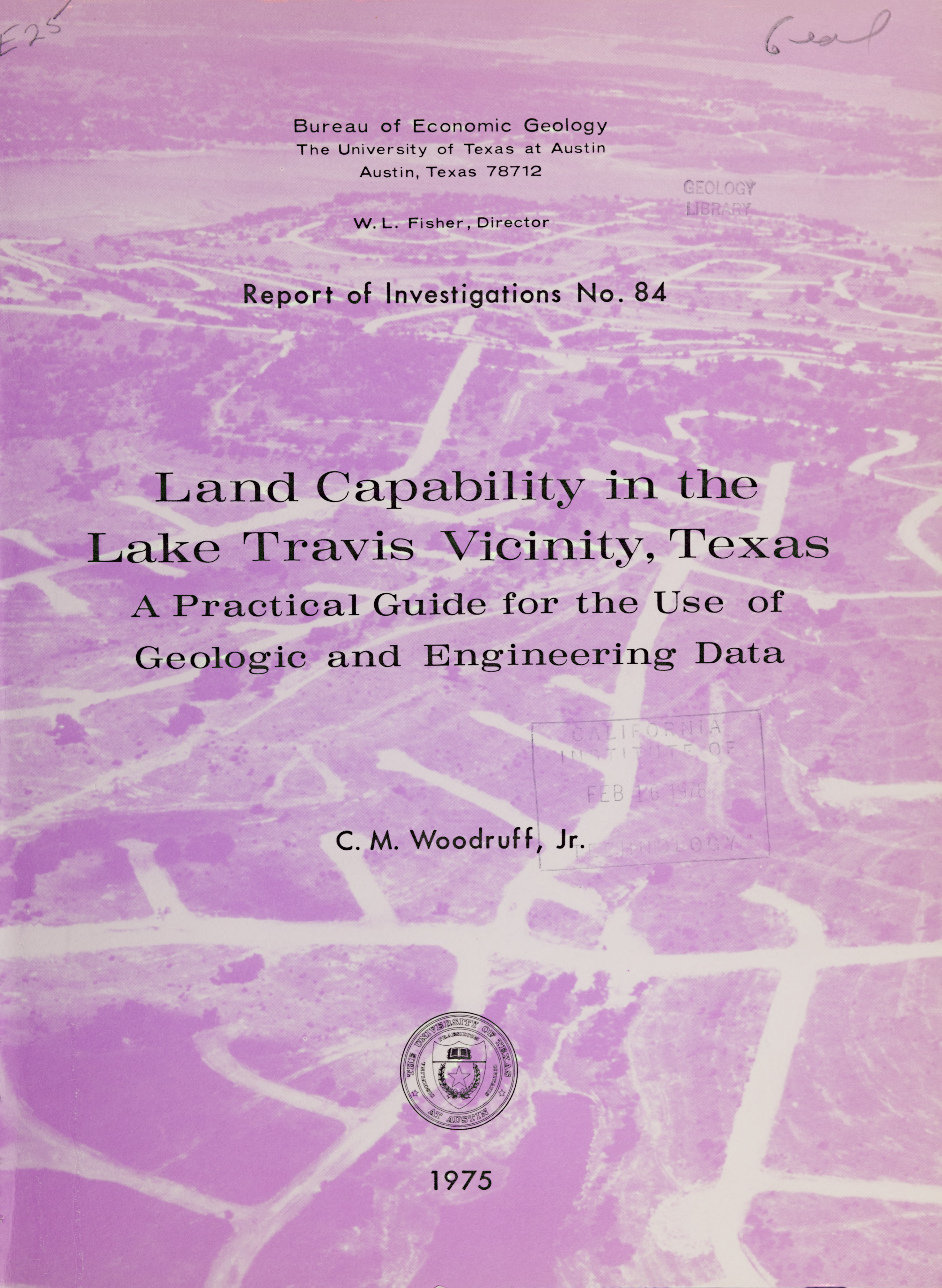

Bureau of Economic Geology
The University of Texas at Austin
Austin, Texas 78712

W. L. Fisher, Director

Report of Investigations No. 84

Land Capability in the Lake Travis Vicinity, Texas

A Practical Guide for the Use of Geologic and Engineering Data

C. M. Woodruff, Jr.

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PREFACE

Land bordering natural or man-made lakes constitutes areas of critical environmental concern because of the convergence of natural processes that either affect or are affected by the lake. These processes include runoff, upland erosion, mass wasting, flooding, shoreline erosion, and water-quality changes due to seasonal temperature variations or changes in water volume. In addition to these natural processes there are pressures imposed by man. For example, lakeshore lands are popular sites for intensive recreational activities as well as for uses such as industrial and residential development. These human activities interfere with hydrologic, geologic, and biologic regimens in a number of ways. Modifications of water quality from various waste disposal systems occur, although concurrent demands are made for water of suitable quality and sufficient quantity for power generation and industrial, agricultural, and residential uses. Furthermore, man may interfere with processes in a way that threatens his own safety, such as by developing a flood-prone area for residences.

Human uses of these sensitive lakeshore lands should be planned in terms of the natural setting, including bedrock substrate, active processes, ambient landforms, and surficial soils. In this way, adverse environmental effects may be predicted and minimized.

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LAND CAPABILITY IN THE LAKE TRAVIS VICINITY, TEXAS
A PRACTICAL GUIDE FOR THE USE OF GEOLOGIC AND ENGINEERING DATA

C. M. Woodruff, Jr.

ABSTRACT

The Lake Travis vicinity lies predominantly within a carbonate rock terrane and is the site of ongoing intensive residential development. Such development may impose adverse environmental effects such as upland erosion, rapid infilling of the lake with sediment, and the ultimate lowering of surface- or ground-water quality. Furthermore, inhabitants may be subjected unwittingly to geologic hazards such as flooding or mass wasting. These adversities can be largely avoided if the natural carrying capacity of the land is assessed and if human activities accordingly compensate for these limitations.

A series of maps shows the facets of the land needed to evaluate the natural capabilities for sustaining various human uses of lakeshore lands. The basic maps show topography, physical properties (of substrate), and environmental geology (which is an integration of processes, substrate, and landforms). These maps and tabular interpretations facilitate judgments regarding engineering-construction feasibility, long-term ground stability, loci of hazards, water regimes, mineral resource localities, and characteristics of biotic and engineering soils. These judgments are further facilitated by a series of simplified maps showing soil distribution, thickness, and texture, fracture-trace intensity, and ground slope.

Areas subject to ongoing hazardous processes pose the most severe constraints on human activities. These include flood-prone areas and unstable-slope areas. Flood-prone areas consist of land below lake-spillway level and areas adjacent to lake tributaries. Unstable-slope areas generally comprise oversteepened claystone terranes.

Most of the carbonate rock terrane is covered by thin soils, so that constraints on uses depend mainly on ground-slope characteristics, properties of substrate, or the possibility of ground-water recharge and storage. High-slope areas pose problems with rapid surface-water runoff and resurfacing of septic effluents as well as construction difficulties related to grading and excavating. The low-slope carbonate rock areas may pose construction difficulties related to a well-indurated substrate. Also, in these gently sloping areas there is the possibility of recharge of septic effluents into local ground-water supplies.

Claystone terranes constrain uses mainly because of substrate-soil properties of relatively low strength and low permeability. However, these properties offer possibilities in terms of potential solid waste disposal sites.

Areas underlain by friable sand and conglomerate and alluvium impose fewer constraints on uses. Soils are generally thicker and slopes are commonly more gentle in these areas than in the carbonate rock terranes. However, uses such as intensive residential developments with septic tanks or solid waste emplacement are largely precluded because of local high substrate permeability and a shallow water table.

Constraints on human uses and activities refer to constraints regarding the land in a natural condition. In most instances the constraints can be mitigated by modification of the land or by adjustment of the proposed activities so that uses may not be, in fact, precluded.

INTRODUCTION

Lake Travis is the largest of seven man-made impoundments of the Colorado River in Central Texas. These impoundments constitute the chain of Highland Lakes that extends northwest from Austin and crosses three counties (fig. 1). Although the original purposes of dam construction were to create flood-control reservoirs, to supply hydroelectric power, and to augment low flow downstream, the lakes became recreational resources, and lakeshore areas have become sites for develop-

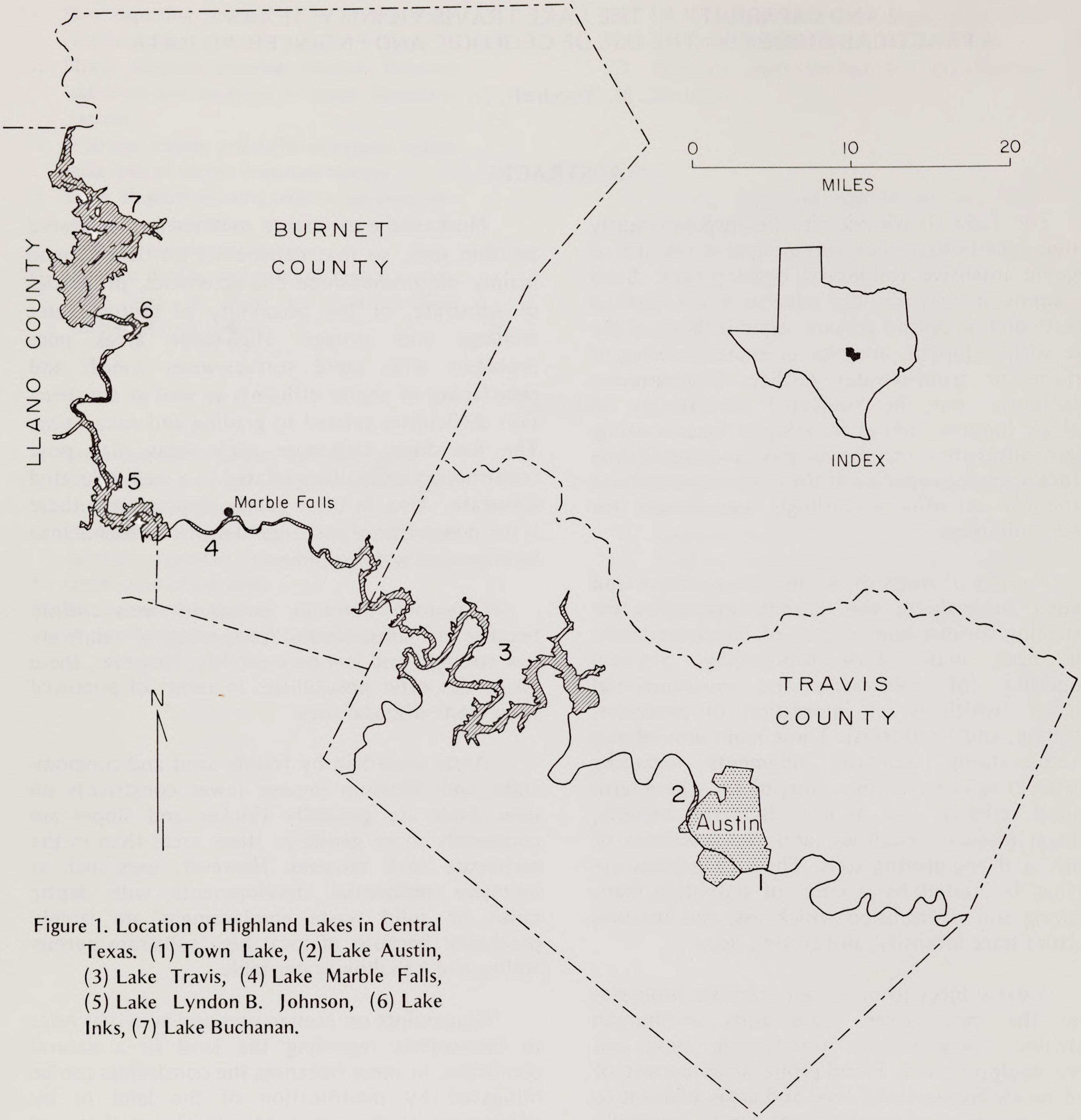

Figure 1. Location of Highland Lakes in Central Texas. (1) Town Lake, (2) Lake Austin, (3) Lake Travis, (4) Lake Marble Falls, (5) Lake Lyndon B. Johnson, (6) Lake Inks, (7) Lake Buchanan.

ment of resorts, vacation cottages, and permanent homes. The economic base for the Highland Lakes area has changed from livestock grazing and mineral extraction to tourism and recreation (Clark and others, 1967).

The Lake Travis vicinity has received a sizable population influx. Inhabitants along the lake totaled 8,535 in 1970, and projections indicate that the total will increase to more than 20,000 by 1990 (Freese, Nichols, and Endress, Consulting Engineers, 1970a, p. 79). Most of the growth thus far has been without regard to constraining factors such as bedrock, topography, soils, and water regimen. If population growth continues without design based on natural constraints, it will eventually pose threats to environmental quality and to human health and safety. Declines in water quality resulting from unwise residential development practices are documented in other areas (Waltz, 1972; Perlmutter and Koch, 1972), and incipient declines in water quality of parts of the Highland Lakes already exist (Pittman and others, 1969). Moreover, threats to human life and property exist in some lakeshore developments resulting from improper siting of homes (Woodruff, 1974, p. 137).

It is the purpose of this report to elucidate factors salient to wise use of the land and water in the Lake Travis vicinity (fig. 2). A first step in such a project is to inventory the land in its natural condition; the results of the inventory are presented in a suite of maps. Natural land features and compatible uses are then cross-matched in a presentation of land capability. Land capability is the measure of the extent to which various uses can be sustained without environmental harm or human hazard. Much of the land capability evaluation is valid in other lakeshore areas of similar terrane, so that the Lake Travis study becomes a model for evaluation of use constraints based on a physical land inventory where carbonate rocks are the dominant substrate.

ACKNOWLEDGMENTS

This report is based on the author's Ph. D. dissertation at The University of Texas at Austin. Dr. Keith Young supervised the research, and the permanent committee consisted of Dr. Peter T. Flawn, President, The University of Texas at San Antonio, Mr. Philip E. LaMoreaux, Alabama State Geologist, and Dr. L. Jan Turk, Associate Professor, The University of Texas at Austin. I am grateful to these men for their involvement

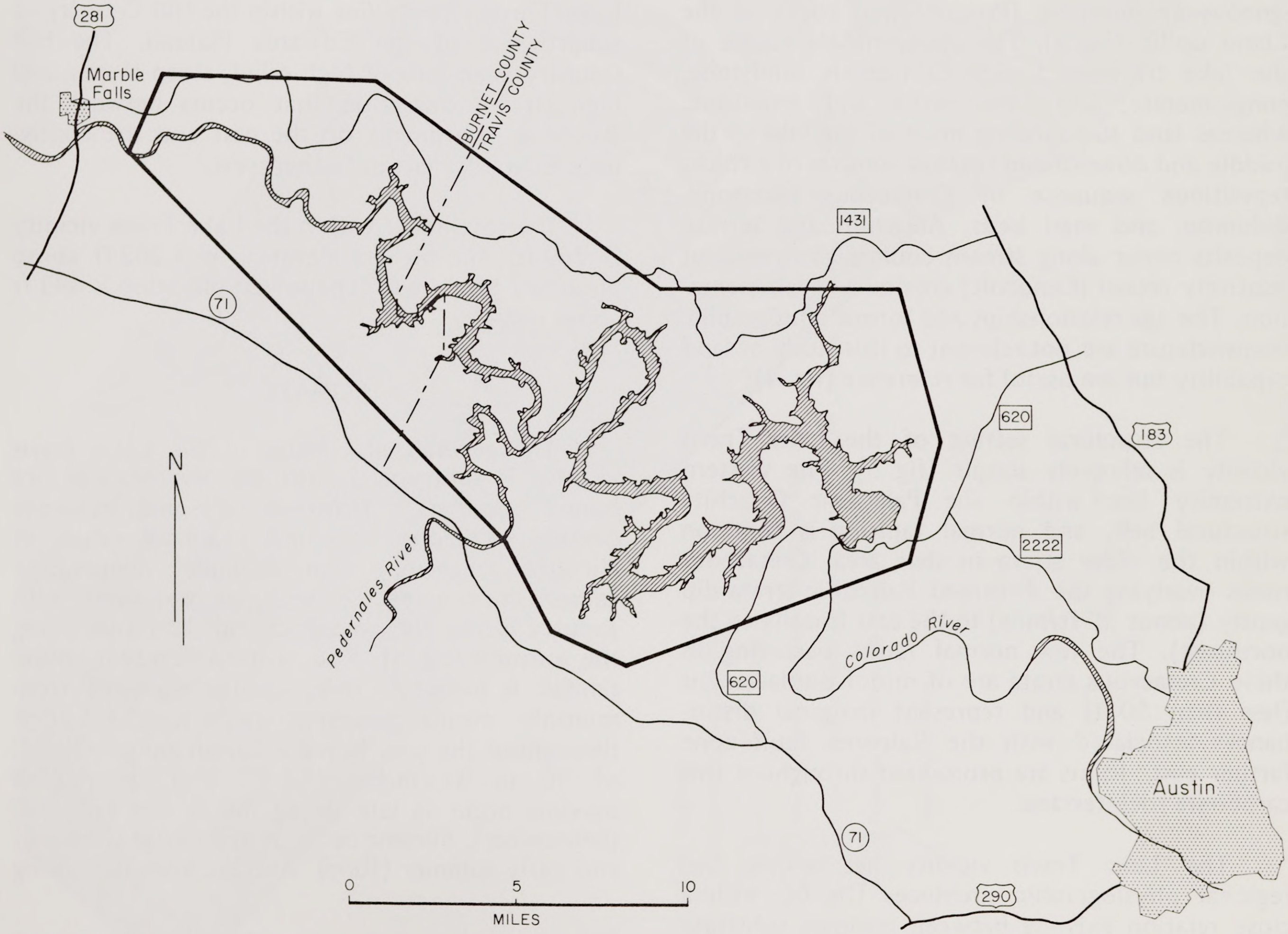

Figure 2. Location of Lake Travis vicinity showing access to Austin and Marble Falls.

throughout the project. The final stage of dissertation preparation was supported by the Owen-Coates Fund of the Geology Foundation, The University of Texas at Austin.

Dr. W. L. Fisher, Director, Bureau of Economic Geology, The University of Texas at Austin, adopted the study as a Bureau research project and critically read the manuscript. Other colleagues at the Bureau of Economic Geology also deserve my thanks for reading the manuscript and making critical comments. They are Drs. Robert A. Morton, W. R. Kaiser, and Thomas C. Gustavson.

Mrs. Elizabeth T. Moore prepared the manuscript. The report was edited by K. M. White, and final composing was done by Dawn R. Weiler. Cartographic work was performed by Barbara Hartmann under the supervision of J. W. Macon at the Bureau of Economic Geology.

NATURAL INVENTORY

REGIONAL ASPECTS OF THE LAND

GEOLOGY—PHYSIOGRAPHY

Lake Travis lies predominantly within a carbonate rock terrane. Its headwaters cross Paleozoic limestones and shales that rim the igneous-metamorphic (Precambrian) rocks of the Llano uplift (fig. 3). The upper-middle course of the lake traverses Lower Cretaceous sandstone, conglomerate, and some shale and limestone, whereas land surrounding most of the lake in the middle and downstream reaches consists of a thick, repetitious sequence of Cretaceous limestone, dolomite, and marl beds. Alluvium and terrace deposits occur along stream courses as a result of relatively recent (Cenozoic) erosion and sedimentation. The age relationships and formal stratigraphic nomenclature are not relevant to this study of land capability but are useful for reference (fig. 4).

The structural setting of the Lake Travis vicinity is relatively simple (fig. 5). The western extremity lies within the Paleozoic Ouachita structural belt, and normal faulting is common within the older strata in that area. Cretaceous rocks overlying the disturbed Paleozoic strata dip gently (about 20 ft/mile) to the east (locally to the northeast). The few normal faults occurring in these Cretaceous strata are of minor displacement (less than 50 ft) and represent marginal disturbances associated with the Balcones fault zone farther east. Joints are prominent throughout this carbonate rock terrane.

The Lake Travis vicinity lies within two regional physiographic provinces (fig. 6), with a close relation existing between geologic substrate and physiographic provinces (fig. 7). The upper reaches of the lake cross the edge of the Llano physiographic basin, which is an area of generally more subdued relief than the hilly land immediately adjacent to the east. This low-relief terrain corresponds to the areas underlain by Paleozoic and (farther west) Precambrian rocks. Most of the Lake Travis vicinity lies within the Hill Country—a subprovince of the Edwards Plateau. The Hill Country is an area of high relief, steep slopes, and high stream dissection that occurs between the Balcones escarpment on the east and the contiguous Edwards Plateau farther west.

The total relief within the Lake Travis vicinity is 769 ft. The highest elevation is 1,262 ft above mean sea level (msl). The lowest elevation is 493 ft above msl.

CLIMATE

The generalized climate of the Lake Travis vicinity is subtropical with dry winters and hot humid summers.[1] However, seasonal extremes deviate markedly from mean annual values of climatic parameters. For example, temperature values show expected seasonal variations with January being the coldest month and July being the warmest (fig. 8). Also, distribution of monthly rainfall is bimodal. This deviates markedly from monthly means assuming uniform distribution throughout the year based on mean annual rainfall of 30 to 31 inches (fig. 9). Monthly rainfall maxima occur in late spring (May) and early fall (September). Minima occur in midwinter (January) and early summer (June). Average annual growing

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[1] Climatic data were obtained from "Climatological Summaries" distributed by The University of Texas at Austin, Bureau of Business Research.

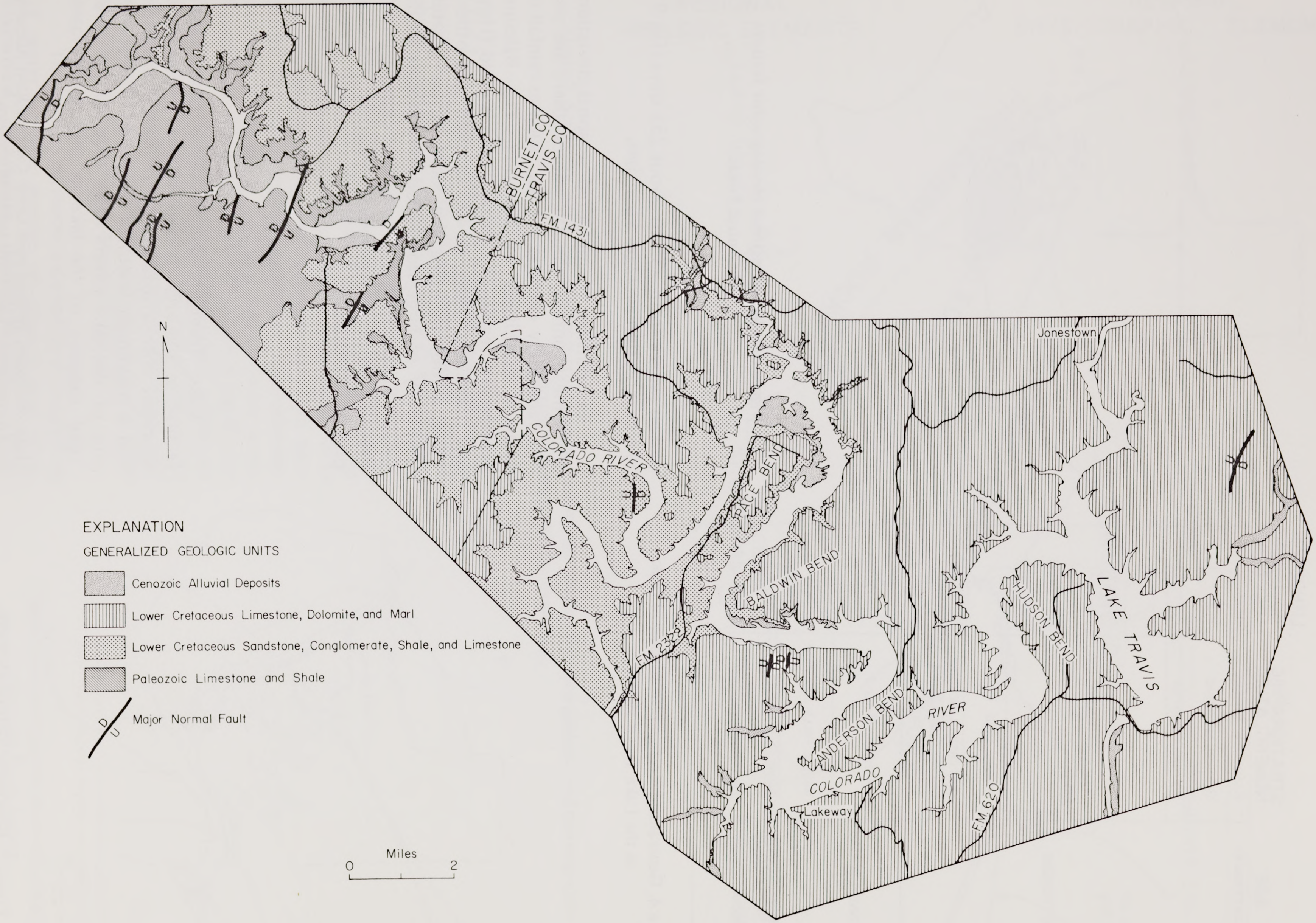

Figure 3. Generalized geologic map of Lake Travis vicinity.

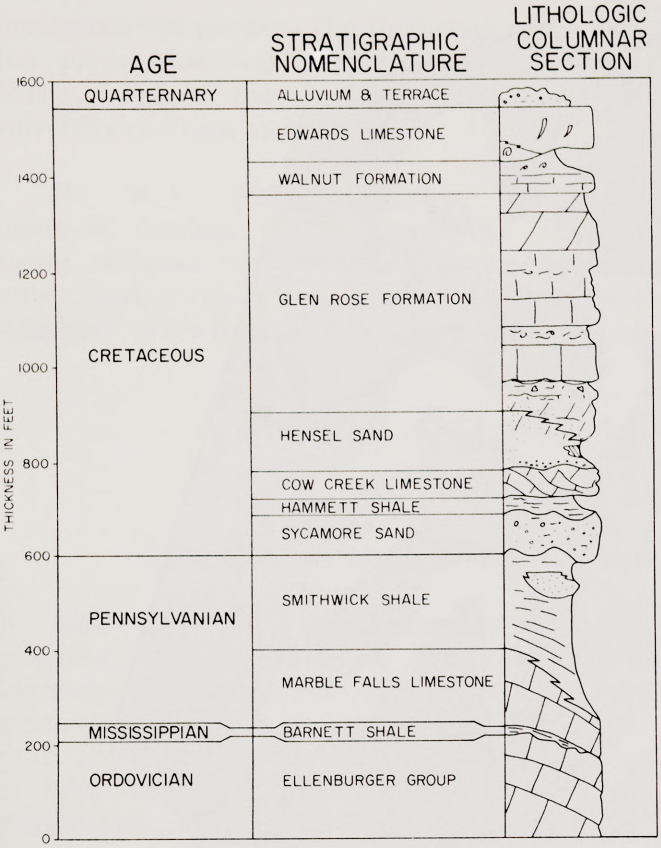

Figure 4. Generalized stratigraphic section of rocks in the Lake Travis vicinity.

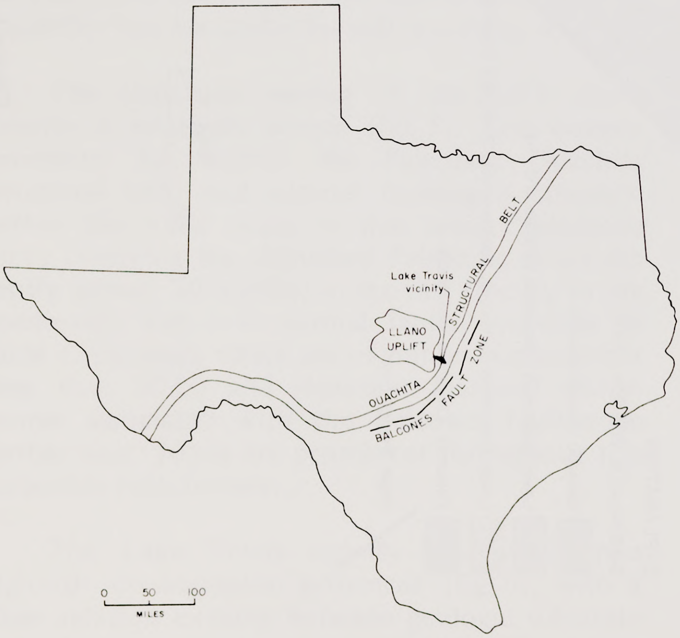

Figure 5. Regional structural elements.

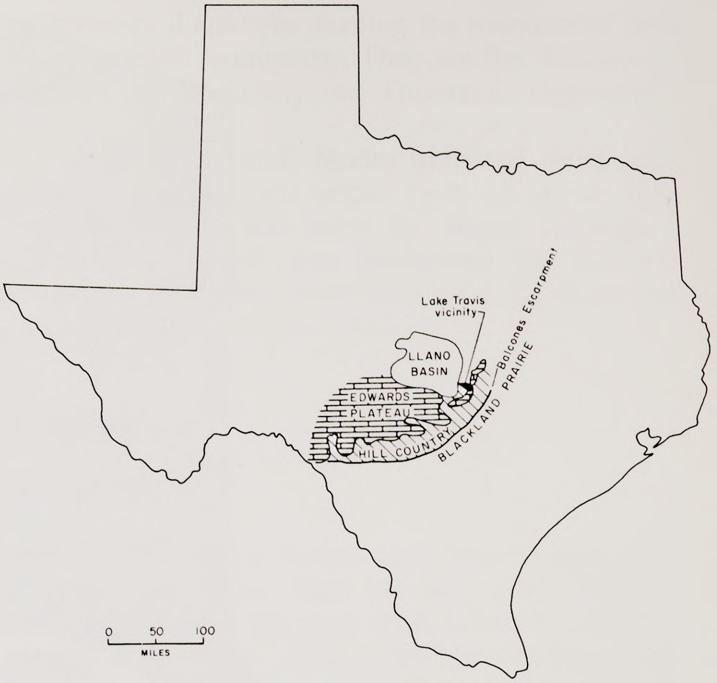

Figure 6. Selected regional physiographic features of Central Texas.

season ranges from 235 to about 255 days (fig. 9). Pan evaporation averages 58 inches.

In addition to measured seasonal deviations from mean annual climatic values, there are also "extraordinary climatic events," such as rainfall of unusual magnitude or duration. The Balcones escarpment region of Central Texas is cited (Hoyt and Langbein, 1955, p. 47; Leopold and others, 1964, p. 66) as being the locus of the greatest frequency of large flood-producing storms in the United States. Such a documented climatic hazard presages an ominous geologic hazard (flooding) present in the area.

WATER

Surface Water

Lake Travis is the dominant hydrographic feature in the area. It encompasses 270 miles of shoreline with a total length of 63.75 miles (mi) and a maximum width of 2.18 mi.[2] The surface area of the lake covers more than 29,000 acres. Total capacity of the lake at spillway elevation

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[2] Lake dimensions obtained from Lower Colorado River Authority (LCRA) pamphlet, "Lake Travis and Mansfield Dam."

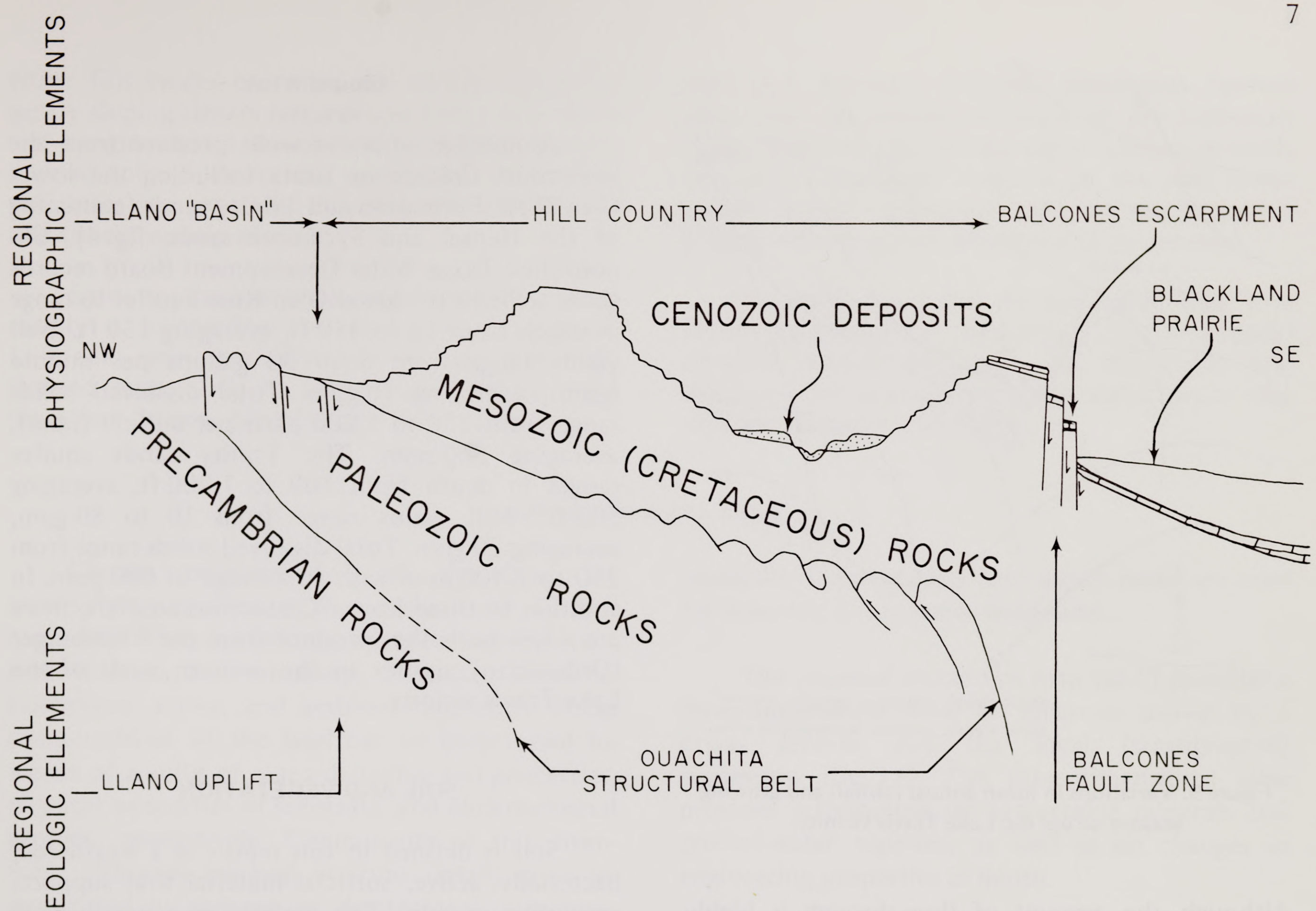

Figure 7. Schematic northwest-southeast cross section showing the relation between geologic and physiographic features occurring near the Lake Travis vicinity.

(714.1 ft above msl) is 1,953,936 acre ft which includes 783,184 acre ft of floodwater storage above normal pool elevation (681.1 ft above msl).

The lake remains below the normal pool level during much of the year. Lake level depends on inflow from upstream sources and adjacent tributaries, evaporation, flow through the dam penstocks for downstream water use, hydroelectric power generation, and on-lake use. A 7-year water balance of the lake (table 1) shows a significant amount of water loss by evaporation, which on two occasions during the brief period of record exceeds the net flow from upstream reservoirs. Still the amount of evaporation (36 in/yr) is less than the projected pan evaporation (58 in/yr).

The lake experiences a complete through-flow of water on the average of once a year (R. J. Harwood, personal communication, 1973).

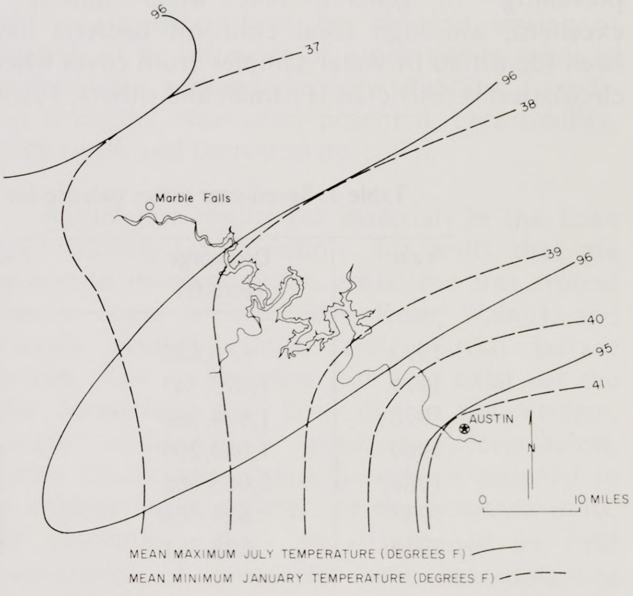

Figure 8. Seasonal temperature variations across the Lake Travis vicinity.

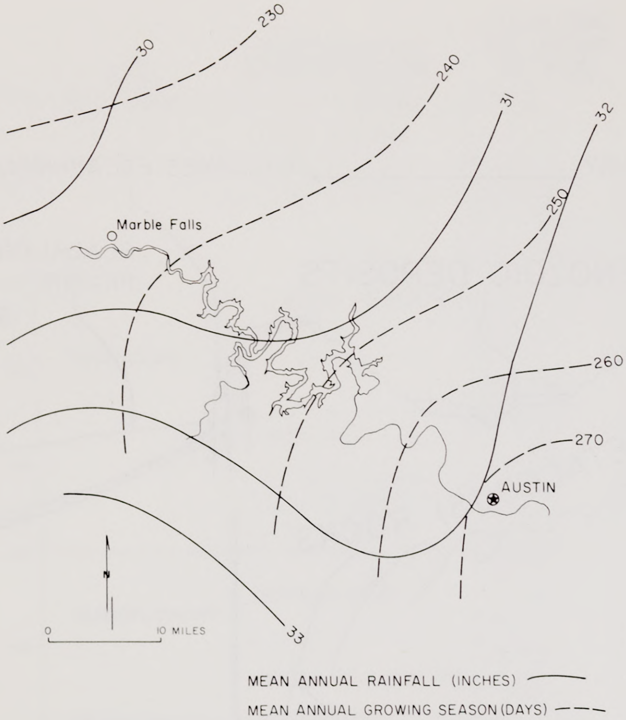

Figure 9. Variations in mean annual rainfall and growing seasons across the Lake Travis vicinity.

Although the amount of flow-through is highly variable from year to year (table 1) reflecting climatic vagaries, the tendency for the lake water to be perennially replaced enhances the quality of lake water and prevents a stagnant situation from prevailing. In general, lake water quality is excellent, although fecal coliform bacteria have been identified in water samples from coves where circulation is restricted (Pittman and others, 1969).

Ground Water

A number of water wells produce from the lowermost Cretaceous strata including the lower Glen Rose Formation and Trinity sands (consisting of the Hensel and Sycamore sands, fig. 4). Unpublished Texas Water Development Board records show wells in the lower Glen Rose aquifer to range in depth from 15 to 450 ft, averaging 150 ft. Well yields range from 5 to 30 gallons per minute (gpm), averaging 10 gpm. Total dissolved solids range from 250 to 1,200 parts per million (ppm), averaging 500 ppm. The Trinity sands aquifer ranges in depth from 100 to 1,200 ft, averaging 500 ft. Well yields range from 10 to 80 gpm, averaging 20 gpm. Total dissolved solids range from 250 to 1,400 ppm with an average of 600 ppm. In addition to these Lower Cretaceous aquifers, there are a few wells that produce from the Ellenburger (Ordovician) aquifer in the western parts of the Lake Travis vicinity.

SOIL AND VEGETATION

Soil is defined in this report as a weathered, bacterially active, surficial material that supports vegetative growth. This material is generally thin (less than 2 ft thick) in the Lake Travis vicinity. Thin soil cover occurs as a response to the dominant parent material (limestone), the subhumid climate, and the high stream dissection associated with steep slopes. Limestones generally weather by dissolution leaving little detritus to form soils. The insoluble residue left from this process is easily eroded from the steep slopes and

Table 1. Seven-year water balance for Lake Travis (from unpublished LCRA sources).

Year	Discharge (acre ft)	Evaporation (acre ft)	Stream Flow (acre ft)	
			net*	uncontrolled**
1972	646,645	88,818	106,071	691,063
1971	1,075,747	77,987	32,114	1,492,074
1970	1,504,380	91,564	321,467	1,465,590
1969	1,083,209	87,462	257,160	1,454,922
1968	2,063,185	82,051	589,716	2,630,246
1967	624,866	85,958	38,122	586,721
1966	823,761	84,967	154,196	955,647

*Net flow is water contributed by inflow from upstream impoundments

**Uncontrolled flow is base flow of streams and direct runoff computed as if upstream impoundments were not present either fills swales or enters the lake directly. The gently sloping stream terraces and Cretaceous sands and conglomerates are covered with thicker, well-drained soils. Soils formed on claystone and shale substrates are generally thin (less than 2 ft thick) and consist mainly of clay.

Soils on the carbonate rock terrane support mainly a juniper/live-oak vegetative assemblage. Live oaks grow preferentially on very thin well-drained soils, such as those that form on hard limestone ledges. Junipers are more abundant on marl and dolomite terranes. Deciduous Spanish oaks grow at certain horizons of the carbonate strata probably indicating a slight increase in sandy and silty (quartzose) material in the soil. Other woody plants commonly seen on the limestone terrane include sumac and Mexican persimmon.

Vegetation on the thicker sandy clay soils (overlying alluvium or the Lower Cretaceous sands) consists mainly of post oak, blackjack oak, mesquite, and acacia. Vegetative indicators of clay soils are mesquite and acacia.

DETAILED DATA BASE

Certain characteristics of the land are especially germane to the evaluation of land capability. They include the properties of materials present (soils and substrate), processes active or potentially active, and ambient landforms. These characteristics of the land can be inventoried by means of a suite of maps depicting soil properties, physical properties of substrate, and environmental geology, respectively. Components of this inventory, although mapped in some detail, must be considered in context of the regional overview—that is, in terms of what climatic, hydrographic, vegetative, and physiographic features are present and regionally dominant.

PHYSICAL PROPERTIES

The physical properties of materials in the Lake Travis vicinity are discussed primarily in terms of substrate (bedrock and surface deposits) and secondarily in terms of biotic soil properties. As soils in the Lake Travis vicinity are mostly less than 2 ft thick, the near-surface bedrock (or surface deposits of alluvium, etc.) dictates constraints on most uses. However, as soil is also defined in an engineering context to include any material that can be excavated using power equipment, some of the substrate material along Lake Travis is discussed in terms of soil engineering parameters. These materials are termed "engineering soils" (fig. 10) to distinguish them from the biotic-supporting soils of the agronomist. The importance of this distinction is that bacterial-biologic soil is essential for agricultural uses and is the medium that regenerates infiltrating waters by physical, chemical, and biological means. This is especially noteworthy where septic tanks are used for domestic waste water treatment.

The physical properties map (pl. 1) provides a three-dimensional view of substrate shown by a cross section and the local (stratigraphic) succession (fig. 11). The three-dimensional view provides information on extractable minerals and ground-water supplies, as well as on changes in engineering properties at depth.

SUBSTRATE PHYSICAL PROPERTIES

Physical properties units are defined by variations in engineering characteristics. These characteristics are determined by physical testing of materials or by inference of properties in terms of the following parameters: slope stability, foundation strength, excavation potential, permeability, shrink-swell, and corrosion potential.

Actual test results for materials in the Lake Travis vicinity exist mainly for units that are exposed in more populous areas (the area around Austin). These include Glen Rose, Walnut, and Edwards geologic units, and alluvial terrace deposits. Few engineering test data exist for the older formations that crop out in the western, mostly undeveloped lakeshore. Nevertheless, relative (qualitative) values have been assigned to the engineering parameters of the untested units. The qualitative values are determined by field observations of properties and extrapolations inferred relative to tested rock materials in the Austin area and other test localities (Rodda and others, 1970; Garner, 1973).

Figure 10. Map of "engineering soils" in the Lake Travis vicinity.

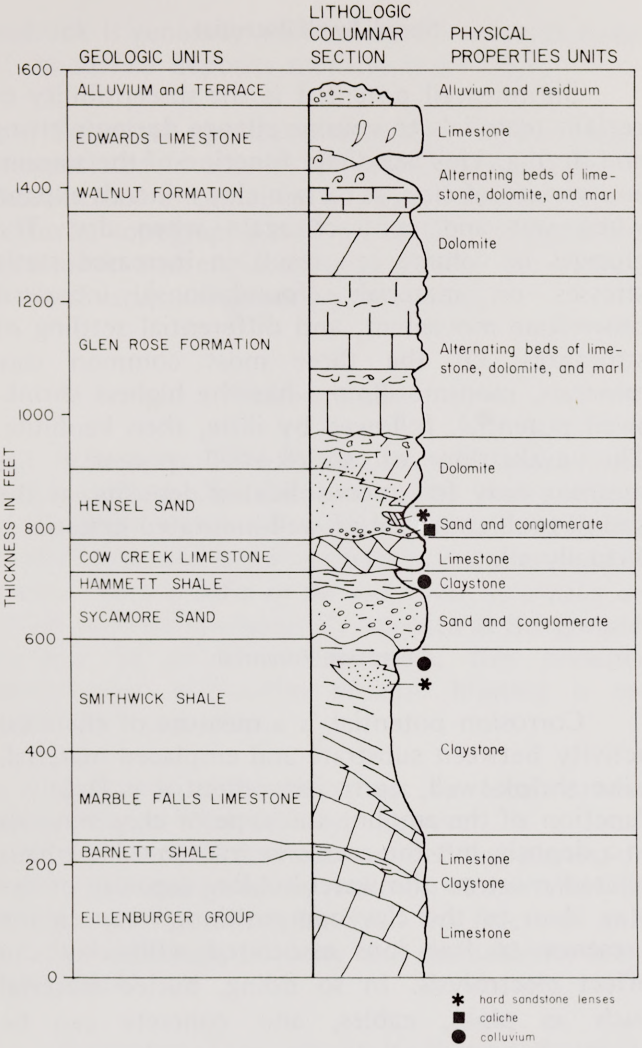

Figure 11. Physical properties units in relation to generalized stratigraphic section.

Where appropriate (that is, where the material is unconsolidated and could be construed as "soil" by engineers), soil engineering data have been used in describing physical properties. These data were obtained from U. S. Department of Agriculture (1974) and Texas Highway Department records. They were used in evaluating the properties of shale, sand, alluvium, and soft marl members of the alternating beds unit.

Slope Stability

Slope stability is an expression of the ability of material to support its own weight in a slope face. Field determination of slope stability (i.e., where engineering test data are not available) is based on landform expression. If the material supports steep slopes or forms escarpments, its slope stability is classed as high. If the material slumps readily and is generally covered by colluvial veneer, the slope stability is assumed to be low (relative to surrounding material).

Foundation Strength

Foundation strength is a qualitative statement of rock competency. In the disciplines of rock mechanics and soil mechanics, there are precise quantitative tests of strength and bearing capacity which are applied to foundation design (table 2). In this study, well-indurated (cemented or crystalline) rock of moderate extent and thickness is judged to have high foundation strength. Evaluations regarding foundation strength of unconsolidated material are based on composition (amount and type of clay), textural aspects (sorting and degree of compaction), and overall geometry (bedding and interfingering of nonhomogeneous facies).

Table 2. Compressive strength of common rock types (from Griswold, 1966, p. 346).

Rock type	Compressive strength (psi)
Granite	20,000 - 40,000
Basalt	10,000 - 35,000
Limestone	10,000 - 35,000
Sandstone	6,000 - 22,000
Shale	6,000 - 28,000

Excavation Potential

Excavation potential, like foundation strength, is a qualitative expression of rock competency. A high excavation potential indicates that the material can be excavated with hand tools or light-duty power equipment such as a backhoe. Low excavation potential means that blasting will probably be required.

Excavation potential also has been quantified. The Caterpillar Tractor Corporation has correlated seismic velocity to rippability of different earth materials (Wylie, 1969). Although no seismic data were available (except by extrapolation from published reports, see fig. 12), the calibration provides a reasonable estimate of excavation potential of certain rock types in the Lake Travis vicinity.

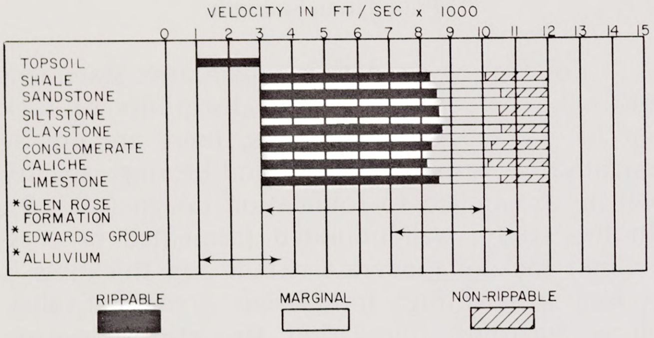

Figure 12. Rippability of earth materials as a function of seismic velocity (after Wylie, 1969). * Formations mapped in Lake Travis vicinity (from Rodda and others, 1970); arrows indicate measured ranges of velocities.

Permeability

Permeability is the capacity of a porous medium to transmit a fluid. Permeability of sand is partially a function of porosity; however, size and interconnection of open spaces within rock or soil is more important to the transmission of water than is total volume of openings. Porosity in rock varies with shape of constituent grains, sorting and packing, and degree of cementation. Porosity and permeability may be enhanced by fractures and solution openings in rock.

Relative permeability is estimated by field observations of rock properties. Any fractured or cavernous limestone is considered highly permeable, although it is recognized that the permeability is extremely localized. Unfractured, semi-indurated deposits with a high clay content are assumed to have a low permeability. Poorly indurated materials are graded for permeability based on the amount of clay at the surface or in near-surface soil horizons. There commonly is a near-surface decrease in permeability because of clay eluviation in soil-forming processes.

Shrink-Swell Potential

Shrink-swell potential is the susceptibility of certain materials to volume change during wetting and drying. This is a direct function of the amount and variety of clay, as certain clay minerals expand when wet and contract again when dry. The changes in volume can result in increased static stresses on materials (foundations), increased downslope movement, and differential settling of structures. Of the three most common clay minerals, montmorillonite has the highest shrink-swell potential, followed by illite, then kaolinite. The evaluation of shrink-swell potential has meaning only for unconsolidated deposits, as the shrink-swell potential of well-indurated material is virtually nil.

Corrosion Potential

Corrosion potential is a measure of chemical activity between substrate and emplaced material. Like shrink-swell, corrosion potential is largely a function of the amount and type of clay minerals in a deposit, but the corrosive influence is perhaps related more to the water-holding capacity of the clay than to the clay composition. Water in the presence of free ions associated with clay can effect electrolysis. In so doing, buried material such as pipes, cables, and concrete can be chemically attacked. In a very well-drained substance or in a dry climate, corrosion will not be as damaging regardless of substrate material.

SUBSTRATE UNITS

Substrate materials are grouped into two categories—bedrock and surface deposits. The main distinction between the types of units is based on geometry, with secondary considerations based on age and mode of occurrence. Surface deposits comprise areally discontinuous, thin (in this area, up to about 50 ft thick) deposits that result from relatively recent geologic processes such as stream deposition, mass wasting, and calichification. Bedrock comprises generally thicker, older, and more areally extensive rock that is commonly traceable into the subsurface. The relative positions of bedrock units are important to subsurface interpretations (see fig. 11). The physical properties of the two types of units may not be different; however, bedrock is generally well indurated, whereas many of the surface deposits are loose and friable.

Substrate physical properties units (pl. 1) are encapsulated in a series of tables (tables 3 and 4) that include information on rock types, structural features, topography, soil properties (in both the agronomic and engineering contexts), and evaluations of various engineering parameters.

Bedrock Units

Limestone.—The limestone unit consists of well-indurated, bedded rock. The rock is not monolithic; planes of weakness occur, including nearly horizontal bedding surfaces and near-vertical joints. There is little or no soil cover, so blocky or flaggy bedrock is commonly exposed at the ground surface. In most circumstances, this presents construction difficulties because blasting is required for excavation.

Scattered sinkholes attest to local cavern development. Permeability, however, is a local property confined to fractures, bedding planes, or fossil casts enhanced by solution rather than to intergranular porosity. Between the fractures and solution openings, porosity and permeability may be very low.

Dolomite.—The physical properties unit, dolomite, does not connote a monolithic assemblage of one rock type. Instead, it contains interbeds of hard limestone, friable limestone (chalk), and marl, with an overall abundance of dolomite strata. Dolomite occurs in two distinct stratigraphic horizons—the lower 100 ft of the Glen Rose Formation and the uppermost part of the same formation. Dolomite occurring in this unit is a porous, surficially friable, thin- to thick-bedded rock with overall properties more closely related to hard limestone than to marl. It is physiographically expressed as prominent benches with sparse vegetative cover.

The major aspects that set dolomite apart from the limestone beds are its weathering characteristics and intergranular porosity. Dolomite weathers to thin residuum that is rippable with power equipment although blasting is required at depth. Poor induration near the ground surface and stained, weathered appearance in outcrop is a diagnostic feature of the dolomite beds. The intergranular porosity consists of small interconnected pores up to 1 mm in diameter that allow fluid to flow in paths other than along bedding planes, fractures, and fossil casts. The extensive intergranular porosity is evidenced by the sudden appearance of seeps from dolomite beds after rains. Seeps may continue for days (or weeks) after the cessation of rainfall. The duration of ephemeral discharge indicates that dolomite beds hold water within intergranular pores that otherwise would flow rapidly through fractured limestone. The stored water is slowly discharged by a sustained flow. No producing wells are known in the upper Glen Rose dolomite, but some water is obtained from the lower dolomite.

Alternating beds of limestone, dolomite, and marl.—The alternating beds unit contains a diversity of rock types and thus has a broad range of physical properties. To derive the overall physical properties of this unit, one must consider the limitations of each rock type.

The properties of the individual limestone and dolomite strata in the alternating beds unit are the same as those discussed regarding the separate limestone and dolomite map units. However, there is a change in gross properties where hard rocks are intercalated with marly recessive beds.

Marl is rippable by hand or with light-duty power equipment, although it might be adjacent to resistant limestone or dolomite ledges up to 10 feet thick. Slope stability of marl is less than that of limestone and dolomite. This is attested to by colluvial material from the resistant beds veneering marl subslopes. Regardless, marl is a moderately stable substrate that will support cut slopes in most instances. Flawn (1970, p. 294) noted a retaining-wall failure in marl, but the collapse was attributed to improper drainage (a construction error) and *not* to inherent weaknesses of the substrate. Corrosion potential is higher within the marl than in adjacent beds but is still moderate to low.

Claystone.—Claystone and shale are soft, homogeneous, poorly indurated materials that do not exhibit prominent bedding partings or secondary openings. Clay mineral composition of this unit is largely illite; thus, only moderate problems with foundations and slope stability might be expected. Claystone can generally be excavated without heavy power equipment. Workability of this material, however, is dependent

Table 3. Physical properties units.

Unit	Description	Topographic expression	Biotic soil (U.S.D.A. classification* and thickness)	Engineering soil+ (Unified classification)*
BEDROCK UNITS				
Limestone	Hard, dense, with fractures and solution features	Broad areas of low to moderate relief; forms escarpments at contacts with less resistant rocks	Loam; clay (locally stony) < 2′	–––
Dolomite	Porous, surficially friable dolomite; also interbeds of siltstone, limestone, and marl	Stairstep topography	Loam; (locally stony) < 2′	–––
Alternating beds of limestone, dolomite, and marl	Interbeds of hard to soft limestone, marl, and dolomite	Stairstep topography	Loam; (locally stony) < 2′	(Marl strata) CL, ML
Claystone	Claystone; shale; minor hard limestone, sandstone, or conglomerate	Low recessive slopes generally covered; also steeply cut stream banks	Clay < 2′	CL
Sand and conglomerate	Poorly indurated sand and gravel and silty clay	Gently rolling lowlands	Fine sandy loam; sandy clay > 2′ < 6′	SP, CL, ML
Hard sandstone	Hard, dense sandstone; minor claystone; also sandy limestone	Local steep slopes, amidst low-rolling terrain	Sandy loam < 2′	–––
SURFACE UNITS				
Alluvium and residuum	Silty clay with admixed "float"; sand and gravel	Low-relief areas along stream courses and high terrace levels; bottoms of steep-walled valleys in limestone terrane	Silty loam; silty clay > 2′ < 6′ locally > 6′	SM, SC, CL, ML
Colluvium	Clay matrix with blocky limestone or gravel-cobble debris	Slump blocks or debris veneers on steep slopes	Stony clay < 2′	–––
Caliche	Caliche without admixed detritus; caliche-welded residuum	Very low slopes	Stony soil < 2′	–––

+Applies to units or parts of units that can be excavated without blasting

*See appendix A

Table 4. Qualitative engineering characteristics of physical properties units.

Units	Slope stability	Permeability	Excavation potential	Foundation strength	Shrink-swell	Corrosion potential
BEDROCK UNITS						
Limestone	High	Low-high	Low	High	NA	Low
Dolomite	High	Moderate-high	Low-moderate	High	NA	Low
Alternating beds of limestone, dolomite, and marl	Moderate-high	Low-moderate	Moderate-low	High-moderate	Low	Moderate-low
Claystone	Low	Low	High	Moderate-low	Moderate-high	High
Sand and conglomerate	Moderate	Moderate-high	High	Moderate	Low	Moderate
Hard sandstone	High	Moderate-low	Low	High	NA	Low
SURFACE UNITS						
Alluvium and residuum	Moderate-low	Moderate-high	High	Moderate-low	Moderate-low	Moderate
Colluvium	Low	Low	Low	Low	High	High
Caliche	High	Low-moderate	Moderate-low	High	Low	Low

NA = Not applicable

upon the weather, with wet ground conditions precluding many activities. Permeability is low and corrosion potential is high because of clay content. Thin clay biogenic soils possess properties similar to the underlying claystone substrate.

Sand and conglomerate.—The sand and conglomerate unit consists mostly of poorly indurated rock with constituent particles ranging in size from a predominant sand fraction to cobbles and boulders with admixed silt and clay. Component particles consist mainly of quartz and feldspar sand grains and coarser rock fragments derived from the Llano igneous-metamorphic terrane. Crossbedding is common, but joints are only rarely seen within thin, well-cemented strata.

Soils formed on this unit contain abundant clay which is derived mostly from weathering of feldspars. Eluviation of clay results in a near-surface decrease in permeability, but this does not extend to a depth of more than a few feet. Within the substrate, permeability is high to moderate.

Hard sandstone.—The hard sandstone unit consists of two rock types. At some localities in the western part of the Lake Travis vicinity, it consists of well-indurated sandstone containing fine-grained rock fragments and quartz-mica sand cemented by silica. At other localities, the unit contains coarse-grained quartz-feldspar sand cemented by calcite. These sandstone deposits occur in lenticular or irregular bodies, which vary from a few feet to 50 ft thick. Jointing and faulting occur locally. Slope stability is high as is foundation strength *if* the area is underlain by a continuous deposit of uniform thickness; but areally continuous substrate does not occur everywhere because of the lenticular geometry of the rock. Intergranular permeability is very low and is not significantly augmented by solution activity or by fossil casts; however, it may be slightly enhanced by fractures. Soil cover is thin and discontinuous, contains a blocky residuum, and commonly has a high clay content.

Surface Units

Alluvium and residuum.—Alluvium and residuum consists of unconsolidated to semiconsolidated, poorly stratified deposits of clay, sand, silt, gravel, and cobbles. The individual clasts consist of a variety of materials including rock fragments derived both from the Llano igneous-metamorphic areas and from the sedimentary terranes along lakeshore. Cementation by caliche occurs locally. Coarse-grained terrace deposits of the Colorado River occur along the upper reaches of Lake Travis as well as along large tributary streams. Valley-fill (alluvial-colluvial) deposits occur along small tributary streams in the hilly limestone/alternating beds terranes. This material is predominantly clayey with admixed blocky float. Residuum is an admixture of alluvial and colluvial materials that veneer broad low-slope areas.

Despite local caliche content, the rock within this unit can be excavated using equipment such as a backhoe. Foundation strength and shrink-swell are moderate to low, predicated upon local variations and amount of clay in relation to pebbles and cobbles (framework fragments). Also, permeability is dependent upon clay content, especially eluviated clay in soil horizons. The permeability of the coarse, unconsolidated deposits ranges from moderate at depth to low in near-surface horizons. Permeability in fine-grained valley-fill deposits is low.

Colluvium.—Colluvium consists mainly of large blocks of limestone admixed with clay. It also consists of cobble-pebble veneers and rotational slump blocks over clay substrate. Most of the physical properties criteria do not apply to colluvium because it is material *in the process of downslope movement.* For example, this unit can be excavated, but such activity upsets the equilibrium profile of the slope and triggers new movements. Construction is hampered by the presence of large limestone blocks that have slumped across the colluvial surface. As clay is a common constituent of this unit, permeability is low. Water saturation resulting from poor drainage further aids the downslope movement process.

Caliche.—Caliche units consist of nearly pure deposits of calicum carbonate (caliche) as well as bodies of cemented colluvial-alluvial detritus. Calichification is a process involving the movement of soil water through pores; upon evaporation of the water, the pore space is filled with precipitated salts (generally $CaCO_3$). Thus, when the process goes to near completion the resultant permeability is essentially nil. Resistant caliche caps above erodible or weak material attest to a high slope stability, high foundation strength, and essentially no shrink-swell. Excavation potential is low to moderate, and corrosion potential is low.

FRACTURES

Areal extent and orientation of fractures are important components of substrate physical properties especially in terms of rock competency and permeability. Aerial photographic interpretations of relative bedrock fracture density were made for areas in the Lake Travis vicinity that are covered by aerial photographs at a scale of 1:20,000. Unfortunately, this coverage is complete only along the downstream lake reaches.[3]

The features mapped are referred to as "fracture traces" and "lineaments." Both are defined by Lattman (1958) as "natural linear features consisting of topographic (including straight stream segments) vegetation or soil tonal alignments visible primarily on aerial photographs." Fracture traces are features that are expressed continuously for less than 1 mile, whereas lineaments are expressed continuously for at least 1 mile or discontinuously for more. These features, although not fractures in rock per se, typically are surface indications of joints or faults in bedrock. The number of such features observed on aerial photographs is thought to be a function of fracture density in bedrock.

Fracture traces were mapped using the techniques of Trainer (1967), and a count of lineations per unit area was made to estimate relative fracture density. Numerical analysis of the fracture traces was done using a moving average based on a map grid at 1:24,000 scale. In this way, there was a continuous overlap within the fracture point count and a dampening of marked discontinuities in fractures per unit area. A contour map showing fracture-trace density (fig. 13) was thus constructed for the part of the Lake Travis vicinity covered by aerial photographs at a scale of 1:20,000.

Areas underlain by less competent rocks show a lower fracture intensity. These areas include the poorly indurated sands and conglomerates and the marl beds in the alternating beds unit. Areas of low relief underlain by limestone and dolomite also show a relatively low fracture density. The example of the low relief/low fracture trace correlation is not necessarily a true relationship. High relief and associated increases in drainage density might result in more fracture traces being discerned. Thus, terrain factors may affect an otherwise unbiased fracture evaluation.

Fractures comprise an important *secondary* physical property of bedrock in the Lake Travis vicinity, as certain areas may preferentially recharge either meteoric waters or waste water because of local fracture-induced permeability.

SOIL PROPERTIES

The importance of soil properties in the Lake Travis vicinity is limited mainly by thickness (or depth) of surficial (biogenic) soil. Soils as engineering entities exist mainly where depth to bedrock is greater than approximately 2 ft (fig. 14). Nonetheless, soils are everywhere important as supporters of biota and as filters for ion exchange in natural waters (fig. 15).

A tabular description of soils in the Lake Travis vicinity (table 5) includes information on parent material, characteristic landscape, thickness, texture, vegetative assemblages, and other distinguishing features.

The soils units mapped within the Lake Travis vicinity are largely based upon work done by the U. S. Department of Agriculture (USDA) Soil Conservation Service (SCS). The agronomists' soil definition is corroborated by the close alignment between soil units and geologic formations. In fact, that part of the soil map extending into Burnet County is derived from the geologic map, whereas the Travis County mapping was compiled and modified from extant SCS information (U. S. Department of Agriculture, 1974). The generalized soil map obtained from the geologic base fits a reasonably accurate picture in terms of soil series as stated in the field by an SCS soil scientist (W. H. Dittemore, personal communication, 1972).

ENVIRONMENTAL GEOLOGY

The environmental geologic map (pl. 2) is an interpretative presentation of interactions between active processes, substrate materials, and ambient landforms (pl. 3) in the Lake Travis vicinity. There are three corresponding classes of units on this map: process units, material units, and material-landform units. The type of unit discriminated in

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[3] McQueen (1963) and Boyer and McQueen (1964) analyzed the upper reaches of Lake Travis for fracture occurrence (although not for fracture intensity).

Figure 13. Map showing density of fracture traces and lineaments in the Lake Travis vicinity.

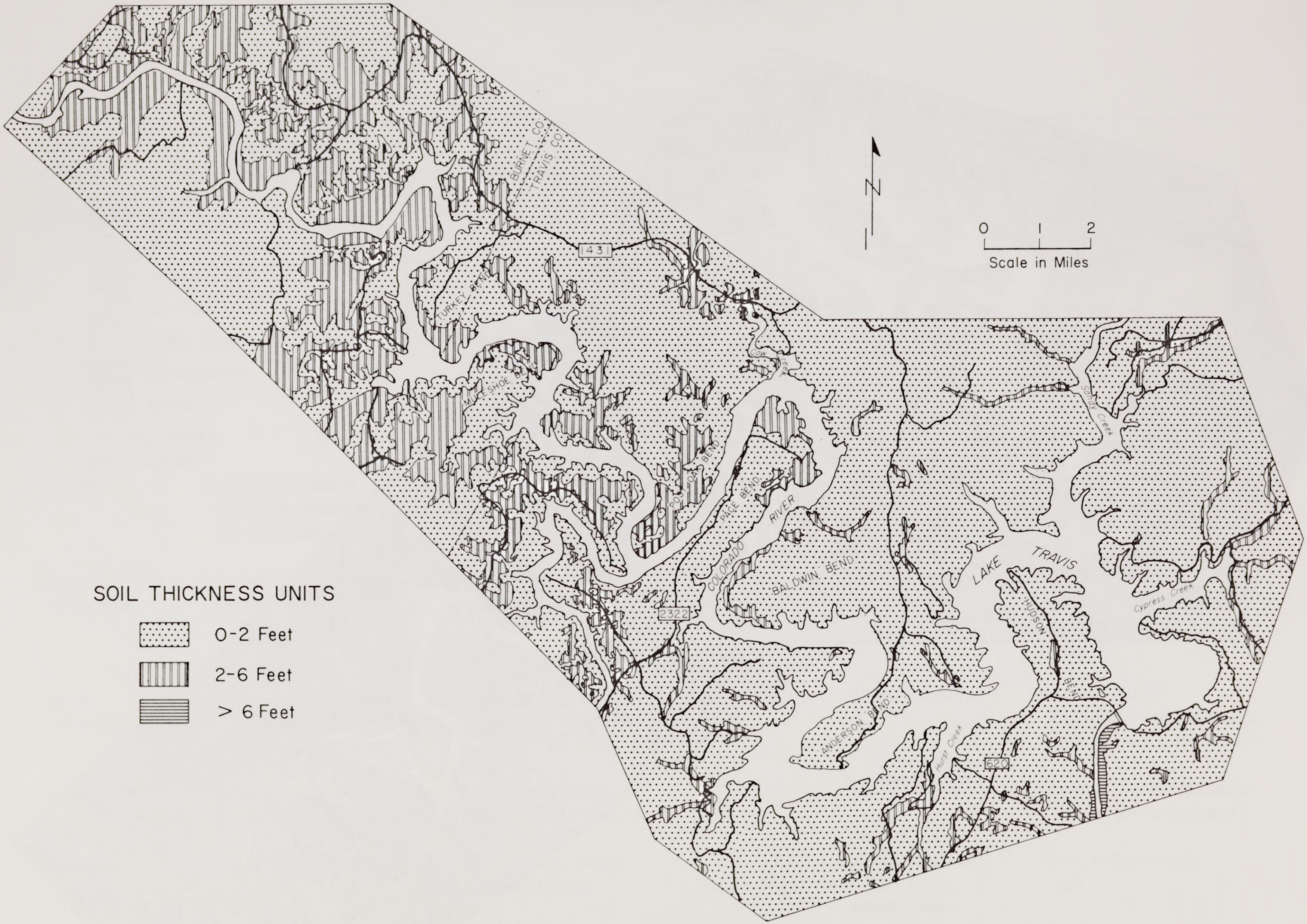

Figure 14. Map showing thickness of biogenic soils in the Lake Travis vicinity.

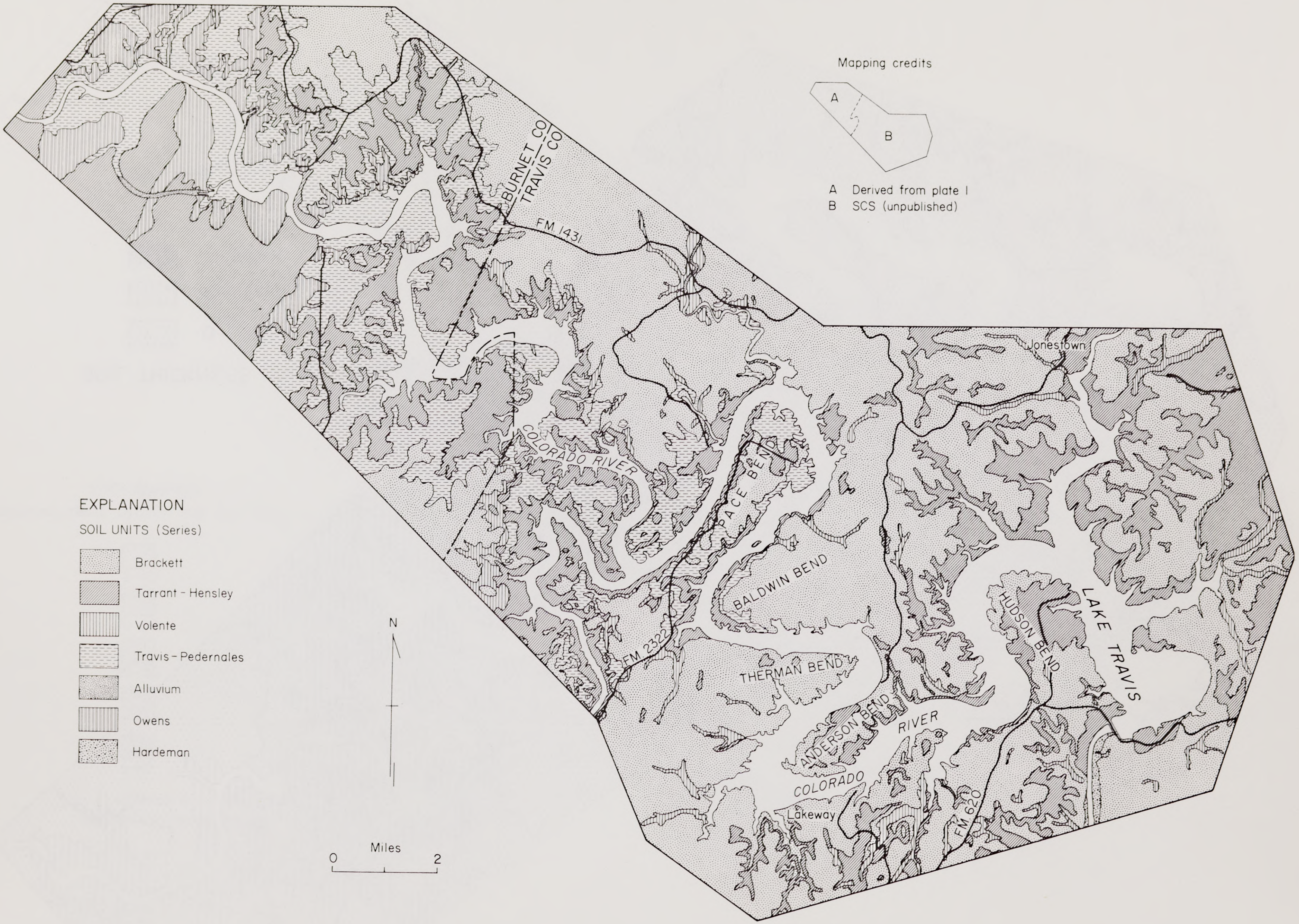

Figure 15. Map showing biogenic soil associations in the Lake Travis vicinity.

Table 5. Description of soil units*.

Soil unit (series)	Parent material (physical properties units)	Landscape	Thickness (inches)	Texture (USDA)+	Comments
Brackett	Limestone; dolomite; alternating beds of limestone, dolomite, and marl	Hilly uplands	0 - 20	Gravelly loam; clay loam	Limestone rubble or bedrock may cover up to 75 percent of surface
Tarrant - Hensley	Limestone; dolomite	Steep slopes; plateau land (low slopes)	0 - 20	Stony clay; loam	85 percent of surface may be covered by limestone blocks; admixed limestone and cherty residuum
Volente	Alternating beds of limestone, dolomite, and marl; dolomite	Concave slopes (valley bottoms)	30 - 50	Clay loam; silty clay	Contains limestone "float"
Travis - Pedernales	Sand and conglomerate; alluvium and residuum	Low slopes; terrace surfaces	0 - 80	Sandy loam; sandy clay; sandy clay loam	Contains admixed pebble- and cobble-sized fragments; locally bedrock at ground surface
Mixed Alluvium	Alluvium and residuum (locally bedrock)	Active stream courses; floodplains	0 - 40	Loam (locally)	Not a true soil; defined by stream course, may be bare rock outcrop
Owens	Claystone (minor hard sandstone)	Low slopes; locally dissected streambanks	0 - 20	Clay; clay loam	Contains blocky sandstone (Exray soil inclusions)
Hardeman	Alluvium and residuum	River terraces below Mansfield Dam	54 - 72 (locally > 72)	Fine sandy loam; silty loam	Thick well-drained soil

*Adapted in part from U. S. Department of Agriculture (1974)

+See appendix A

an area depends on which environmental factor is locally dominant. That is, all three factors (materials, processes, and landforms) interact at every locality, but a judgment is made as to the most important entity in terms of human activities. Every unit in each of the three classes is defined not only in terms of the dominant environmental entity, whether it be process, landform, or material, but information is also provided on the ancillary features. Thus, process units are defined in terms of materials and landforms, as well as dominant processes. These three types of units have been discussed previously by Woodruff and Lentz (1973) and Woodruff (1974).

The environmental geologic map is complementary to the physical properties map that shows only substrate materials without regard to processes and landforms. Furthermore, slope maps (fig. 16) and soil maps (fig. 15) supplement information on both the physical properties and environmental geologic maps. The complementary nature of the various thematic maps is seen in consideration of an area adjacent to a tributary to Lake Travis. The physical properties map shows the areal extent of alluvium versus bedrock. The soil map indicates the distribution of soils of different thicknesses and textures, whereas the slope map emphasizes terrain features that are also visible on topographic maps. These data are useful in a variety of ways. Information on substrate properties is needed by the extractor of sand and gravel, whereas substrate, soil conditions, and slope are germane to agricultural activities. The environmental geologic map, however, shows information beyond the explicit features of the land (i.e., soil, bedrock, and slope)—it delimits locations of hazard areas by means of process units such as flood-prone areas. This is of vital importance in choosing a homesite.

Process Units

Process units represent those areas dominated by recurrent or ongoing natural processes. They include areas subject to geologic hazards such as flooding and mass wasting. They also include such natural processes as aquifer recharge even though such processes do not pose *immediate* direct hazards to human populations. Instead, recharge areas are sensitive zones with regard to maintaining suitable quality of water supplies and are subject to subtle changes (abuses) over the long term.

Process units mapped in the Lake Travis vicinity include flood-prone areas, unstable slope areas, and aquifer recharge areas (table 6). Within the overall subdivision of process units, there is a ranking determined by immediacy or severity of impact of the process. This ranking allows a consistent choice of units wherever two or more processes occur in the same area. Within this scheme flood-prone areas take precedence over all

Table 6. Process unit descriptions.

	Material	Terrain	Dominant Process
Flood-prone areas	Alluvium; variable bedrock types	Low-slope valley bottoms; steep-walled valley sides	Flooding; erosion; sedimentation
Unstable-slope areas	Colluvium; limestone blocks in clay matrix; sand and conglomerate admixed with clay	Steep slopes (generally greater than 15 percent)	Slumping; creep; erosion
Aquifer recharge zone	Sand and conglomerate admixed with clay; limestone	Variable low slopes (generally less than 8 percent); low-relief rolling terrane	Recharge; erosion; local flooding

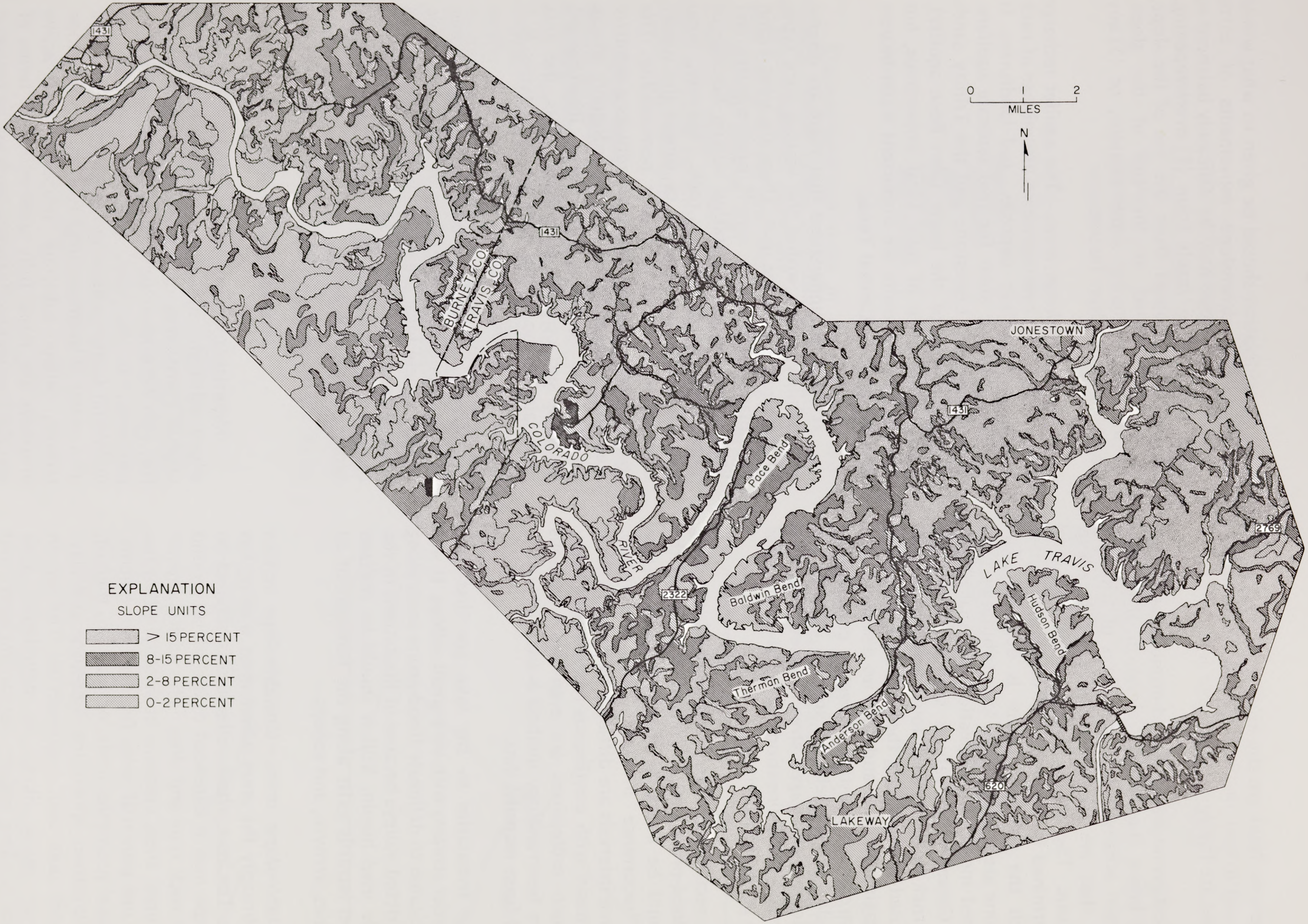

Figure 16. Map depicting ground slope in the Lake Travis vicinity.

other factors. Next are the areas of slope-stability hazard, and lowest in the hierarchy of immediate limitations are the aquifer recharge areas.

Flood-prone areas.—Flood-prone areas include the land below the spillway elevation of the lake and certain areally restricted valleys of tributary streams that are above influence of lake-level fluctuations. The shoreline below spillway level was determined by inspection of topographic maps on which the spillway datum is depicted. The flood-prone areas adjacent to lake tributaries were determined mostly by inspection of aerial photographs. Geomorphic features such as incisement into bedrock or presence of low-level terraces were criteria used in delimiting these floodplains. There are no gaging stations and thus no discharge data for the streams in question; however, comparisons were made between selected streams in the Lake Travis vicinity and gaged streams elsewhere. This corroborated the delineations of flood-prone areas based on geomorphic criteria.

No recurrence interval is implied regarding these "flood-prone areas." Indeed, the user of the land should be aware of the limitations of projecting "recurrence intervals" into the future. Recurrence intervals are difficult to project within a gaged basin with continuous records over many years. Such projections are even more tenuous where the basin-analogy method is used instead of historical (gage records) data.

Most tributaries to the lake are first- and second-order streams with very small valleys. It was not practicable to delineate flood-prone areas along such restricted valleys because of limitations of the map scale used herein. Still it should be realized that flood hazards exist along the bottoms of all these swales, arroyos, and valleys.

Unstable-slope areas.—Unstable-slope terrain includes broadly the areas where mass wasting has occurred. The area where colluvium is mapped on the geologic map is extended to include all ground of similar rock type and slope. This environmental geologic unit, then, contains both terrain that has slumped and potential areas for mass movements. The physical properties units, or fractions thereof, include claystone underlying limestone and claystone under sand and conglomerate. The terrain mapped as most likely to experience mass movements is along steeply cut stream banks and other oversteepened slopes.

Consideration should be given to what would cause further downslope movements of earth materials. The slope may be delicately balanced so that failure may result from (1) oversteepening, (2) removing support from the toe of the slope, (3) increasing load at the top of the slope, (4) increasing internal water content, or (5) any combination of these factors.

Aquifer recharge areas.—The aquifer recharge unit consists of a heterogeneous assemblage of rock types, soils, surface deposits, and landforms. It includes recharge areas for two separate aquifers: the Ellenburger Limestone and the Trinity sands (including part of the lower Glen Rose aquifer). Both aquifers are of only local importance, but correlative rock units are important water-bearers in other areas of Central Texas.

It must be understood that there are diverse permeability values within the various rock types of the aquifer recharge unit. There are areas within this map entity where runoff predominates and little ground-water infiltration occurs because of steep slope or impervious rock. However, these impermeable zones channel or spread the runoff onto adjacent rocks of higher permeability. The recharge zone is considered broadly as a sensitive area that ultimately (if not immediately) affects quality and quantity of water interchanged between surface and subsurface. Thus, the area underlain by an entire suite of rock types is a potential recharge zone.

There are also local but discontinuous zones of high permeability elsewhere in the stratigraphic section. These local areas are not delimited on the environmental geologic map, but an example on the physical properties map is the dolomite unit capping many high hills.

Material-Landform Units

Material-landform units include those areas where substrate and terrain interact mutually to impose constraints on (or provide enhancements for) specific human uses. These areas are subject to processes, to be sure, but the processes are incidental to the general terrane. A prime example of a material-landform unit is a karstic limestone terrane, where substrate properties and active processes are more fully understood in terms of specific topographic features—such as the presence of sinkholes and caves.

Table 7. Material-landform unit descriptions.

	Material	Terrain	Dominant Process
Karstic limestone terrane	Limestone	Low slope (less than 8 percent); sinkholes and caves locally evident	Infiltration
High- to moderate-relief carbonate rock terrane	Alternating beds of limestone, dolomite, and marl; dolomite	Generally steep slopes (greater than 8 percent); stairstep topography	Runoff; erosion; local flooding

Material-landform units in the Lake Travis vicinity include karstic limestone terrane and high- to moderate-relief carbonate rock terrane. These units can be further described in terms of processes and surficial soils as well as materials and terrain (table 7). Similar material-landform units have been described for another carbonate rock terrane by Wermund and others (1974).

Karstic limestone terrane.—Karstic limestone terrane comprises those "non-aquifer" parts of the resistant limestone unit on the physical properties map. This unit, which characteristically exhibits solution features (fig. 17), is similar to a limestone aquifer recharge system, but because of terrain conditions or local rock geometry, storage of water does not occur. In short, the strata included within this unit do not constitute a producing aquifer. Rapid infiltration into the subsurface may locally occur, however. The landscape of this karstic terrane is typically one of low relief (about 120 ft/sq mi, maximum) and low slope (less than 8 percent). Soil cover is very thin (less than 2 ft) or absent. As a result of low slope and high infiltration of meteoric waters, drainage density is low (fig. 18).

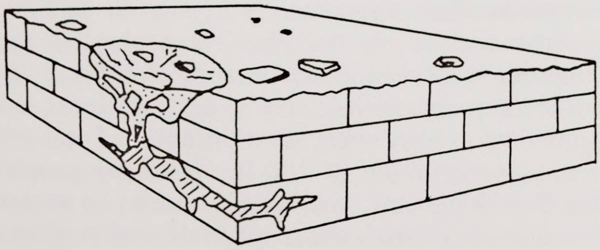

Figure 17. Block diagram showing relation between substrate and landform in karstic limestone terrane.

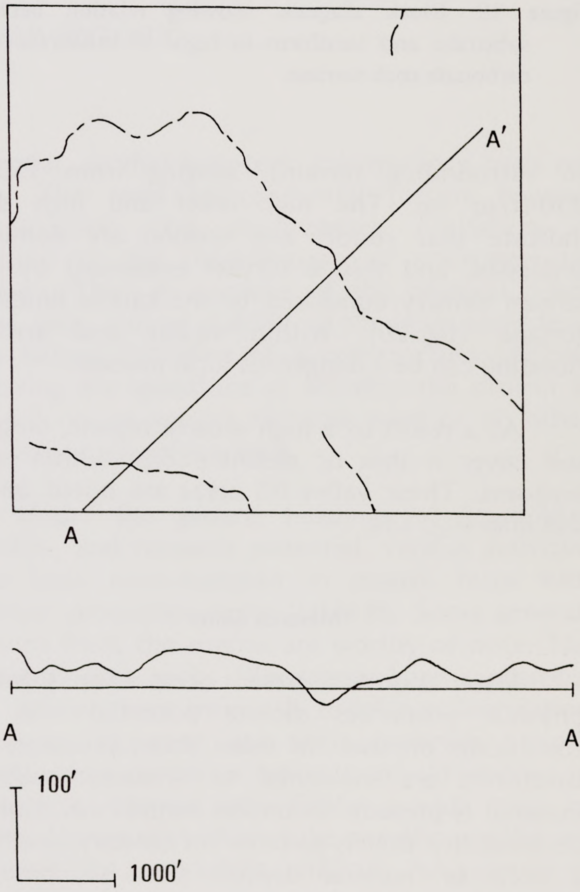

Figure 18. Drainage density and relief of typical square-mile area of karstic limestone terrane (drainage density = 2.12 mi/sq mi).

High- to moderate-relief carbonate rock terrane.—The high- to moderate-relief carbonate rock terrane is characterized by steep slopes (greater than 8 percent, commonly greater than 15 percent) and stairstep topography. This unit comprises parts of the alternating beds, dolomite, and limestone units from the physical properties map (fig. 19). Relief is high to moderate (relative to surrounding terrain), ranging from 150 to 350 ft/sq mi. The high relief and high slope indicate that runoff and erosion are dominant processes, and this is further evidenced by high stream density compared to the karstic limestone terrane (fig. 20). Within swales and arroyos, flooding can be a dangerous local process.

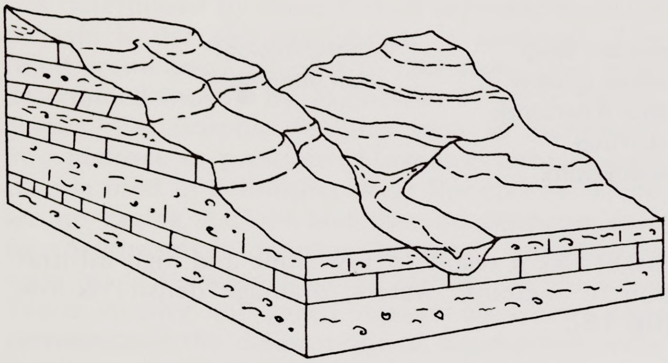

Figure 19. Block diagram showing relation between substrate and landform in high- to moderate-relief carbonate rock terrane.

As a result of a high erosive regime, biogenic soil cover is thin or absent except within valley bottoms. These valley-fill areas are noted on the soil map (fig. 15).

Material Units

Material units represent areas where substrate physical properties dictate potential uses and constraints on uses. In these areas, processes and landforms are incidental to whatever substrate material is present. Examples include a clay of low permeability that is suitable for sanitary landfill or a rock or mineral deposit that has potential economic value. Material units can be derived directly from the physical properties map, and one should refer to the discussion of physical properties units for detailed descriptions.

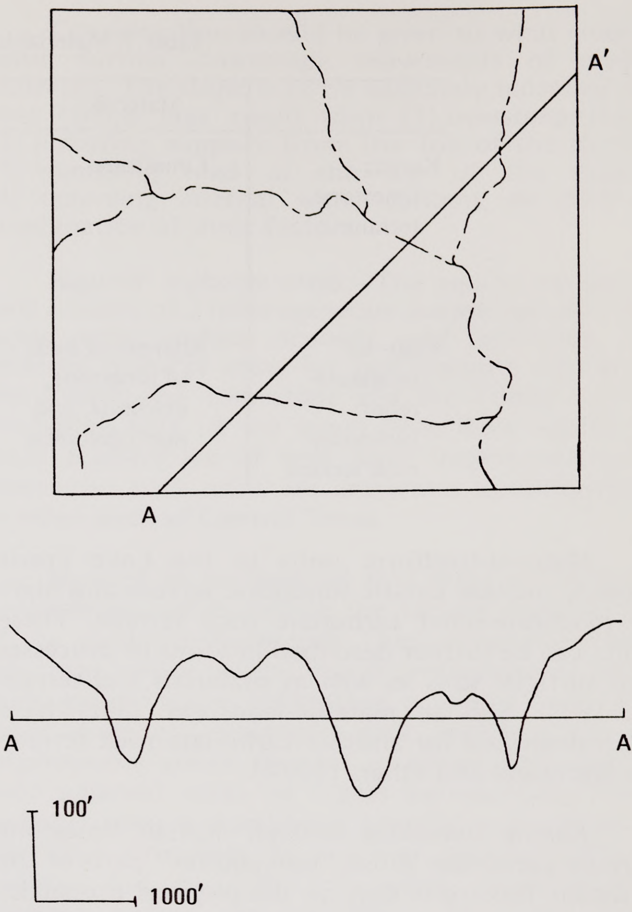

Figure 20. Drainage density and relief of typical square-mile area in high- to moderate-relief carbonate rock terrane (drainage density = 3.45 mi/sq mi).

Material units in the Lake Travis vicinity include claystone-sandstone and alluvium. These units are discussed beyond the physical properties description to encompass factors of terrain and processes (table 8).

Claystone-sandstone.—Claystone-sandstone comprises the claystone and part of the hard sandstone units on the physical properties map. This unit is discriminated because of typically low substrate permeability, and except for local sandstone lenses, high excavation potential. Total relief reaches a maximum of 100 ft. Slopes are generally less than 8 percent, but locally exceed 15 percent. The dominant processes are runoff and erosion on steep slopes. Mass wasting is a potential process on oversteepened slopes. Soils are thin (less than 2 ft thick) and clayey.

Table 8. Material unit descriptions.

	Material	Terrain	Dominant Process
Claystone-sandstone	Claystone; shale; local lenses of sandstone	Low recessive slopes, generally (less than 8 percent); local steep slopes	Runoff; erosion
Alluvium	Sand and gravel; silty clay	Nearly flat terraces; narrow valley bottoms	Infiltration; runoff; erosion

Alluvium.—Alluvium comprises part of the alluvium-residuum unit from the physical properties map. It includes a diversity of material including gravelly stream terraces, clayey valley-fill (alluvial-colluvial) material, and calichified coarse-grained residuum. This land characteristically has low total relief (less than 60 ft) and low slope (less than 2 percent) and is covered by thick (greater than 4 to 6 ft), well-drained soil. Dominant processes are runoff and some ground-water infiltration. The unit is included within the material category as a prevalent local source for sand and gravel. More importantly, it is also an agricultural land resource.

EVALUATION OF LAND INVENTORY

CONSTRAINTS

The three types of natural constraints on land use in the Lake Travis vicinity are related to substrate physical properties, biogenic soil, and environmental geology. There are other constraining factors such as slope and fracture intensity, but in general these are subordinate to broader threefold division. Of the three types of constraints, substrate properties and environmental geologic factors overshadow soil properties because thin soils cover substrate throughout most of the area.

PHYSICAL PROPERTIES CONSTRAINTS

Physical properties units can be evaluated in terms of three factors: short-term *feasibility* of activity, long-term *stability* of finished product, and location of *potential rock or mineral resources.* The distinction between short-term (construction) activities and long-term use is important for estimating the short- and long-term costs of a project (such as maintenance versus initial investments). For example, a plastic clay is generally very rippable, so that short-term construction costs for a pipeline are low. However, plastic clay has a high corrosion potential and a high shrink-swell potential, so that long-term maintenance costs are high. The *total* environmental picture beyond construction and maintenance limitation is deferred to the consideration of environmental geology. Thus, in context of the physical properties map, ground stability is the main consideration before initiation of a construction project, deferring the questions of whether the project is located on an aquifer recharge zone or on other sensitive or hazardous areas.

Under the general headings of feasibility, stability, and resource potential, various activities have been cross-matched in matrix form with physical properties units (table 9). Some generalizations from the matrix are worthy of note. The well-indurated rocks (limestone, hard sandstone, and dolomite) are eminently suitable as foundation substrate. However, the same materials present construction problems because of difficulties in excavation. Certain units display a wide range of physical properties that make specific predictions of feasibility or suitability difficult. An example of this is the alternating beds unit that contains hard limestone ledges adjacent to soft marl. The limestones generally require blasting, but the marl is rippable with light-duty power equipment. Lime-

Table 9. Land-use constraints based on physical properties units.

	Feasibility	Suitability					Resource Potential
	Grading & excavation	Heavy construction	Light construction	Pipeline maintenance	Catchment ponds	Waste containment	Mineral resource
BEDROCK UNITS							
Limestone	—	+	+	+	—	—	+
Dolomite	—	+	+	+	—	—	—
Alternating beds of limestone, dolomite, and marl	—/+	—/+	+	+/o	—	—	—/+
Claystone	+	—	—/+	—	+	+	—
Sand and conglomerate	+/o	o	+	+/—	—/o	—	—
Hard sandstone	—	+/—	+	+	—	—	—
SURFACE UNITS							
Alluvium and residuum	+	—/o	+/o	+/—	—/+	—	+/—
Colluvium	—	—	—	—	—	—	—
Caliche	o	+/o	+	+	—	—	+

+ = little or no constraints; high potential
o = moderate constraints
— = severe constraints; low potential

stone is locally very permeable, whereas marl tends to restrict subsurface drainage. Such areas that possess variations in properties are depicted on the matrix by a range of engineering constraints for a given unit. Besides the alternating beds unit, other materials with variable properties are sand and conglomerate and alluvium. Site investigations of geologic and engineering properties are especially important in these areas.

The colluvium unit exhibits severe limitations on almost all engineering activities. Such limitations are further corroborated in view of the corresponding unstable-slope unit on the environmental geologic map.

Potential raw materials for construction include limestone, alternating beds of limestone, dolomite, and marl, and caliche. Chert-free limestone may be quarried for crushed aggregate, and quarries producing crushed stone and dimension stone exist in nearby areas. Road metal is extracted locally from marl beds of the alternating beds unit and from discontinuous caliche deposits.

SOIL CONSTRAINTS

As shown on figure 14, most of the biogenic soil in the Lake Travis vicinity is less than 2 ft thick. Under these circumstances, properties of substrate (not soils) dictate constraints on construction and engineering uses. Thin soils all but preclude most agricultural uses as well, grazing being the only such use compatible with thin soil cover. Also, the functions of soil as an ion-exchange filter for percolating waters is greatly limited by the thin biogenic soil cover.

Where soils are more than 2 ft thick, as over alluvium or sand and conglomerate, the soil textures dictate limitations on various uses. Most of these thicker soils in the Lake Travis vicinity have similar properties regardless of substrate. They consist of stony or sandy surficial horizons (about 2 to 4 ft thick) over a clayey sand or silt horizon which, in turn, overlies weathered parent material. Maximum soil thickness (about 6 ft) occurs on alluvial terrace deposits downstream from Mansfield Dam. The general uniformity of properties of the thicker (greater than 2 ft) soils means that *soil thickness* (not texture) is the dominant factor determining constraints on use of biogenic soils. The exception to this rule is where a clay soil overlies a clay substrate; there, even though the biogenic soil is thin (less than 2 ft thick), the gross physical properties do not change between soil and bedrock. This results in a clay "soil" (defined in the engineering context; fig. 10) of considerable thickness. Thus, for uses that demand an impermeable substrate such as sanitary landfill or feedlot, a condition prevails in which the thickness is locally "not applicable" (see table 10) because of similarities in properties between biogenic soil and substrate.

Components of the soil-thickness matrix (table 10) differ from those of the matrix evaluating physical properties units (table 9). The soil-thickness matrix lists categories of land use instead of showing feasibility and long-term suitability .of activities and locus of mineral resources. These land-use categories for evaluating soils will also be applied to the environmental geologic units in terms of other interacting natural factors—namely processes, landforms, and materials.

Table 10. Land-use constraints based on soil thickness.

	LAND USE	Commercial-industrial development	Residential development	Intensive septic tank use	Sanitary landfill	Feed lot	Agriculture (cultivation)	Agriculture (grazing)	Recreational-parkland	Wild-scenic (unused)
Soil thickness	> 6 ft	+	+	+	—/NA	+/NA	+	+	+	+
	2 - 6 ft	+	+	o	—/NA	—/NA	+	+	+	+
	0 - 2 ft	+	+	—	—/NA	—/NA	—	+	+	+

+ = little or no constraint
o = moderate or questionable constraint
— = severe constraint
NA = not applicable

ENVIRONMENTAL GEOLOGIC CONSTRAINTS

The environmental geologic map bears connotations beyond substrate materials, so that each unit is presented in terms of processes and landforms as well as materials. This map gives a comprehensive overview of the land and the types of changes that can be expected in a given area. The comprehensive long-term view of the land encompasses environmental facets beyond stability of foundations or other such engineering properties. For example, a large shopping center *can* be built on an aquifer recharge zone, and it will probably be structurally sound. However, such use of the land will most likely have adverse effects on both quality and quantity of water recharged unless special precautions are taken to protect water quality.

Where environmental geologic units are considered in terms of specific uses (table 11), the map becomes a resource (or land) capability map. A unit of a resource capability map has been defined by Brown and others (1971, p. 94) as "an environmental entity—land, water, area of active process, or biota—defined in terms of the nature, degree of activity, or use it can sustain without losing an acceptable level of environmental

Table 11. Land-use constraints based on environmental geologic units.

	LAND USE MAP UNITS	Commercial-industrial development	Residential development	Intensive septic tank use	Sanitary landfill	Feed lot	Agriculture (cultivation)	Agriculture (grazing)	Recreational-parkland	Wild-scenic (unused)
Process Units	Flood-prone areas	—	—	—	—	—	+/o	+	+	+
	Unstable-slope areas	—	—	—	—	—	—	+	o	+
	Aquifer recharge zone	o/—	+/—	—	—	—	+	+	+	+
Material-Landform Units	Karstic limestone terrane	o	+/o	—	—	—	+/—	+	+	+
	High- to moderate-relief carbonate rock terrane	—/o	+/o	—	—	—	—	+	+	+
Material Units	Claystone-sandstone	—	o	—	+	+	+/o	+	+	+
	Alluvium	+	+	+	—	—	+	+	+	+

+ = little or no constraint
o = moderate or questionable constraint
— = severe constraint

quality." Based on land-use constraints of specific map units in table 9, a number of special-use maps of land capability (a special case of resource capability) can be derived, such as septic tank suitability maps, sanitary landfill suitability maps, and intensive residential development suitability maps.

Process Constraints

Process units sustain the least use without an eventual or immediate decline in environmental quality. These areas are most suited for such low intensity uses as parklands, rangeland, or wild-scenic country (i.e., left unused).

Flood-prone areas occur beyond the land delimited as such on the environmental geologic map because of the many small first- and second-order drainage courses. The warning must be categorical: *avoid building in arroyos and restricted lowland areas adjacent to stream courses.* Flood-prone areas also occur below lake spillway as shown on a topographic map of the Lake Travis vicinity. Astoundingly, there are residential developments even below spillway datum.

Areas of unstable slope should be left in their natural condition, although engineering design can compensate for possible problems. Limited grazing is a possible use, but the vegetation on the slope should remain a natural assemblage because changes in vegetation can alter the water-retention capacity and erosional regime of a slope which may, in turn, affect slope stability.

Aquifer recharge areas sustain diverse uses. However, the demand for acceptable quality and quantity of water recharged imposes certain restrictions. Normal agricultural use is permissible, but feedlot and stockyard operations should be excluded. The land is suitable for low- to moderate-density residential development, provided that the method of waste disposal receives close scrutiny. Improperly placed septic tanks, too many septic tanks, or leaky sewer lines may induce sewage recharge. If. septic tanks are used, the residential density should remain low (less than one house per acre, Freese, Nichols, and Endress, Consulting Engineers, 1970b, p. 207). If central sewage collection facilities and treatment plants are installed, the common suburban house density of three or four houses per acre may be sustained. This is based on the assumption that sewer lines are well attended (they do not leak) and that realistic guidelines regarding domestic fertilizer and pesticide use are stated and enforced in zoning ordinances.

Where large areas of ground surface are laid bare during construction, both quality and amount of water available for recharge are reduced (Leopold, 1968). This is because of rapid runoff and high suspended-sediment content of the water.

A large density of buildings and great expanses of pavement have detrimental effects on water quality. The pavement and buildings reduce the areal extent of ground through which recharge can occur; pavement also provides sluiceways along which debris, chemicals, and biological pollutants are washed from the streets, lawns, and parking lots, and dumped as a slug of low-quality water into a natural basin. Urban-suburban street wash following rainfall can adversely affect the quality of both ground and surface water (Ruane and Fruh, 1972).

Material-Landform Constraints

Material-landform constraints are largely dependent on processes that reflect the interactions of substrate and topographic form. These processes, however, do not loom so catastrophic as do flooding and mass wasting, and do not connote the extremely sensitive nature of the land that aquifer recharge areas do. Nonetheless, processes such as runoff, erosion, and infiltration, as well as soil properties predictable from studies of materials and landform, all impose land-use constraints.

The presence of karst features serves as a warning to users of the land that conduits exist for immediate underground transfer of waterborne wastes. The wastes may be discharged directly into surface-water bodies (i.e., the lake) or may travel undiluted and unneutralized into a subjacent aquifer. Because of these conduits and the thin soil cover on karstic lowland terrane, septic tank systems are not adequate waste treatment facilities unless special absorption field design compensates for the natural deficiencies of the land. Problems with proper septic tank operation on this unit have been documented by Texas Water Quality Board geologists. A septic tank system was subjected to dye injection to determine leakage rates into cavernous conduits near Lake Travis. A total of 6,000 gallons of "Rhoan W T" dye solution (concentrated 240 x visible level) was injected at a rate of 50 gpm over a total time period of 2 hours. No seepage was seen at the ground surface or in surface waters (Bill Trippet, personal communication, 1974). This indicates that an extensive cavernous conduit system exists, which may be recharging wastes into the underlying Ellenburger aquifer. However, lake water is evidently *not* being polluted by this specific cavern system.

Besides the formidable problems with domestic waste disposal, there are short-term construction difficulties based on substrate properties. Otherwise, there are few constraints on foreseeable uses of this terrane.

High- to moderate-relief carbonate rock terrane imposes constraints on various uses mainly because of steep slopes and thin soil cover. Erosion on steep slopes of alternating hard and soft limestone presents problems because the increased sediment supply to the lake accelerates eutrophication (Rickert and Spieker, 1971). Erosion is especially a problem where large areas are laid bare during construction. After residential construction is completed, declines in water quality continue because streets and roofs act as sluiceways for increased runoff, including bacterial, chemical, and detrital pollutants.

Steep slopes and thin soil cover combine to limit the effectiveness of septic tank filter field operation. Biogenic soil is necessary for beneficiation of domestic wastes in the aerobic part of a septic tank system—as microbes digest part of the wastes—whereas aeration accomplished by filtration through a porous medium augments the bacterial digestion. Gentle slopes are necessary to prevent surfacing of effluent near the absorption field.

Many of the septic tank filter fields in the Lake Travis vicinity are emplaced in the soft marl strata of the alternating beds (physical properties) unit. This material is bedrock and *not* biogenic soil. Some beneficiation of waste water locally occurs in this medium as a result of aeration (Walz, 1974). However, this substrate has highly variable properties so that at one locality, permeability is essentially nil and ponding of effluent occurs, whereas at another locality in the same area, effluent drains too rapidly via conduits into the subsurface. Variability of infiltration rates is demonstrated by results of percolation tests conducted under the auspices of the Lower Colorado River Authority. In one area near Lake Travis, 92 tests were performed at 28 sites (Woodruff, 1973). The mean percolation rate of these 92 tests was 34.4 minutes/inch (min/in) of drawdown. The mean deviation (or average deviation from the mean), however, was 31.9 min/in—*a value almost as great as the mean*. This, of course, strongly detracts from the validity of such a mean for projecting infiltration rates.

The fate of chemical and biological pollutants derived from domestic waste water was tested by Walz (1974). He injected raw sewage into bedrock at shallow depths (comparable to depths of septic tank emplacement) near Lake Travis and analyzed seepage from observation wells. As the tests were performed in the zone of aeration, rain was necessary to flush and transmit the wastes to the observation wells. Over a period of 9 days (including a 30-hour period of rainfall) total coliform bacteria declined from 130,000 total coliform per 100 ml to 4,500 total coliform per 100 ml across a distance of about 30 ft. Fecal coliform declined from 11,000 coliform per 100 ml to 30 coliform per 100 ml. This compares to "background" bacterial counts in natural waters of 100 total coliform per 100 ml and less than 10 fecal coliform per 100 ml.

Considerable beneficiation of waste water occurs within the abiotic marl. However, this test was performed over a brief time period, and the volume of sewage injected was small compared to average daily domestic output. Septic tank effluent from intensive housing developments (greater than 1 house/acre) is regarded as a long-term threat to water quality.

If waste disposal problems are solved (by centralized collection and treatment systems, or by "engineered" drain fields), and if erosion abatement methods are practiced during construction on steep slopes, this unit can provide stable and scenic sites for residential development. Other competitive but acceptable uses of this terrane include raising range animals and leaving the terrane wild (unused) as a haven for natural Hill Country flora and fauna.

Material Constraints

The constraints imposed by material units are basically physical properties constraints, and indeed, these environmental geologic units correspond roughly to units on the physical properties map. Constraints imposed include those of physical limitations (an impermeable clay, for instance) or value of natural resources (which imposes economic constraints).

The claystone-sandstone unit imposes constraints mainly because of low permeability, but it also exhibits moderate to low slope stability and moderate foundation strength. This clay substrate prevents proper operation of septic tank drain fields, so that effluent ponds at the surface. However, this same property allows containment of wastes and provides a generally suitable host material for sanitary landfills. Locally, lenticular sandstone bodies preclude this use because of decreased workability and increased permeability.

Alluvium is an easily excavated substrate of moderate to high permeability and moderate foundation strength. It is covered by thick, well-drained soils and is an area of generally low slope. These factors combine to make such terrane ideally suited for residential development, for local septic tank use, for recreational parkland, and for various agricultural activities. It is not well suited for heavy construction because of foundation properties. It is unsuited for solid waste emplacement because of moderate to high substrate permeability and the presence of local ground-water supplies.

Slope Constraints

Some slope constraints exist (fig. 16), regardless of material substrate, and beyond the implications of material-landform units on the environmental geologic map (table 12).

The major constraints on land use of steep slopes result from greater costs for construction: the steeper the slope, the more earth must be moved to level grades and foundations. The expenses are indeed high where solid rock is to be excavated. The 8- to 15-percent slope increment is marginal or unsuitable for most construction uses without engineering modification. Slopes greater than 15 percent present severe limitations.

Slopes greater than about 6 to 8 percent impose constraints on heavy vehicular traffic because sustained climb of vehicles in high gear cannot be maintained above this threshold slope value (Chapin, 1972, p. 372-374). Also rapid soil erosion is a potential problem on slopes greater than about 5 percent. This precludes many agricultural uses of the land.

Table 12. Land-use constraints based on slope units.

LAND USE		Commercial-industrial development	Residential development	Intensive septic tank use	Sanitary landfill	Feed lot	Agriculture (cultivation)	Agriculture (grazing)	Recreational-parkland	Wild-scenic (unused)
Slope	> 15%	—	o	—	—	—	—	+	+	+
	8 - 15%	—	+	o	—	—	o	+	+	+
	2 - 8%	+	+	+	+	+/o	+	+	+	+
	0 - 2%	+	+	+	+	+	+	+	+	+

+ = little or no constraint
o = moderate or questionable constraint
— = severe constraint

CONCLUSIONS

Two maps are basic to determining constraints on land use in the Lake Travis vicinity—a physical properties map and an environmental geologic map. These two maps are complementary—one depicting the engineering characteristics of substrate and the other showing the interactions between processes, landforms, and materials. The physical properties map delimits areas in terms of ease of construction, stability of constructed features, and location of potential rock and mineral resources. The environmental geologic map mainly delimits areas subject to geologic hazards or areas characterized by long-term changes in the land resulting from subtle (noncatastrophic) processes. The subtle, long-term processes are themselves based on materials present and ambient landforms. Three types of environmental geologic units are discriminated: process units, material-landform units, and material units.

Most of the Lake Travis vicinity is carbonate rock terrane. This includes strata of dolomite, limestone, and thick alternating bed sequences of limestone, dolomite, and marl. This carbonate rock terrane offers a generally stable substrate, but soils are thin, bedrock is resistant, and permeability is locally enhanced by fractures and solution features. The remainder of the Lake Travis vicinity consists of recently deposited alluvium, sand and conglomerate bedrock, and local claystone deposits. The sand and conglomerate and alluvium provide moderately stable substrates for construction, are easily excavated, and possess a moderately high (uniform) permeability. Claystone is also easily excavated but is a relatively weak substrate of low permeability.

Process units on the environmental geologic map sustain the fewest uses without harm to the environment or danger to human populations. Flood-prone areas and unstable-slope terranes are hazardous zones for human occupation. Aquifer recharge areas sustain a variety of uses, but certain intensive uses (commercial development and intensive residential development) can threaten the quality of water recharged.

Material-landform units in the Lake Travis vicinity describe two kinds of carbonate rock terrane, both of which sustain a variety of uses. However, thin soils and either karst features or steep slopes pose problems with construction activities and long-term septic tank use. The septic tank problems will ultimately limit residential growth on these terranes unless alternative waste disposal methods are employed.

Constraints on (and possibilities for) various uses of the material units are based mainly on consideration of physical properties of substrates.

Another factor germane to land-use limitations is surficial, biogenic soil. Soil cover is thin throughout most of the Lake Travis vicinity, so that the importance of this surficial material is largely eclipsed by bedrock characteristics. Nevertheless, soils are basic to agricultural uses and to certain kinds of waste disposal methods (such as septic tank systems). Soil texture and thickness maps are useful presentations that further complement the physical properties and environmental geologic maps regarding waste disposal practices and agricultural uses.

The environmental geologic map can be interpreted in terms of various uses. In this context it becomes a land capability map and shows where the land will sustain a variety of uses without long-term or immediate adverse environmental impact.

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Appendix A

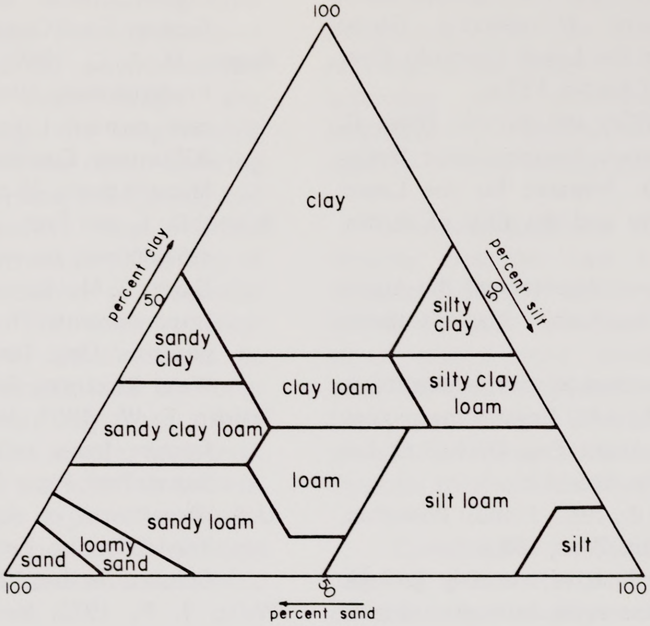

Figure 21. U. S. Department of Agriculture Soil Textural Classification (from Portland Cement Association, 1962).

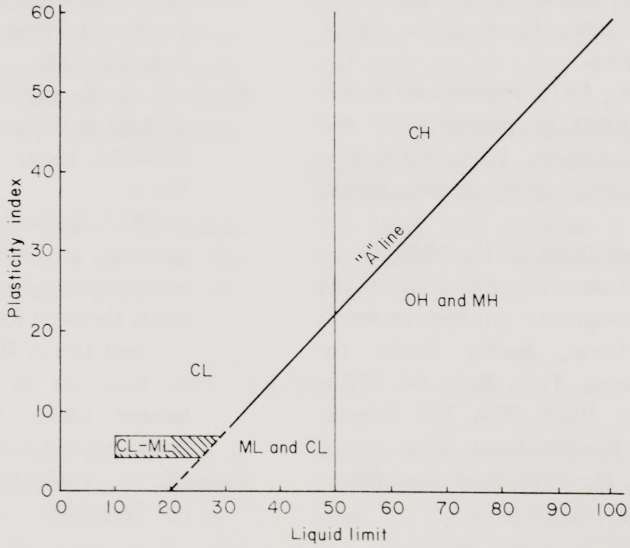

Figure 22. Plasticity chart–Unified Soil Classification System (from Portland Cement Association, 1962).

Table 13. Unified soil classification system (from Portland Cement Assoc., 1962). See also figure 22.

Major divisions			Group symbols	Typical names
Coarse-grained soils (More than half of material is larger than No. 200 sieve size)	Gravels (More than half of coarse fraction is larger than No. 4 sieve size)	Clean gravels (Little or no fines)	GW	Well-graded gravels, gravel-sand mixtures, little or no fines
			GP	Poorly graded gravels, gravel-sand mixtures, little or no fines
		Gravels with fines (Appreciable amount of fines)	GM	Silty gravels, gravel-sand-silt mixtures
			GC	Clayey gravels, gravel-sand-clay mixtures
	Sands (More than half of coarse fraction is smaller than No. 4 sieve size)	Clean sands (Little or no fines)	SW	Well-graded sands, gravelly sands, little or no fines
			SP	Poorly graded sands, gravelly sands, little or no fines
		Sands with fines (Appreciable amount of fines)	SM	Silty sands, sand-silt mixtures
			SC	Clayey sands, sand-clay mixtures
Fine-grained soils (More than half of material is smaller than than No. 200 sieve size)	Silts and clays (Liquid limit less than 50)		ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
			OL	Organic silts and organic silty clays of low plasticity
	Silts and clays (Liquid limit greater than 50)		MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
			CH	Inorganic clays of high plasticity, fat clays
			OH	Organic clays of medium to high plasticity, organic silts
	Highly organic soils		Pt	Peat and other highly organic soils

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PLATE 1
PHYSICAL PROPERTIES MAP OF THE
LAKE TRAVIS VICINITY, TEXAS

EXPLANATION

BEDROCK UNITS

▨ **LIMESTONE**
Hard, dense limestone with fractures and solution features

▨ **DOLOMITE**
Porous, surfically friable dolomite; also siltstone, limestone, and marl

▨ **ALTERNATING BEDS OF LIMESTONE, DOLOMITE, MARL**
Interbeds of hard to soft limestone, marly limestone, and dolomite

▨ **CLAYSTONE**
Claystone, shale, minor beds of hard sandstone and conglomerate

▨ **SAND AND CONGLOMERATE**
Poorly indurated silty clay, and sand, and gravel

▨ **HARD SANDSTONE**
Hard, dense, fractured sandstone, minor claystone; also sandy limestone

SURFACE UNITS

▨ **ALLUVIUM-RESIDUUM**
Silty clay, sand and gravel; clay with admixed blocky float

▨ **COLLUVIUM**
Blocky limestone or gravel-cobble debris in clay matrix

▨ **CALICHE**
Caliche without admixed detritus; caliche-welded residuum

CREDITS: U. S. Geological Survey 7½ minute (1:24,000) maps comprising base: Jollyville, Mansfield Dam, Bee Cave, Travis Peak, Pace Bend, Shingle Hills, Smithwick, Spicewood, and Marble Falls. Geologic mapping from which this map is in part derived includes: Dawe (unpublished, Bureau of Economic Geology Maps), Namy (1969), Rogers (1969), Warner (1961), and Woodruff (1973)

PHYSICAL PROPERTIES MAP OF THE LAKE TRAVIS VICINITY, TEXAS

By C.M.Woodruff, Jr.

1975

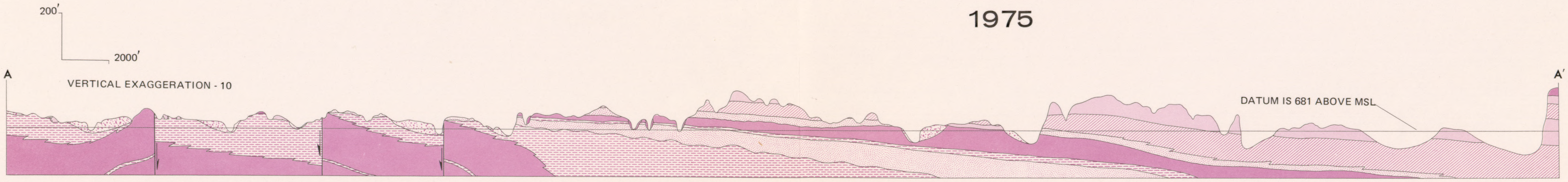

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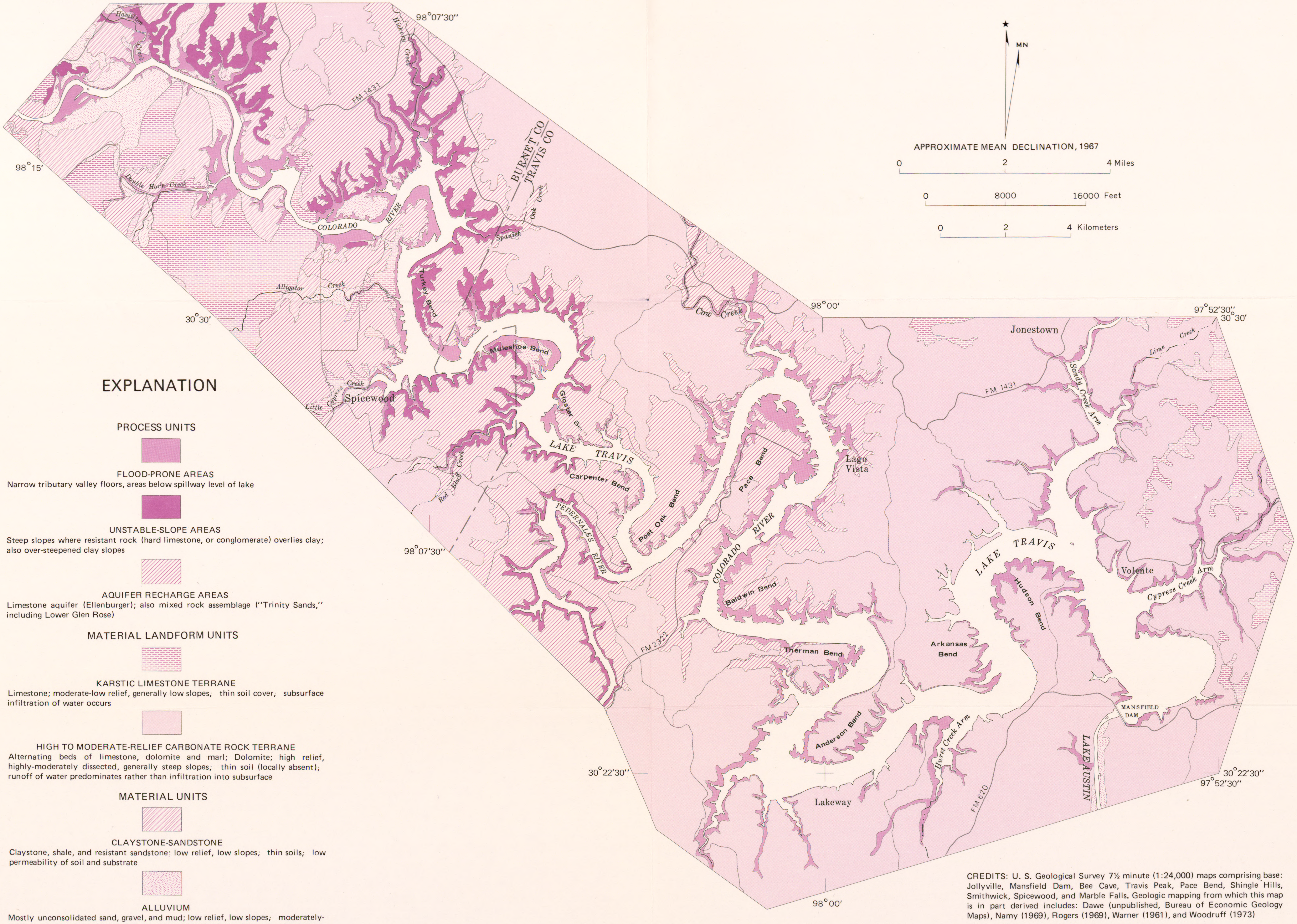
PLATE 2
ENVIRONMENTAL GEOLOGIC MAP OF THE
LAKE TRAVIS VICINITY, TEXAS



EXPLANATION

PROCESS UNITS

▨

FLOOD-PRONE AREAS
Narrow tributary valley floors, areas below spillway level of lake

▨

UNSTABLE-SLOPE AREAS
Steep slopes where resistant rock (hard limestone, or conglomerate) overlies clay; also over-steepened clay slopes

▨

AQUIFER RECHARGE AREAS
Limestone aquifer (Ellenburger); also mixed rock assemblage ("Trinity Sands," including Lower Glen Rose)

MATERIAL LANDFORM UNITS

▨

KARSTIC LIMESTONE TERRANE
Limestone; moderate-low relief, generally low slopes; thin soil cover; subsurface infiltration of water occurs

▨

HIGH TO MODERATE-RELIEF CARBONATE ROCK TERRANE
Alternating beds of limestone, dolomite and marl; Dolomite; high relief, highly-moderately dissected, generally steep slopes; thin soil (locally absent); runoff of water predominates rather than infiltration into subsurface

MATERIAL UNITS

▨

CLAYSTONE-SANDSTONE
Claystone, shale, and resistant sandstone; low relief, low slopes; thin soils; low permeability of soil and substrate

▨

ALLUVIUM
Mostly unconsolidated sand, gravel, and mud; low relief, low slopes; moderately-thick to thick soil, some calichification, moderately permeable soil and substrate

CREDITS: U. S. Geological Survey 7½ minute (1:24,000) maps comprising base: Jollyville, Mansfield Dam, Bee Cave, Travis Peak, Pace Bend, Shingle Hills, Smithwick, Spicewood, and Marble Falls. Geologic mapping from which this map is in part derived includes: Dawe (unpublished, Bureau of Economic Geology Maps), Namy (1969), Rogers (1969), Warner (1961), and Woodruff (1973)

ENVIRONMENTAL GEOLOGIC MAP OF THE LAKE TRAVIS VICINITY, TEXAS

By C. M. Woodruff, Jr.

1975

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PLATE 3
TOPOGRAPHIC MAP OF THE
LAKE TRAVIS VICINITY, TEXAS

Base adapted from U. S. Geological Survey 7½ minute (1:24,000) topographic quadrangle maps: Jollyville, Mansfield Dam, Bee Cave, Travis Peak, Pace Bend, Shingle Hills, Smithwick, Spicewood, and Marble Falls. Contour interval 50 feet.

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