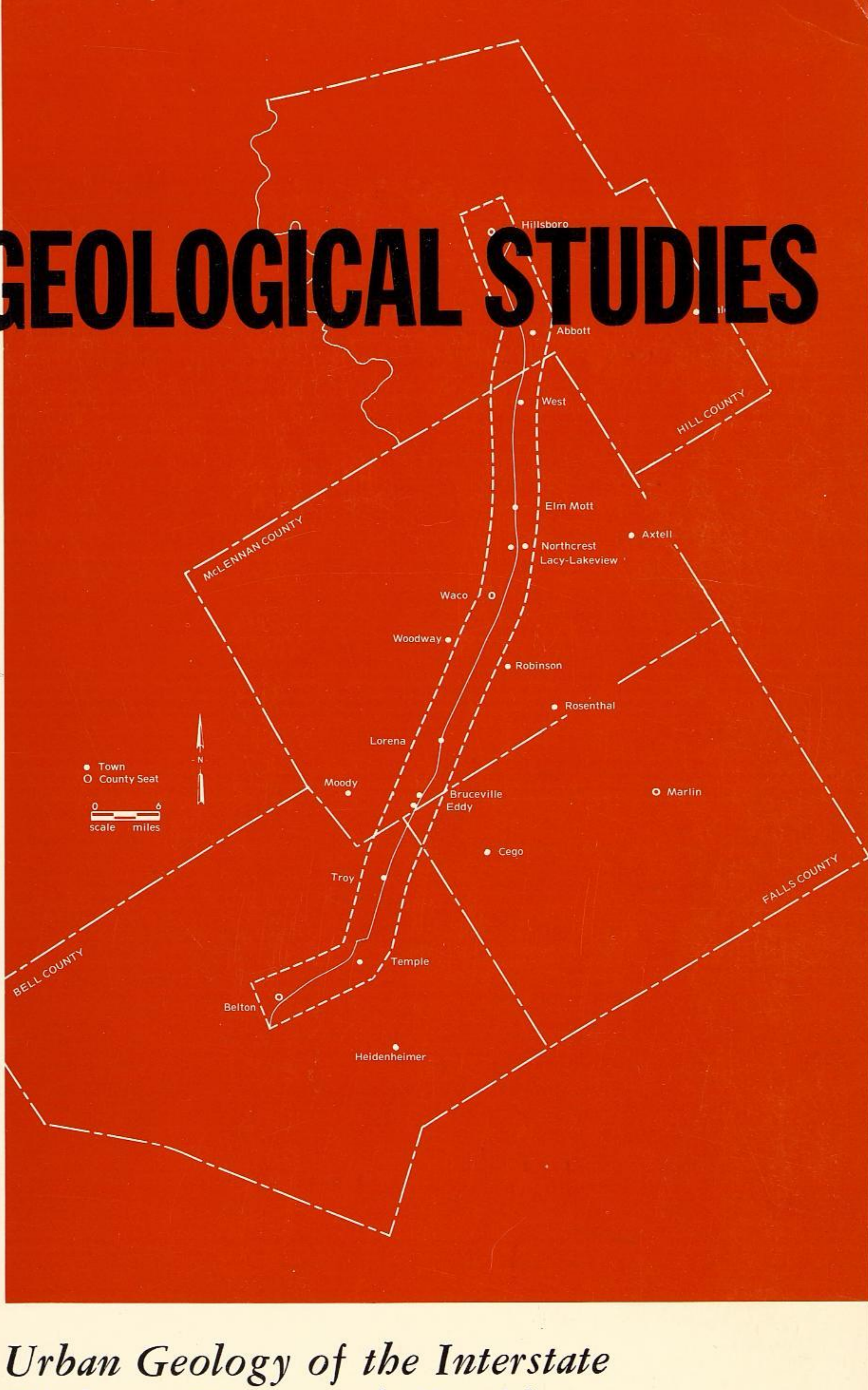
BAYLOR GEOLOGICAL STUDIES



FALL 1974

Bulletin No. 27

BAYLOR UNIVERSITY – WACO, TEXAS
FOUNDED
PRO ECCLESIA
PRO TEXANA
1845

Urban Geology of the Interstate Highway 35 Growth Corridor Between Belton and Hillsboro, Texas

Ellwood E. Baldwin

"Creative thinking is more important than elaborate equipment--"

Frank Carney, Ph.D.
Professor of Geology
Baylor University
1929-1934

Objectives of Geological Training at Baylor

The training of a geologist in a university covers but a few years; his education continues throughout his active life. The purposes of training geologists at Baylor University are to provide a sound basis of understanding and to foster a truly geological point of view, both of which are essential for continued professional growth. The staff considers geology to be unique among sciences since it is primarily a field science. All geologic research including that done in laboratories must be firmly supported by field observations. The student is encouraged to develop an inquiring objective attitude and to examine critically all geological concepts and principles. The development of a mature and professional attitude toward geology and geological research is a principal concern of the department.

The Baylor University Press
Waco, Texas

BAYLOR GEOLOGICAL STUDIES

BULLETIN NO. 27

Urban Geology of the Interstate Highway 35 Growth Corridor Between Belton and Hillsboro, Texas

Ellwood E. Baldwin

BAYLOR UNIVERSITY
Department of Geology
Waco, Texas
Fall, 1974

Baylor Geological Studies

The Baylor Geological Studies Bulletin is published semi-annually, Spring and Fall, by the Department of Geology at Baylor University. The Bulletin is specifically dedicated to the dissemination of geologic knowledge for the benefit of the people of Texas. The publication is designed to present the results of both pure and applied research which will ultimately be important in the economic and cultural growth of the State.

ISSN 0005-7266

Additional copies of this bulletin can be obtained from the Department of Geology, Baylor University, Waco, Texas 76703. $1.05 postpaid.

CONTENTS

ILLUSTRATIONS

Urban Geology of the Interstate Highway 35 Growth Corridor Between Belton and Hillsboro, Texas

Ellwood E. Baldwin

ABSTRACT

Urbanization along the growth corridor of Interstate Highway 35 is bringing to the area problems which heretofore did not exist. In many cases these problems are caused by insufficient knowledge of the physical environment of the region. The purpose of this study, therefore, is to describe the physcial environment in its relationship to urban growth along the corridor.

The basic premise employed in this study is that the suitability of land for a particular purpose is the sum of its physical attributes which, together with historical and biological attributes, constitutes social values. Each area has an intrinsic suitability for certain land uses, and certain land areas have multiple coexisting uses. Thus an understanding of the physical environment leads to enlightened planning. The physical environment is described in terms of geology, soils, water, and climate, as well as the natural communities which result from those factors.

The route of Interstate Highway 35, within the studied area, traverses the Washita, Eagle Ford, White Rock, and Taylor Prairies, which together make up the Grand and Black Prairies of central Texas.

Geologic formations which crop out in the area include the lower Taylor Marl, Austin Chalk, South Bosque Shale, Lake Waco Formation, Pepper Shale, Del Rio Clay, Georgetown Limestone, and Edwards Limestone, as well as terraces of the Leon, Bosque, and Brazos Rivers and alluvium. Weathering of these formations produces eleven distinctive soil associations.

The climate of the area is characterized by long hot summers and short mild winters. Mean annual precipitation ranges from 35.7 inches at Hillsboro to 33.9 inches at Temple. The driest months are July and August; wettest months are April and May.

Southerly winds normally prevail the year round. Though strongest winds are the peak gusts and squalls associated with thunderstorms, the strongest persistent wind speeds occur in March and April.

Relative humidity is fairly uniform throughout the year but varies considerably during the day. Mean annual sunshine is about 63 percent of the total possible, and lake evaporation is estimated at 56 inches annually.

The Hensel and Hosston sands, the principal aquifers, provided about four thousand acre feet of water in 1970. Surface waters impounded at Lake Waco and Lake Belton provided approximately thirty thousand acre feet of water in 1970.

INTRODUCTION*

Urban expansion is taking place rapidly along Interstate Highway 35 through central Texas. In addition to the benefits of growth, urban expansion normally brings: (1) conflict beween urban, rural, and industrial interests; (2) financial losses resulting from uncontrolled development in areas with unanticipated natural hazards; (3) an increase in waste products of urbanization; and (4) destruction of aesthetic features of the landscape by uncontrolled development. To a large extent problems result from lack of knowledge of natural environmental factors, disregard for natural resources, and unconcern for natural environment. However, if all factors are considered in utilization of the lands bordering the highway, planned growth, based on environmental knowledge can minimize the damages of uncontrolled growth along Interstate Highway 35.

PURPOSE

The purpose of this study is to provide citizens, regional planners, engineers, contractors, and government officials the geological, environmental, pedological, climatic, and engineering data necessary for planned urban development in harmony with natural processes

*A thesis submitted in partial fulfillment of the requirements for the M.S. degree in Geology, Baylor University, 1972.

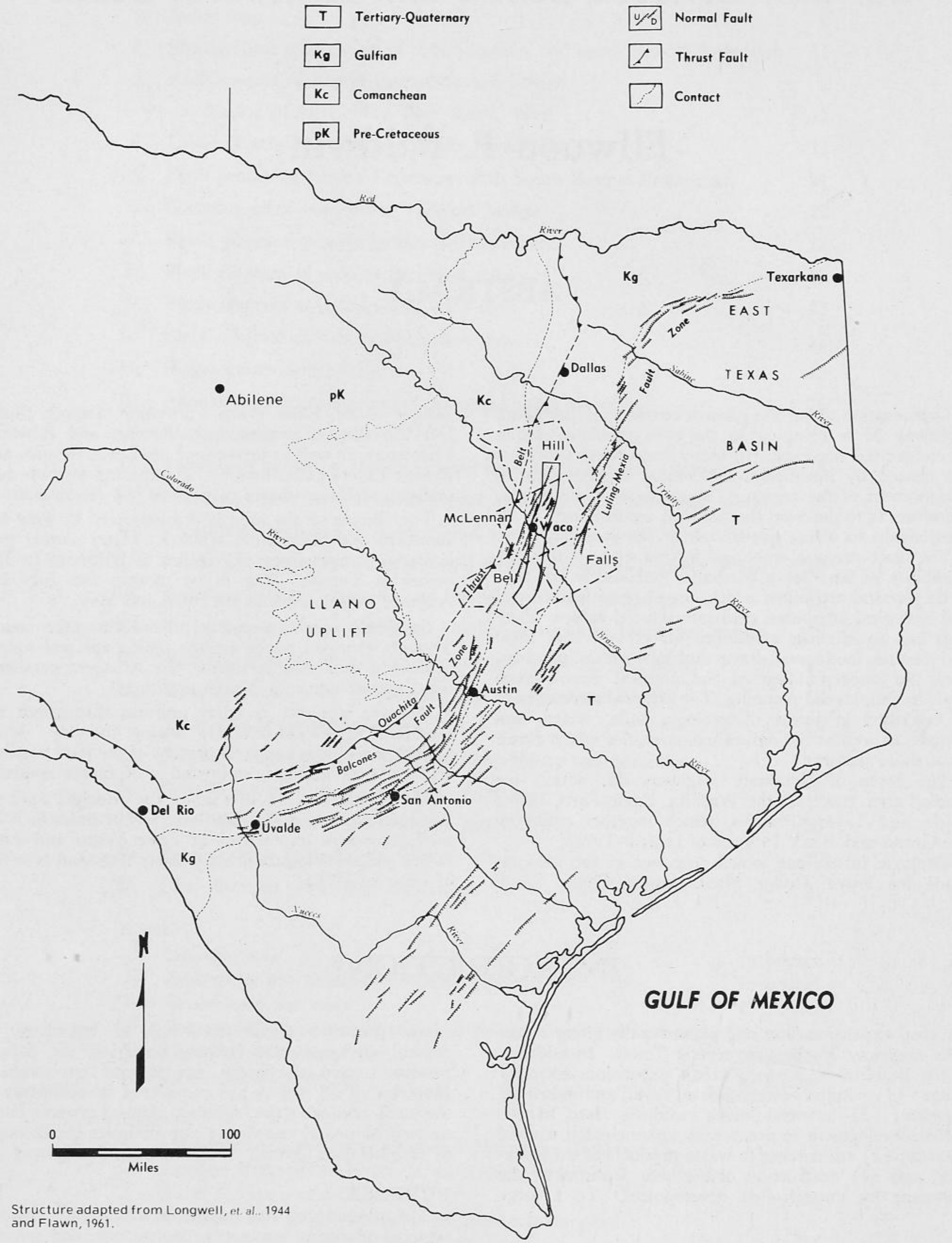


Fig. 1. Index map showing location of the Interstate Highway 35 corridor of this study.

and environmental characteristics of the area. The study establishes a physical frame of reference for coordinated land use planning and warns individuals of probable hazards and benefits of specific areas.

LOCATION

The Interstate Highway 35 corridor (hereafter referred to as the corridor) is a four-mile strip of land through central Texas, centered on Interstate Highway 35 and extending from the city of Belton, on the south, to the city of Hillsboro, on the north. The area is bounded by latitudes 31° 2′ 30″ and 32° 0′ 15″ north, and by longitudes 97° 5′ 0″ and 97° 28′ 45″ west and traverses parts of Bell, Falls, McLennan and Hill Counties. It covers an area of approximately 288 square miles and follows the White Rock escarpment, a strip of elevated land extending northeast-southwest across much of Texas (Fig. 1).

POPULATION

In 1970 the corridor had an estimated population of 180,000 persons. This represented about 1.7 percent of the population of Texas. Approximately 170,000 persons (94.5 percent) lived in urban areas having 1,500 or more inhabitants, including the cities of Belton, Temple, Robinson, Waco, Bellmead, Lacy-Lakeview, Northcrest, West and Hillsboro. The remaining population resides within the geographic region known as the Blackland Prairie, a major physiographic region within which the corridor is situated.

ECONOMY

The principal economy of the corridor is based on manufacturing and services, with agricultural activities of less importance. Some of the products which contribute toward this economy include the manufacturing or processing of aerospace products, trailers, monuments, caskets, glass, furniture, mattresses, clothing, cotton, grain, peanuts, pecans, livestock, poultry, and products of wood, concrete, gravel, rubber, wool, candy, and food. Other factors which contribute to the economy of this area include educational institutions; state and federal hospitals, institutes, and offices; private medical facilities; home offices of major insurance companies; recreational and resort facilities; and convention facilities.

The principal manufacturing plants are in or near the larger cities; however, other plants located in or near the smaller cities process local products, especially those related to agriculture. Waco and Temple are important manufacturing centers, while Belton and Hillsboro, although having light industry, derive their economy from farming activities.

Agriculture has contributed substantially toward the economy of this region. Farming includes the raising of various grains, small garden and truck vegetables and fruits, and various forms of livestock. Dairy farming is found throughout the region and is of local importance. Ranching consists of raising cattle, goats, hogs, and sheep, and is especially important in those areas where the soils are thin.

Industrial activities concerned with the production and processing of mineral products include the operation of sand and gravel pits and stone quarries, the production of clay and manufacture of brick and tile products, the production of cement materials and manufacture of cement.

METHOD

The method of approach used in this study involves six phases: (1) geologic mapping, (2) soil mapping, (3) determination of soil and rock properties, (4) compilation of significant climatic data, (5) evaluation of water supply, both surface and subsurface, and (6) interpretation of data in terms of significance to urban development. The presentation is divided into five sections: geology, pedology, climate, hydrology, and resources.

The surficial investigation involved detailed studies of the physiography, rock outcrops, geologic structure, and soils. The work was based on literature, survey, field mapping, air photo interpretation (1:69,000), and electric well log interpretation. Field observations were plotted on U. S. Geological Survey 7½ minute topographic quadrangles (1:24,000). These data were then transferred to the Surficial Geological Map, 1:126,000 (Plate I). Standard geological nomenclature was used in the mapping of geology so that interpretive maps could be prepared based on known properties of importance to urban planning.

Engineering properties of rocks described in this text (Plate II) were based on studies by R. G. Font (1969) and E. F. Williamson (1967).

Soil maps were prepared from published soil surveys (U. S. Soil Conservation Service 1958) and Soil Conservation Service field sheets (1:20,000 aerial photographs) covering Bell, Falls, and Hill Counties. The data were first plotted on U. S. Geological Survey 7½ minute topographic quadrangles (1:24,000) and then transferred to the Generalized Soil Map (1:126,000) (Plate III). Mapped soil associations are the same as those used by the Soil Conservation Service. Soil maps were checked in the field and approved by Gordon S. McKee, State Soil Scientist, Soil Conservation Service. Engineering properties of soils (Plate IV) were obtained from the Soil Conservation Service Established Series (U. S. Soil Conservation Service 1971a).

Hydrologic data on ground and surface waters are based on publications of the Texas Water Development Board and information supplied by R. L. Preston, Texas Water Development Board, Waco, Texas.

Climatic information was obtained from Climatological Summary sheets published by the U. S. Department of Commerce. Figures 12 through 20 were prepared by P. M. Allen (1972).

Recommendations, based on the integration of all data accumulated during the study, are divided into two groups: regional recommendations concerning the overall effective management of the natural environment for the best interests of all and local recommendations based on the geology and soils found in the study area.

To make the information more useful it has been presented in map or chart form, and instructions on use of maps and charts form a part of this study.

PREVIOUS WORKS

Previous works of significance to this study are divided into six categories: (1) geology of central

Texas; (2) soils and soil mapping; (3) general climatology and specific papers on climates of the study area; (4) hydrogeology both general and specific; (5) works dealing with civil and geological engineering; and (6) general works on urban planning and studies of urban and environmental geology within the study area. These are considered individually in this section.

Geology

Geologic studies of central Texas date back to the late 1800's. One of the earliest studies of significance to the area is the work of R. T. Hill (1901) *Geography and Geology of the Black and Grand Prairies, Texas,* a monumental work which lay the groundwork for all later studies.

Descriptive studies of the geology of McLennan County were made by Lula Pace (1921) and W. S. Adkins (1923). A similar study of the geology of Bell County was made by W. S. Adkins and M. B. Arick (1930).

The Geology of Texas, Vol. I, Stratigraphy (Sellards, Adkins, and Plummer, 1932) was useful for detailed descriptions of the Gulfian Cretaceous formations. Stephenson (1937) studied the stratigraphic relations of the Austin, Taylor and equivalent formations in the central Texas area. Bronaugh (1950) and Stricklin (1961) studied Brazos River terraces. The Woodbine Symposium (Lozo, 1951) was helpful in correlating stratigraphy of the Eagle Ford, Washita, and Woodbine Groups in the studied area (Plate II). The *Geology of the Austin Chalk along North Cow Bayou* by Brown, Montgomery, and Reynolds (1956) and a study of the Balcones fault system (O. T. Hayward, 1957) were useful in interpreting both regional and local faulting in the Balcones fault zone. They were particularly useful in relating air photo alignments to structural relations within the study area.

The *Austin Group in Central Texas,* a work by C. O. Durham (1957) was the key reference in dividing the Austin Chalk into two members in the study area. Lithologic and stratigraphic relationships of the Georgetown Formation were described by Dixon (1967) and T. E. Brown (1971).

A study of the Austin Chalk in McLennan County (Seewald, 1959) was particularly useful because of its local emphasis. Work in the Taylor Marl was aided by *Stratigraphy of the Taylor Formation (Upper Cretaceous), East-Central Texas* (Beall, 1964).

Other descriptive stratigraphic works useful in this study were those by: Chamness (1963), Silver (1963), Frost (1963), Ray (1964), C. F. Johnson (1964), and Fandrich (1968), which dealt with stratigraphy of various formations exposed in the study area.

A number of unpublished quadrangle studies which were helpful in mapping the growth corridor were: Abbott and Peoria quadrangles (Tyner, 1964), Gholson and Aquilla quadrangles (Taylor, 1962), Moody quadrangle (Vann, 1969), and West quadrangle (Boyd and Janek, 1958).

Soils

The basic reference for soil mapping was the U. S. Department of Agriculture's Soil Survey of McLennan County (1958). Soil mapping in Hill and Bell Counties was aided by air photo worksheets provided by C. H. Brooks of Hill County and J. W. Huckabee of Bell County. D. R. Thompson of Bell County provided information on soils in Falls County.

The U. S. Soil Conservation Service, Department of Agriculture, descriptive soil sheets, the *Established Series,* provided by A. L. Newman and G. S. McKee of Temple, were used in the preparation of soil charts.

Texts on soils by Clarke (1957), Felt (1950), Hough (1957) and Jenny (1941), and the Soil Survey Staff (1951) provided information on soil genesis and physical properties of soils.

Climate

Climatic information was derived from climatological summaries compiled by the U. S. Study Commission (1961), Orton (1964) and Environmental Data Service (1968).

General references used to interpret the data were those by Berry, Bollay, and Beers (1945); Conrad and Pollack (1950); Critchfield (1966); and Haurwitz and Austin (1944).

Hydrogeology

Specific hydrologic data were obtained from studies published by the Texas Water Development Board. Additional background information was derived from *Hydrogeology* by Davis and DeWiest (1966), and *Groundwater and Wells* by E. E. Johnson (1966).

Data on ground water conditions in the studied area, aquifer descriptions, depth to aquifers, groundwater usage; past, present, and projected pumping rates from the aquifers were obtained from an unpublished report by the Texas Water Development Board. Information on aquifer geology was from Holloway (1961).

Chemical quality of groundwater in the study area was described by Henningson (1962). Hem (1970) and Swenson and Baldwin (1965) described the general nature of groundwater chemistry.

Surface water resources for Waco were evaluated by Spencer (1966) and Proctor (1969). Chemical quality of surface waters was considered in studies by Spencer (1966), Moore (1970), and Rawson (1967). Information on the use of waste waters was taken from the Texas Water Plan (Texas Water Development Board, 1971). The work by Schroeder (1971) was consulted for data on discharge of small streams.

General works on hydrology used in this study include those by Savini and Kammerer (1961) and Leopold (1968).

Engineering

Data on the engineering characteristics of the rocks and soils exposed along the growth corridor were derived from works by Williamson (1967) and Font (1969). The Texas Highway Department through R. S. McKinney provided additional information. Engineering data on soils in the growth corridor were from Elder (1965), Established Series reports of the U. S. Soil Conservation Service, and personal communications with G. S. McKee and A. L. Newman.

General texts on engineering geology and civil engineering that provided background information for this study were those by Ambrose (1967); Baidyuk (1967);

Capper, Cassie, and Geddes (1966); Eckel (1958); Handin and others (1963); Gillott (1968); Happ (1955); Harr (1966); Hough (1957); Judd (1964); Krynine (1947); Legget (1962); Leonards (1962); Logan (1948); McLean and Nelson (1962); Paige (1950); Seullin (1966); Slossan (1969); Stagg and Zienkiewicz (1969); D. W. Taylor (1960); Terzaghi (1960); Terzaghi and Peck (1968); Tipps (1964); Trask (1950); and Yong and Warkentin (1966).

Urban and Environmental Planning

Works dealing specifically with urban and environmental development along Interstate Highway 35 which were useful to this study include: Burket (1965); Flawn, Turk, and Leach (1970); Font (1969); Howell and Thomas (1969); and Williamson (1967).

Works of general nature include: Adhern (1964); Aschman, Engelen, and Rodney (1962); J. B. Brown (1963); Christiansen (1970); Flawn (1965, 1966, 1970a, b); Foley (1968); Hackett (1968); Hilpman and Stewart (1968); Hughes (1967); J. H. Johnson (1968); McDougal (1947); McGill (1964); McHarg (1969); and Schellie and Rogier (1963).

Master plans for Temple, Woodway, Waco, Bellmead, Lacy-Lakeview, Northcrest, and Hillsboro were sources of additional information.

ACKNOWLEDGEMENTS

I wish to extend my appreciation to O. T. Hayward, Professor of Geology, Baylor University, who suggested this project and contributed to field studies, cartography, photography, and manuscript revision; to J. W. Dixon, Chairman, Department of Geology, Baylor University, for his continued support; to R. G. Packard, Professor of Physics, Baylor University, for his review of the manuscript; and to J. N. Namy and J. M. Spencer, Professors of Geology, Baylor University, for their help and support. Acknowledgement is due to R. L. McKinney, District 9 Laboratory Engineer and Geologist for the Texas Highway Department, for use of highway information and for personal consultation and aid in material evaluation. I am indebted to G. S. McKee, A. L. Newman, J. W. Huckabee, D. R. Thompson, and C. H. Brooks (Soil scientists, U. S. Soil Conservation Service) and to R. L. Preston and R. S. Perkins (Texas Water Development Board). I extend thanks to Peter M. Allen, who compiled much of the climatic data used in this study. A special notice of appreciation goes to J. O. Maberry (U. S. Geological Survey) for kindly reviewing the manuscript before publication and to the Texas Real Estate Research Center for financing publication of this study. The author assumes responsibility for any errors or omissions of data in this publication.

PHYSIOGRAPHY

The corridor contains areas characteristic of two major physiographic provinces: the Grand Prairie and the Blackland Prairie which are located on the northwestern edge of the Gulf Coastal Plain. The boundary between these prairies is located at the base of the White Rock escarpment which trends northeastward through the study area from Moody, Texas, on the south to the northeastern border of the Gholson quadrangle. It is terminated by faulting approximately five miles north of Waco, Texas. This escarpment, supported by the resistant Austin Chalk, is a westward-facing cuesta with an average height of 150 feet.

The Grand Prairie is located west of the escarpment and is developed on Comanchean rocks. It is divided into two subprovinces: the Lampasas Cut Plain on the west, developed on rocks of the Fredericksburg Group, and the Washita Prairie on the east, developed on the limestones and clays of the Washita Group. The topography is that of a maturely dissected rolling prairie.

The Blackland Prairie, located on the east side of the White Rock escarpment, is developed on rocks of the Gulf Series. It is subdivided into four north-south belts: the Eagle Ford Prairie, developed on the rocks of the Eagle Ford Group; the White Rock Prairie, developed on the Austin Chalk; the Taylor Prairie developed on the Taylor Marl; and the Eastern Marginal Prairie, developed on glauconitic sands and clays of the Navarro Group. Within the corridor, physiographic subprovinces include: the Lampasas Cut Plain, Washita Prairie, Eagle Ford Prairie, White Rock Prairie, and Taylor Prairie. Most of the corridor consists of gently rolling hills and rounded shallow valleys.

GEOLOGIC STRUCTURE

The corridor is located on the up-dip edge of the Gulf Coastal Plain. The Cretaceous formations compose a wedge of sediments which thickens gulfward to form a southeastward dipping homocline. Generally the rock strata strike N 10° E. Dip west of the corridor is generally 10 to 40 feet per mile in the Texas craton. This rate of dip increases to 90 feet per mile immediately east of the corridor in the East Texas basin. Secondary structural features of this area include faults and joints of the Balcones fault zone, consisting of prominent *en echelon* faults trending N 20° E and other sets of secondary fractures. It marks the approximate boundary between outcropping Lower Cretaceous strata of the stable Texas craton to the west and the more steeply eastward dipping Upper Cretaceous rocks of the East Texas basin. Major faults are downthrown to the southeast and displacement varies from a minimum of less than one foot to a maximum of 350 feet at West.

Faults were identified by alignments observed on aerial photographs and by field observations. Joints and faults are most abundant in the outcrop areas of Austin Chalk and Taylor Marl. Joints and faults are fractures or planes of weakness in bedrock, thus, they are of considerable importance where foundation properties of bedrock are considered. Faults or joints may reduce the actual field strength of rock to values far below those obtained by laboratory tests, so for this reason it is essential to know the fault and joint pattern in an area before construction. Plate I shows the relationships of major alignments in the area. The inserts on Plate I show strike frequency patterns for jointing at three locations. These diagrams show the relative abundance and direction of strike of fractures to be expected throughout the corridor.

STRATIGRAPHY

GENERAL

The construction of streets, dams, homes, and large buildings, and the placing of underground pipes and cables are processes of urbanization. For maximum economy and design in harmony with the natural environment these processes require a knowledge of rock and soil behavior. Failure to understand these aspects of the physical environment commonly leads to excessive capital expenditures and frequent failures most of which are predictable.

ROCK OUTCROPS IN GROWTH CORRIDOR

The geologic map of the growth corridor (Plate I) shows the distribution of outcropping geologic formations; which are, from younger to older: recent alluvium; terraces of the Leon, Brazos, and Bosque Rivers; lower Taylor, Austin, South Bosque, Lake Waco, Pepper, Del Rio, Georgetown, and Edwards Formations.

Formations found only in the subsurface of the corridor include: Comanche Peak, Walnut, Paluxy, Glen Rose, Hensel, Pearsall, Sligo, and Hosston of Cretaceous age, and the undifferentiated rocks of the Paleozoic Ouchita foldbelt. Descriptions and distribution of these formations appear on Plates I and II and in Figure 2. Each of the mapped units (Plate I) is described in terms of physical properties on Plate II, and its relationship to urban development is emphasized in the section on Geologic Factors Affecting Urbanization and on Plate VI, Land Capability Groups.

GEOLOGIC FACTORS AFFECTING URBANIZATION

INTRODUCTION

Limestone, shale, marl, and alluvium are found in the growth corridor. Each has unique physical properties which influence its suitability for urban development. Therefore, a knowledge of the local geology and an awareness of the physical properties of these rocks are necessary tools for proper urban planning.

Plate I (Surficial Geological Map) shows the geologic formations which crop out within the growth corridor. The geologic map, used in conjunction with Plate II (Geologic Factors Affecting Urban Development), permits the construction of interpretive maps which are based on known engineering properties of the ~~rocks~~ and are consistent with standard geological nomenclature.

GEOLOGIC INTERPRETATIONS FOR URBAN USE

COLUMN 1

Each geologic unit is described for recognition in the field.

COLUMN 2

Each geologic unit is located within the corridor area.

COLUMN 3

Predominant vegetation of each formation is listed. Field recognition of outcropping formations will be aided by the use of these data.

COLUMN 4

Mineralogical composition is shown for all outcropping formations within the corridor area. Certain clay minerals, if present in the rock, can cause expansion when they are exposed to water and swell. This is a common cause of foundation problems where these clays are present.

COLUMN 5

Bearing Strength Capacities (the ability of material to support a load before collapse) have a wide range of values throughout the area. They range from intermediate to low in shale, alluvium, and some terrace deposits to high in limestone. Bearing capacity increases with depth in shale because of confining pressure. Lateral stress relief must also be considered when excavating near existing foundations.

Generally, foundation problems will vary with the thickness of the deposit, clay content, and degree of consolidation. A change in founding strength occurs both laterally and vertically because of dip angle, stratigraphic position, and topographic slope (Figs. 3, 4, 5).

When rock is not homogeneous, as in the corridor area, the load bearing capacity is that of the weakest

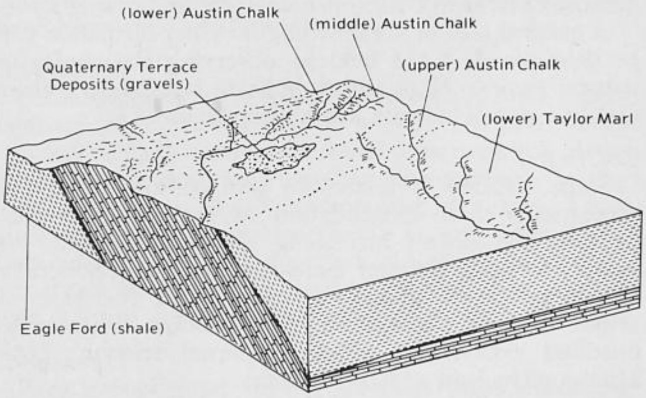


Fig. 2. Stratigraphic relationship of upper, middle, and lower Austin Formation. *From* Allen, 1972, Urban Geology along Interstate 35 growth corridor from Hillsboro through Ellis County, Texas.

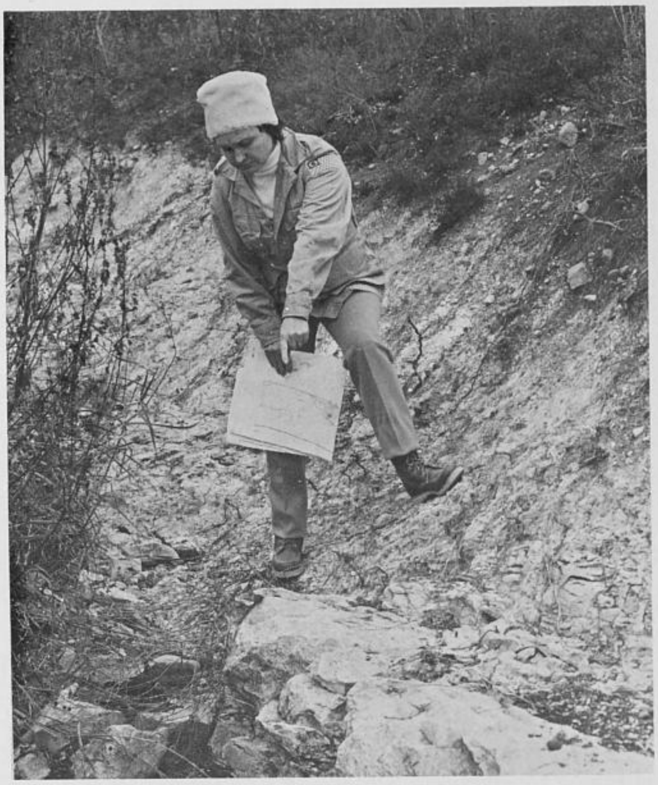


Fig. 3. Fault contact of the Austin Formation and lower Taylor Marl about one mile east of Interstate Highway 35 on County Line Road near West. This is one of the few localities where the actual contact can be seen. In faulted areas the weaker rock present will determine the foundation design. Thick soils can be anticipated in faulted areas which will make on-site testing necessary.

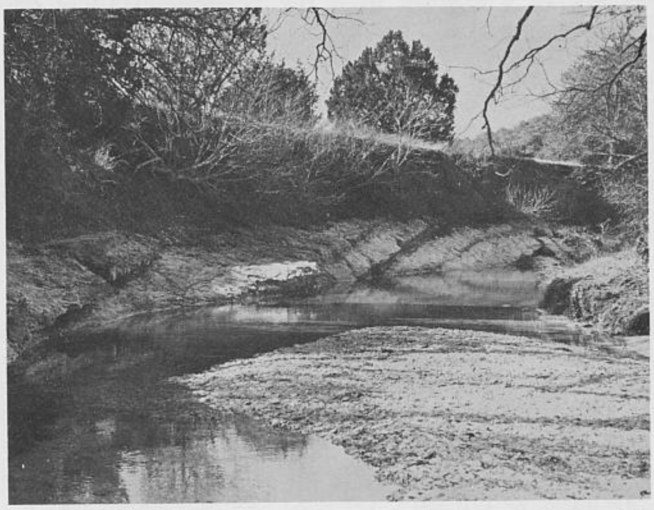


Fig. 4. Lower Austin on White Rock Creek, Locality 2. This location is about 100 yards north of Gholson Road. Notice the extreme dip in the Austin Chalk causing alternate beds of marl and chalk to lie just under the alluvium. Support strength in locations such as this will be controlled by the weaker marl beds. Areas like this require extensive site listing to determine the extent of these near vertical alternate beds and the extent of faulting and jointing.

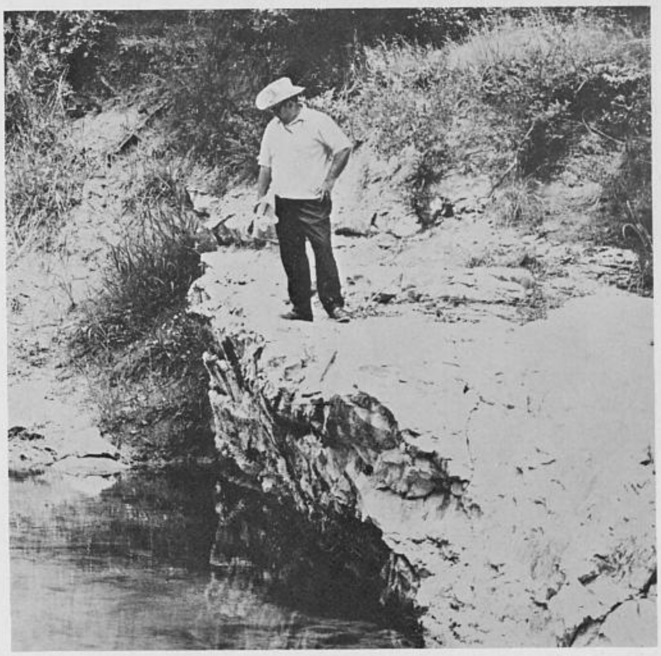


Fig. 5. Fault contact of the Austin Formation with the South Bosque Formation about one half mile north of I-35 on the South Cow Bayou, Locality 8. The faulting at this location has a strike of N 57° E. This is an example of how faulting can bring an incompetent formation in contact with a competent formation. Foundations in such areas shculd be designed to compensate for this condition.

unit. Conditions producing low support values include (1) alternate strata of different but sound rock (Fig. 4, Locality 2); (2) sound rock overlying weak, or compressible material; (3) jointing (Fig. 6, Locality 6); (4) bedding planes, dikes, and faults (Fig. 3, Locality 1; Fig. 5, Locality 8); and (5) cavities and caverns (Leonards, 1962, p. 626).

All of these limiting conditions are found in the growth corridor. Sound rock overlying unsound, weak, or compressible materials occurs where the Austin Chalk overlies the South Bosque Formation along the White Rock escarpment. At these locations the less competent South Bosque Shale determines to a large degree the strength of the Austin Chalk. With excessive loads, blocks of Austin Chalk may founder into the lower shale in shear failure which commonly follows the perimeter of the foundation. Undermining the Austin Chalk by erosion of the supporting South Bosque Shale, due to poorly controlled drainage, may cause shearing and slumping of Austin Chalk blocks.

Where jointing separates the Austin Chalk into interlocking but unconnected blocks, the load-bearing limit is equal to the unconfined compressive strength of the rock. Density of faults and joints (inserts, Plate I) is greatest in the Austin Chalk and may complicate construction because of local reduction in shear strength, increased depth of weathering and development of thicker soils.

Cavities and caverns occur in some limestone formations. A small cavity compared with the thickness of formations above it should create no serious problem. If the cavity is large relative to formation thickness serious foundation problems may occur (Leonards, 1962, p. 627). Caverns such as those encountered along Interstate Highway 35 at Georgetown and West may require filling, grouting, or other internal supports. While presence of caverns may be difficult to predict, they are known to occur in rocks similar to those in the corridor.

Column 6

Shear strength and bearing strength capacity are generally related. When bearing capacity is high the shearing strength is also high in a formation of uniform thickness.

The Austin Formation has generally a high shear strength. However, near its stratigraphic contact with the South Bosque Formation, the Austin may fail because of failure of the less competent underlying shale.

A general idea of shear strength of any formation can be determined in the field by observing the angles of natural slopes. High slopes indicate high shear values and low slopes indicate low shear values.

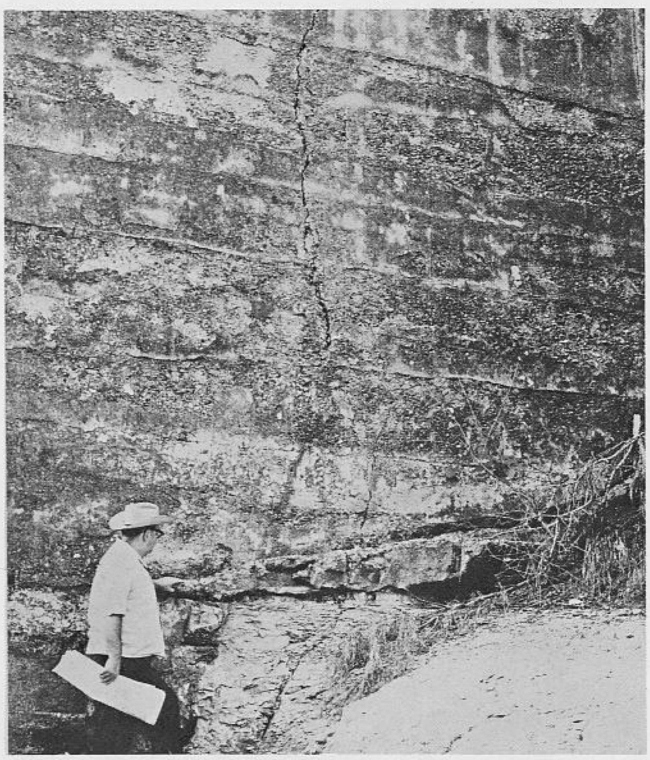


Fig. 6. Concrete piers supporting the railroad bridge over North Cow Bayou just west of I-35, Locality 6. The pier rests on beds of the lower Austin Chalk. Jointing in these beds has continued into the pier at two places. The base of the pier when poured was below ground level. Continued erosion has exposed the base and the chalk bed upon which it rests. The chalk has apparently shifted because of failure along joints causing a slight settlement in the pier and the resultant cracks.

Column 7

Slope stability is related to composition, degree of cementation, and consolidation of the materials that underlie the slope. Increasing heights of slopes, removal of vegetation, and increasing loads will generally encourage slope failures. Excavation at the base of slopes removes support and the addition of water to unsealed excavations reduces internal friction; both actions often lead to slope failures.

Slope stability is generally high in limestone beds which contain only small amounts of clay minerals. There is no truly stable angle of repose for shale beds. Montmorillonite clay in shale and siltstone leads to low strength and the foundation may slip on inclines as gentle as 5 degrees from the horizontal (Lung and Proctor, 1969, p. 139).

Column 8

Excavation difficulty varies with material and amount of water present. Shale and marly limestone are easily excavated with light machinery. However, major excavations should be made during dry seasons (Figs. 20, 21) for two reasons: (1) shales become sticky and difficult to manage when wet; (2) the addition of fresh water to shales decreases shear strength and causes slope failure.

Limestone normally is less difficult to excavate, if advantage is taken of existing joints and fractures. However, massive beds such as Edwards and lower Austin Formations may require blasting.

Column 9

Properties when used as fill are often related to the

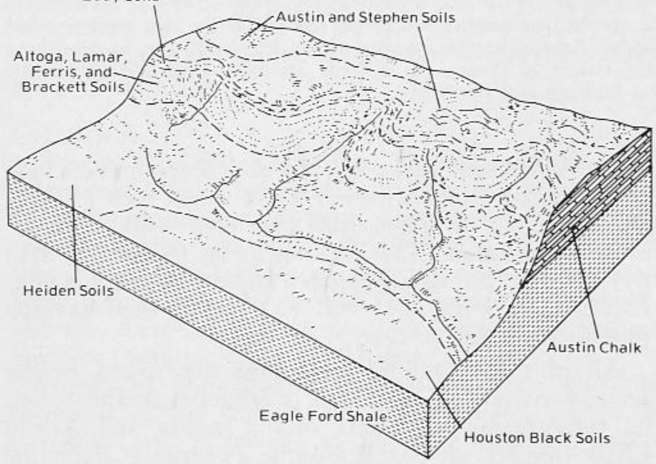


Fig. 7. Block diagram of soils in the Hillsboro area. *After* U. S. Soil Conservation Service, 1964, Soil Survey, Ellis County, Texas.

presence of clay. Generally fill suitability is in inverse proportion of the amount of clay present. However, in sand and gravel some clay may be desirable to increase the cohesiveness of the material.

COLUMN 10
Potential swell or expansion potential is the latent tendency of certain clays in a rock to swell when exposed to fresh water and thereby increase the elevation of its upper surface together with anything resting upon it. Potential swell is expressed in inches. These values can range from low (0.05) to very high (2.0). This column gives both adjective and numerical ratings. Structures located in areas with potential swell ratings over 1.5 are subject to serious engineering problems.

COLUMN 11
Free groundwater or the potential water-producing capabilities, including probable best use and degree of pollution, are shown for each formation. This column permits prediction of probable sources of groundwater.

COLUMN 12
Permeability and infiltration rates are given for each formation. These data enable the isolation of areas suitable for sanitary land fills, the selection of areas suitable for ponding of water, and the determination of size of drainage field for septic sewage systems.

COLUMN 13
Associated soils names include all soils series associated with the outcropping formations within the corridor. This enables the correlation of rock properties (Plate II) with the properties of soils formed on these formations.

COLUMN 14
Economic properties or commercial uses are shown for the outcropping formations. Thus a reader of the resources section of this Bulletin can determine physical and mineralogical properties of the resource item and the areal extent of the geologic formation containing the resource.

SOIL FACTORS AFFECTING URBANIZATION

INTRODUCTION

Soils in the study area are developed on marine limestone; marine sediments of chalk, marl, and calcareous clay; alluvium; and stream terraces (Table 1). This variety of parent material is reflected in the soil and physiography of the area (Figs. 7-10).

Soils are formed through the interaction of five soil-forming factors: parent material, topography, climate, biologic actions and time. The principal factor is parent material, the geologic deposit upon which the other variables react to produce soil. Parent material is mostly responsible for soil texture and provides the original supply of minerals necessary for plant growth.

A soil association, the map unit used in this study, is a group of similar soil series which have developed on similar parent material and under similar climatic conditions. There are eleven soil associations in the study area (Plate IV, Col. 1). The soil series (Plate III), members of a given association, occur in close geographical association, because they develop on related geological formations (Plate I). The many variables that make up soil series (slope, drainage, parent material, and vegetation) cause rapid changes in physical and engineering properties within small areas and make on-site testing necessary (Plate III).

Variations in soil series are called phases and are most common with variations in topography and drainage which also control the temperature and moisture content of the soil.

Topography of the corridor is of gently rolling hills and rounded shallow valleys with some maturely dissected rolling prairies. Because of high rates of runoff the hills and uplands are the driest sites in the area. Here the soils are shallow and low in organic content. Areas with gentle slopes have less runoff and consequently more water enters the soil, resulting in deep, well-drained soils and more luxuriant plant growth. The lowlands often receive excess surface water and the soils are poorly drained. Soil temperature is partially

TABLE 1. SOIL ASSOCIATIONS AND PARENT MATERIAL INTERSTATE HIGHWAY 35[1]

Parent material	Soil association
Limestone	Austin-Eddy-Stephen Denton-Purves San Saba-Crawford Tarply-Tarrant-Brackett-Purves
Marine sediments of marl, chalk, and calcareous clay	Houston Black-Heiden Houston Black-Heiden-Austin
Old Alluvium	Wilson-Burleson
Recent Alluvium	Trinity-Frio-Bosque Trinity-Pursely Miller-Norwood-Yahola
Stream terraces	Axtell-Irving

[1]See Plates I and III.

controlled by topography and drainage; north- and east-facing slopes are generally cooler and more moist than south- and west-facing slopes.

The soil profile (Fig. 11) results from interaction of all the soil-forming factors. It is the link between soil classification and mapping.

Plate III is a general soil map of the corridor and shows by color the major soil associations which have been devised to show major soil trends or patterns. They do not show specific soils but do show groups of soil series and phases which are interrelated. Soil maps of this type are aids to urban and regional planning because they classify, define, and delineate each soil association and its set of physical properties (Plate IV).

GENERALIZED SOIL MAPS

Generalized soil maps (Plate III) convey an idea of the distribution of soils in a particular area. They are useful in comparison of various areas, and to identify tracts of land which have similar properties. These are not suitable for planning details of land management or for detailed regional or urban planning. For the latter use more detailed interpretive maps are necessary. Inserts on Plate III show the complexity of soils at three locations in the growth corridor. Map scales of one inch equals 100 feet are common in urban geology and give the details necessary for urban planners.

Plate IV describes the mapping units in terms of (1) physical factors and (2) degree of limitation and factors affecting specific urban usage. This plate, when used with the generalized soil map (Plate III), permits evaluation of most effective land use.

PEDALOGICAL INTERPRETATIONS FOR URBAN USE

Plate IV (Soil Factors Affecting Urbanization) shows the mapping units and dominant soil series in each unit. Plate III (Generalized Soil Map) shows the geographic delineation of these units in the corridor. When used together they permit an evaluation of the lands bordering Interstate Highway 35 by soil parameters and urban limitations.

The first five columns show physical factors, and columns 6 through 16 show degree of limitation for selected urban usage.

Appendix I shows the characteristics, properties, and qualities used in evaluating each soil series for the particular physical factor or degree of limitation shown in columns 1 through 16 on Plate IV. Two additional unnumbered columns on Plate IV show the degree of hazard (1) when excavating and (2) from flooding.

Plate IV is to be used with the general soil map (Plate III). This map is useful to give a general idea of the distribution of soils in the area, to compare different parts of the area, or to determine suitability of soils to certain land uses for general planning. More specific interpretations should be based on a more detailed soil survey and on-site examination. Within one association the soils may differ widely in slope, drainage, texture and other characteristics that affect land use.

CLIMATE

The corridor is located on the western edge of the Gulf Coastal Plain of Texas and experiences the humid coastal climate as well as the continental climate of the interior regions. The Koppen climate classification for this region is Cfa (humid sub-tropical), and the Thornthwaite climate classification is Cbr (sub-humid, mesothermal, rainfall adequate in all seasons).

Tropical maritime air controls the climate of the region during the spring, summer, and fall. During the winter and early spring, frequent surges of polar and arctic air (referred to as northers) cause sudden drops in temperature and add considerable variety to the daily weather.

This section describes the climate in terms of means and extremes and isolates climatic limitations on potential land use. Data found in Figures 12 through 20 represent climate averages in the corridor. By using these averages regional interpretations can be made.

WIND SPEED AND DIRECTION

Wind direction and speed have an influence on weather and are important factors to be considered in any land use plan.

Prevailing winds in the corridor are from the south. The strongest winds are the peak gusts and squalls associated with thunderstorms. The strongest persistent winds occur in March and April in association with intense low pressure centers (extratropical cyclones), that move eastward from the Texas Panhandle, and with fast moving cold fronts.

Figure 12 shows percentage frequency of surface wind direction for Fort Worth and Waco. Waco has southerly winds 19 percent of the time and throughout the year the winds are predominantly out of the south.

Figure 13 shows mean annual wind speeds for Fort Worth and Waco. Mean annual winds at Waco average 11.5 knots 60 percent of the time. Figures 14 through 17 show seasonal variations of mean wind speed and direction for Waco. Wind speed is in knots.

South and southwest winds are dominant during the summer and fall with speeds of 1 to 10 knots 65 percent of the time. North winds are dominant during the winter with speeds of 1 to 10 knots 5 percent of the time. Winds from the west or east are the least common. However, northeast winds appear in all seasons with greatest frequency in the fall.

SOLAR ELEVATION AND RADIATION

Incoming solar radiation (insolation) determines the seasonal fluctuation in climate. The amount of insolation received at any place on any date is controlled by:

1. The solar constant, which depends on:
   (a) energy output of the sun
   (b) distance from the earth to the sun

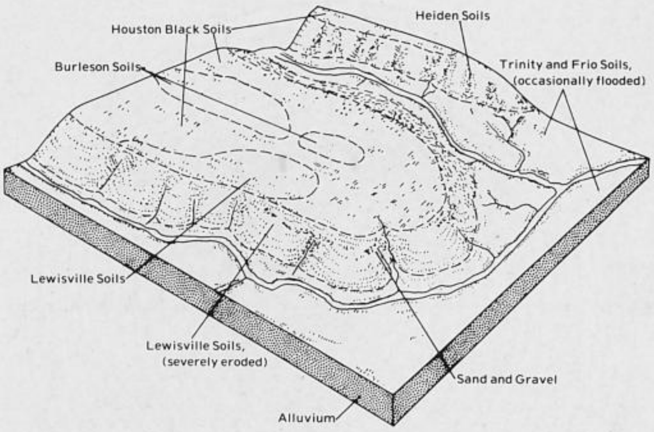


Fig. 8. Block diagram of soils in the West area. *After* U. S. Soil Conservation Service, 1964, Soil Survey, Ellis County, Texas.

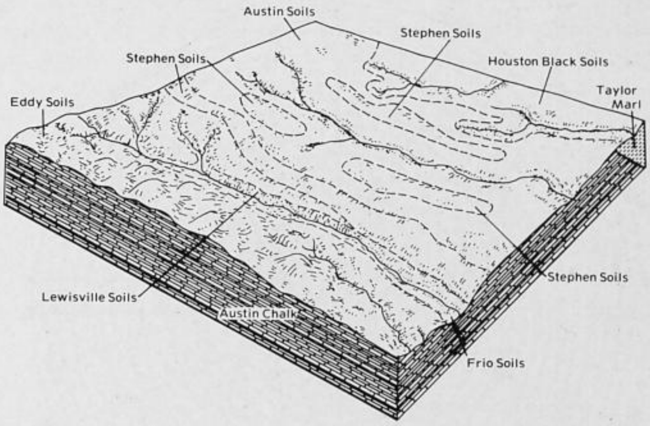


Fig. 9. Block diagram of soils in the Waco area. *After* U. S. Soil Conservation Service, 1964, Soil Survey, Ellis County, Texas.

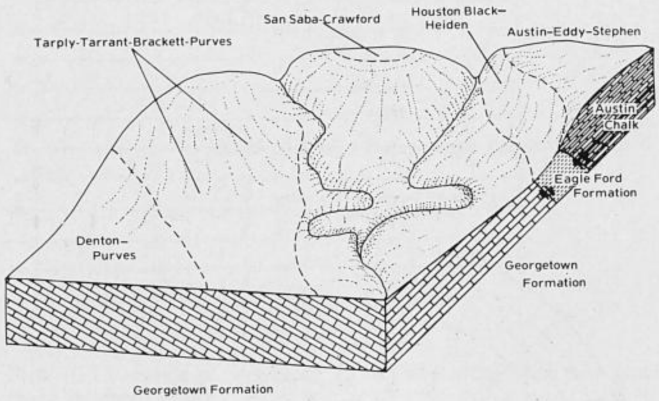


Fig. 10. Block diagram of soils in the Belton area. *After* U. S. Soil Conservation Service, 1964, Soil Survey, Ellis County, Texas.

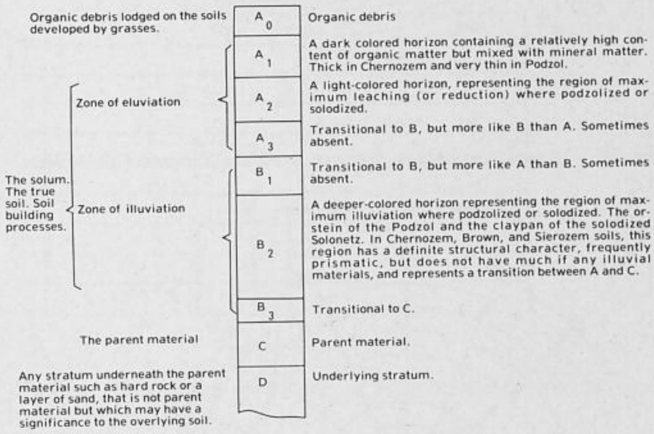


Fig. 11. Diagrammatic soil profile with all soil horizons. No one soil would be expected to have all these horizons well developed, but every soil has some of them. Sketch is not drawn to scale and thicknesses of horizons as sketched are not proportional to actual thicknesses. *After* American Society for Testing Materials, 1950, Special Tech. Pub. 113.

2. Transparency of the atmosphere which is a function of latitude.
3. Duration of the daily sunshine period which varies with latitude, seasons, and cloud cover.
4. Angle at which the sun's noon rays strike the earth which is influenced by latitude, seasons, and topography.

The solar constant is the least variable of the above factors. Measurements have shown that the amount of heat energy coming into the outer atmosphere amounts to 2 gram calories per square centimeter per minute (two langleys per minute). It takes 140 langleys to evaporate 1/10 inch of rainfall. Figure 18 shows the solar elevations above the horizon at noon and mean solar radiation in langleys. Decline from maximum possible insolation is pronounced from December to March. These are the months with the greatest frequency of cloud cover (Fig. 19). Maximum daily insolation of over 600 langleys per day occurs during the summer months of June and July.

SUNSHINE HOURS, CLOUD COVER, AND SUNRISE-SUNSET

Mean annual sunshine hours per month are shown in Figure 19. The number of sunshine hours received in the study area is about 63 percent of the total possible. The possible number of sunshine hours a month in the southern part of the continental United States is 370. This total is affected by cloudiness and topography.

Figure 19 shows that the period from May through mid October receives more than the average number of sunshine hours with the peak occurring in July. From the middle of October through April the number of sunshine hours is below average.

When solar radiation data are not available the following equation can be used to convert sunshine hours into radiation intensities:

$$Q/Q_A = 0.23 + 0.48n/N$$

where: $Q =$ radiation actually received on a horizontal surface. $Q_A =$ total radiation received if atmosphere

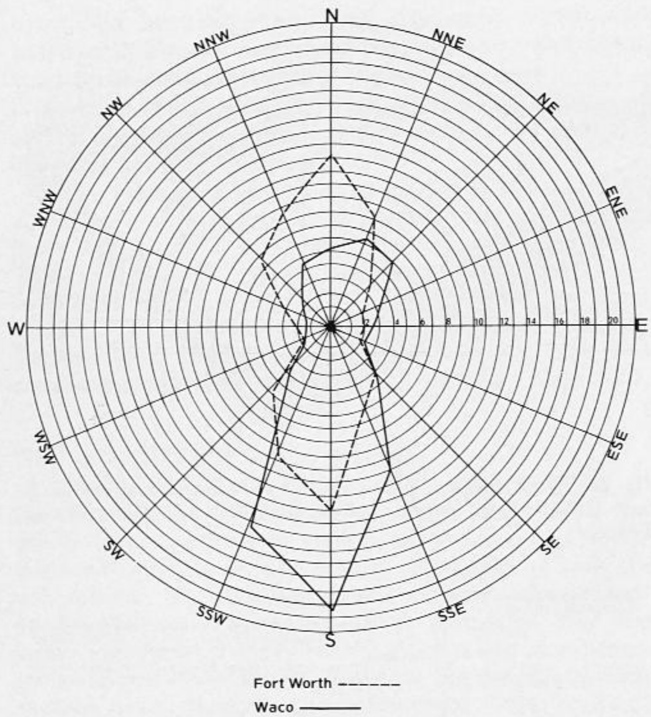


Fig. 12. Annual percentage frequency of surface wind direction.

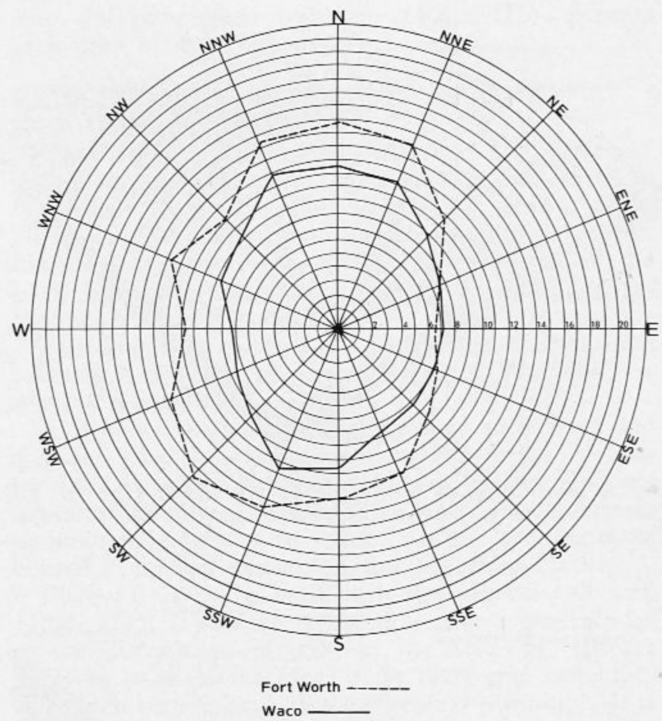


Fig. 13. Annual mean wind speed in knots.

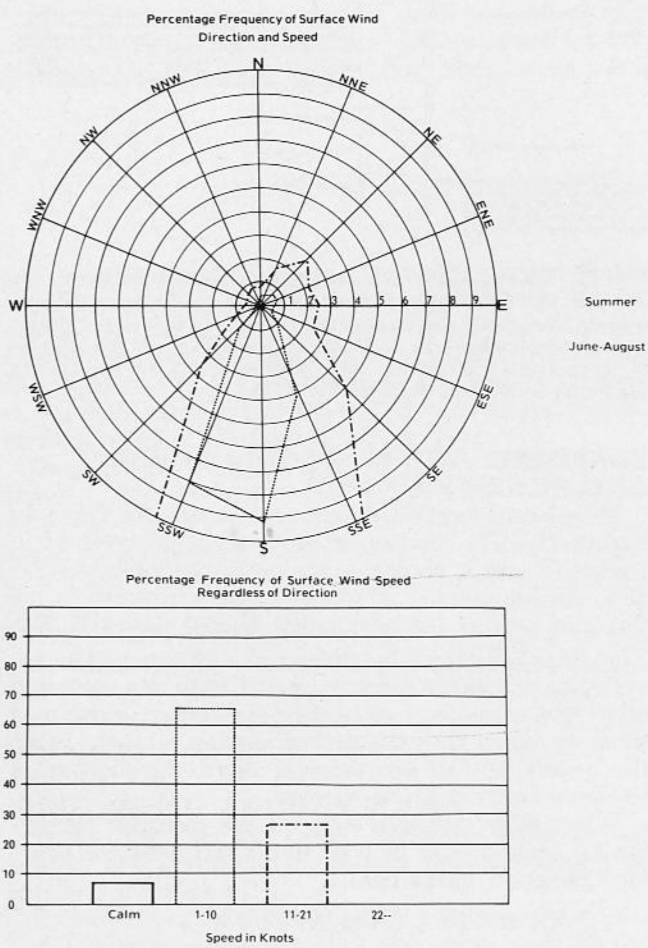


Fig. 14. Percentage frequency of surface wind direction and speed, summer, Waco.

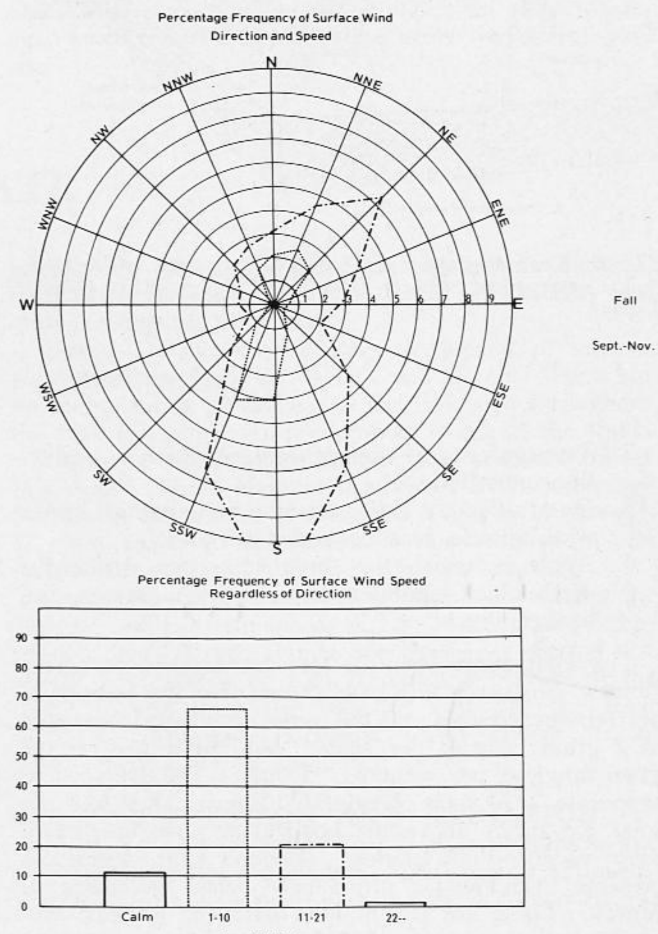


Fig. 15. Percentage frequency of surface wind direction and speed, fall, Waco.

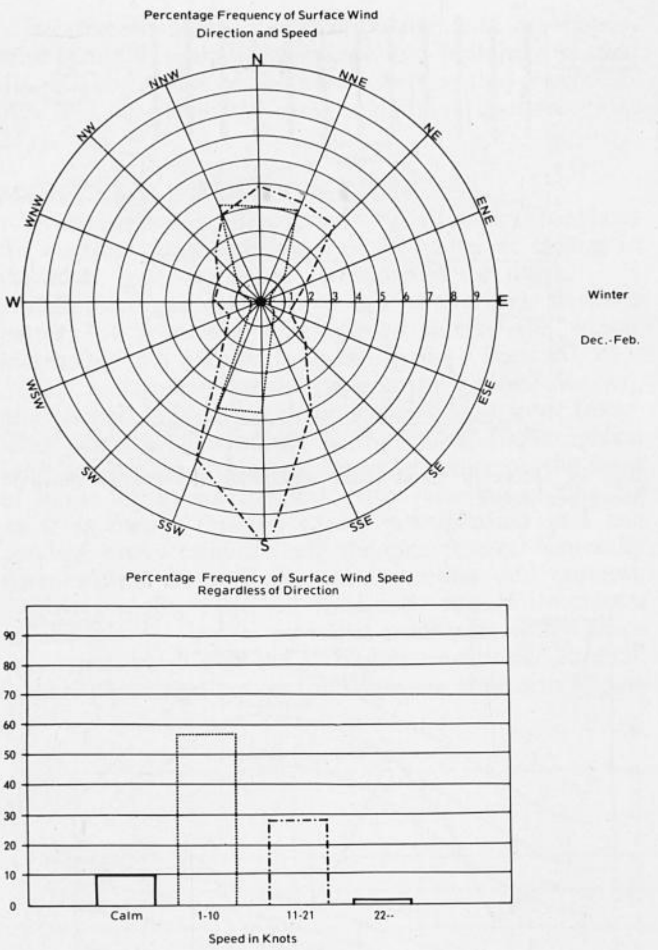


Fig. 16. Percentage frequency of surface wind direction and speed, winter, Waco.

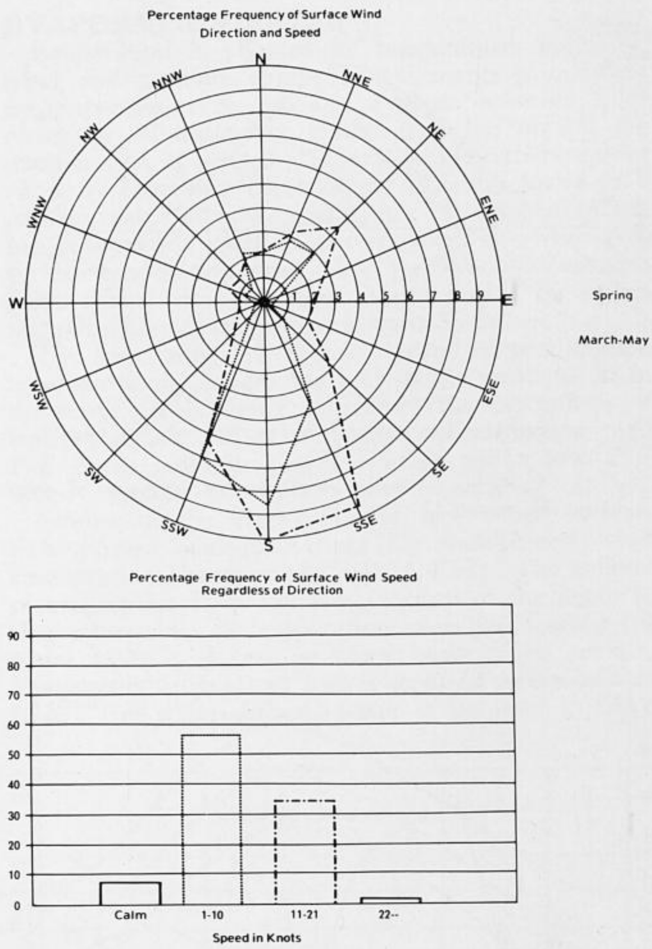


Fig. 17. Percentage frequency of surface wind direction and speed, spring, Waco.

were perfectly transparent. n = actual duration of sunshine. (This figure is approximately 370 hours per month in the study area.) N = maximum possible duration of sunshine.

Mean percentage values of cloudiness per month are shown in Figure 19. These data have been included in this study because of the interrelation of cloud cover and sunshine. The scale on the left shows the percentage of total area covered by clouds within the corridor per month. Partly cloudy percentages are shown by the thicker areas on the columns. Percentages of clear skies are represented below the thicker bar representing partly cloudy conditions while percentages of cloudy skies are shown above the thicker area of the bar. Percentage cloudiness values are convertible to tenths by using the column on the right. Cloudiest months are December through March while June through October are the least cloudy.

The column on the left of Figure 19 shows the time (Central Standard Time) of sunrise and sunset on the 15th day of each month.

MONTHLY TEMPERATURES

In the corridor there is a wide range of annual temperature extremes, a characteristic of continental climates. Monthly averages (1938-1967) are shown for Hillsboro (Fig. 20) and Temple (Fig. 21).

High summer temperatures are generally associated with fair skies, westerly winds, and dry air. Low winter temperatures may drop 20° F in one hour, but cold weather usually persists only 48 to 72 hours following an intrusion of cold polar air.

The mean length of the warm season (freeze free period) averages 250 days. The mean dates of the last freeze in the spring and the first in the fall range from March 9 to March 13 and November 13 to November 21 respectively.

RELATIVE HUMIDITY AND DEW POINT MEASUREMENT

Relative humidity is fairly uniform throughout the year but varies considerably during the day. Average annual relative humidity is 82 percent at 6:00 a.m., 55 percent at noon, and 51 percent at 6:00 p.m., Central Standard Time.

Mean dew point measurements for Dallas, Fort Worth, and Waco are shown in Figure 22. Dewpoint is the temperature at which the existing water vapor in the air will saturate it. Therefore it represents the temperature below which condensation will occur.

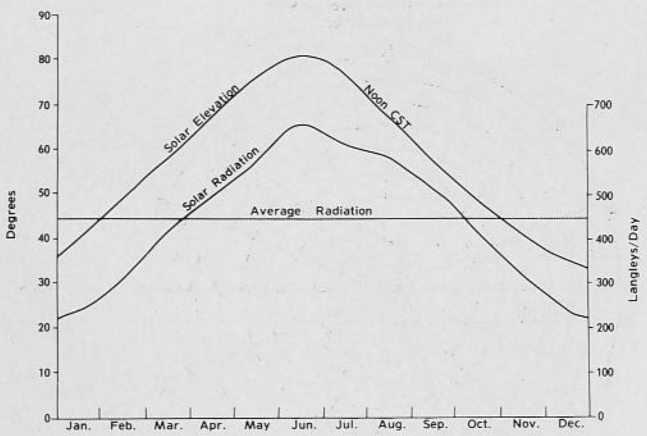


Fig. 18. Variation of solar elevation and intensity of solar radiation by month.

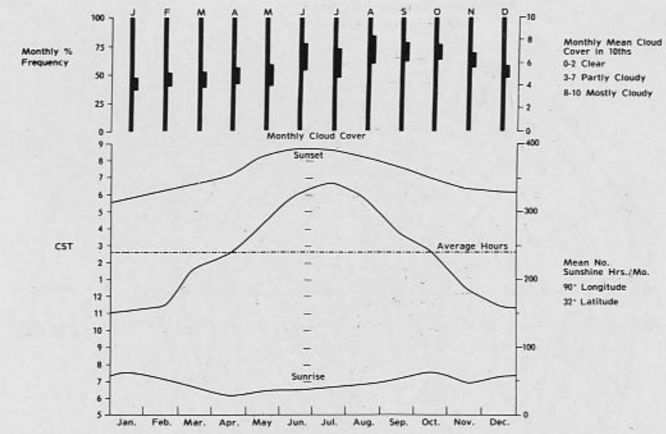


Fig. 19. Monthly cloud cover and mean number of sunshine hours per month.

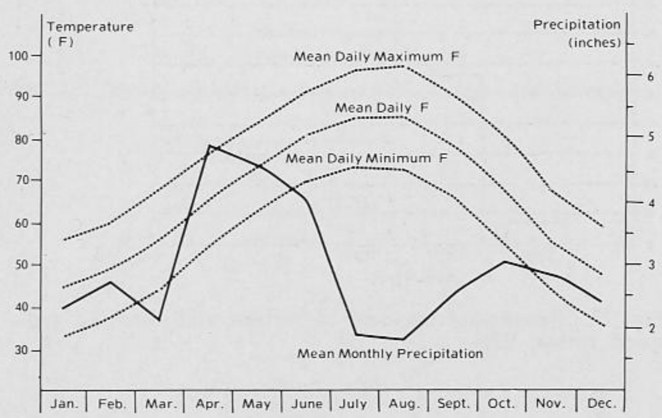


Fig. 20. Monthly averages of temperature and precipitation, Hillsboro.

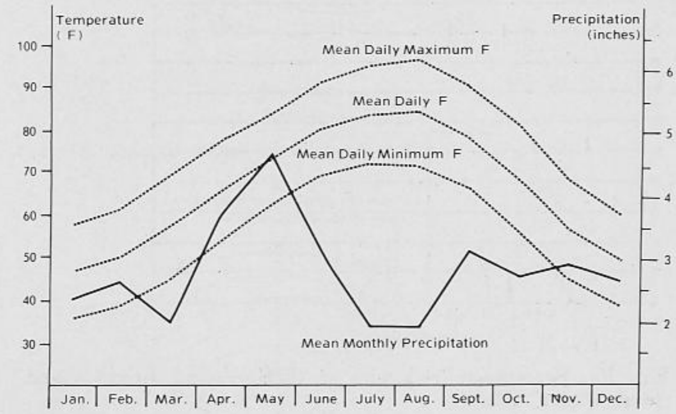


Fig. 21. Monthly averages of temperature and precipitation, Temple.

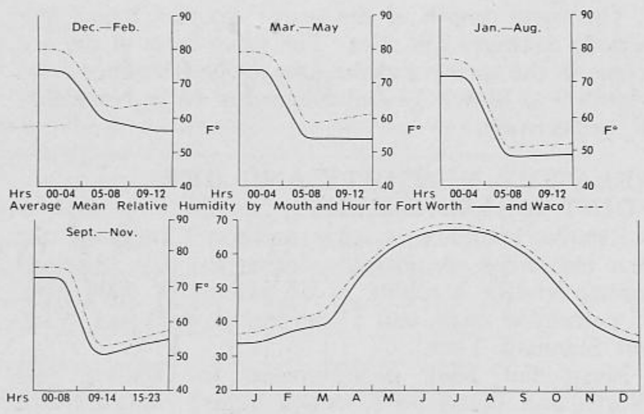


Fig. 22. Mean dew point temperatures, Dallas-Fort Worth, Waco.

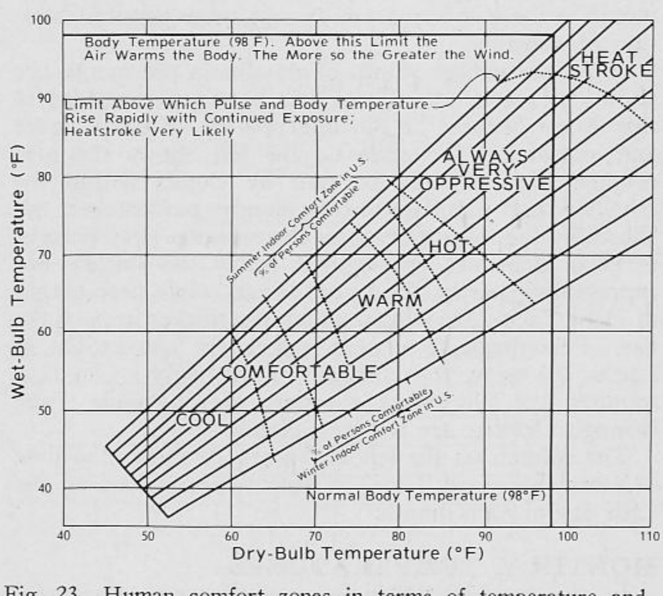


Fig. 23. Human comfort zones in terms of temperature and humidity.

Relative humidity and temperature data are important in the design of equipment and buildings so that the proper control of the atmosphere within the buildings will be within the range of human comfort (Fig. 23).

MONTHLY PRECIPITATION

Precipitation is fairly evenly distributed throughout the corridor area and averages 30 inches at Belton in the south to 36 inches at Hillsboro in the north.

Mean average rainfall throughout the area shows a pattern of relatively light rainfall during the winter increasing to a maximum in the spring (Figs. 20, 21).

The source area for moisture is the Gulf of Mexico, and storms originating there strike inland into Texas. The Balcones escarpment is the major topographical high and appears to have a direct influence on the mass of moist air by forcing it to rise. Cooling of this air as it is forced upward causes precipitation and can produce heavy rainfall along the escarpment. Generally these storms occur during late summer and autumn.

Heavy spring rains are frequently caused by masses of cool air moving in from the northwest which force the moist warm gulf air to higher elevations. Rainfall intensity duration curves for Waco are shown in Figure 24.

EVAPORATION RATES

Evaporation is affected by temperature, humidity, wind, and sunshine. The principal source of moisture for evaporation is open bodies of water; however, large quantities of water are returned to the air by the transpiration of plants. Evaporation measurements are taken by observing the lowering of water levels in a pan or tank. Monthly coefficients are applied to the pan evaporation rates to convert them to gross lake-surface evaporation rates. For the Waco-Dallas area mean annual class "A" pan evaporation is 80 inches and mean annual lake evaporation is 56 inches.

The mean annual P-E index (ratio of precipitation to evaporation) ranges from 48 in the south to 56 in the north. This figure represents the percentage of water available for plant growth. Therefore a high P-E index indicates plentiful water and a low P-E index indicates little water.

Studies of the evaporation of free water surfaces have proven inadequate from the standpoint of soil conservation (Berry et al., 1945, p. 738). The amount of evaporation from soil is a function of the depth of the water table; no evaporation takes place when the water table is 4 feet or more beneath the surface. Evaporation from clayey soils is about 72 percent of that from a free water surface (Berry et al., 1945, p. 743).

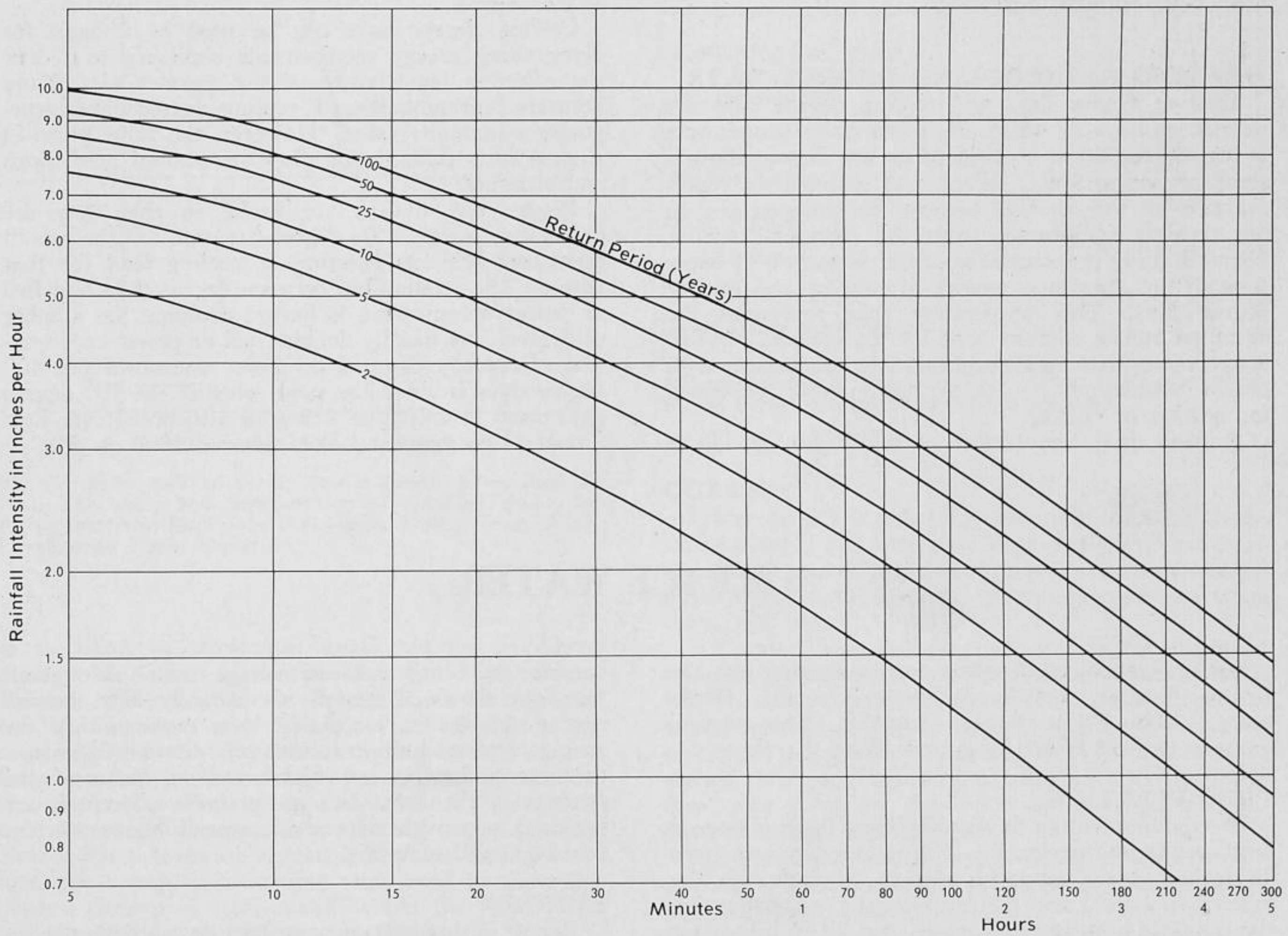


Fig. 24. Rainfall intensity duration curve, Waco.

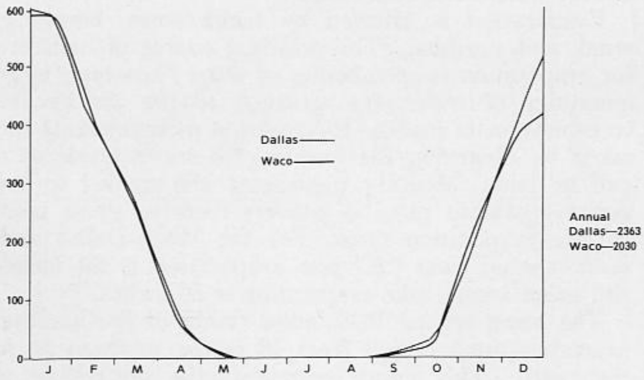


Fig. 25. Total heating degree days, Dallas and Waco. Base 65°F.

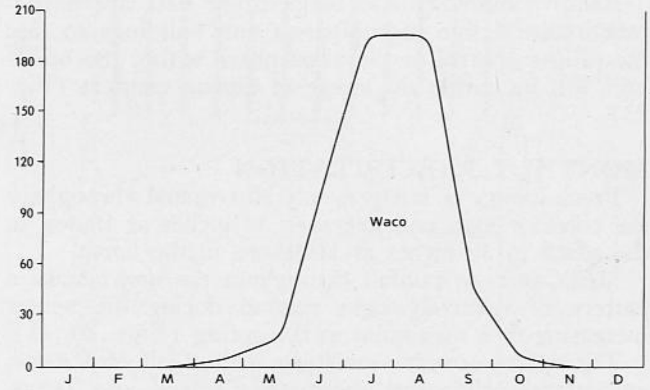


Fig. 26. Total cooling degrees days, Waco. Base 80°F.

This rate is reduced in proportion to the amount of covering vegetation. This evaporation data can be used for general estimates in preliminary design of major reservoir projects and are fully adequate for smaller projects, such as tanks, farm ponds, and low water dams. Most of the annual evaporation occurs from January through September. Approximately two-thirds of this evaporation loss occurs during the warm months from April through September.

HEATING AND COOLING DEGREE DAYS

Heating degree days and cooling degree days are defined as days in which the mean daily temperature is one degree below a standard or one degree above a standard, respectively. Waco was selected as representative of the corridor because its temperatures do not deviate significantly from the corridor's norms. For this study the standards of 65° F and 80° F were selected for the measurements of heating and cooling degree days. This temperature span represents the optimum human comfort zone for the corridor. When temperatures are within these two extremes, with proper ventilation, no energy needs to be expended for heating or cooling.

A mean daily temperature of 60° F for any given day would yield five heating degree days. Total heating degree days by month are shown in Figure 25. This index does not take into account cooling or heating effects by radiation, wind, or evaporation.

Cooling degree days based on 80° F are shown in Figure 26. A cooling degree day is one in which the temperature is one degree above 80° F. Figure 26 shows the total cooling degree days, by months, for Waco, Texas.

Cooling degree days can be used as a basis for determining energy requirements necessary to reduce the effective temperature of the warmer air. More accurate representations of cooling degree days incorporate a humidity value. However, the value given in Figure 26 is sufficient to allow generalized predictions and planning.

Degree day figures are useful in that they are cumulative, so that the degree-day sum for the month represents the total heating or cooling load for that period. The relationship between degree days and fuel or power consumption is linear; doubling the number of degree days usually doubles fuel or power consumption. Generally the fuel or power consumed per 100 degree days is about the same whether the 100 degree days occur in only 3 or 4 days or are spread over 7 or 8 days (Environmental Data Service, 1968, p. 36).

SURFACE WATER

Surface water includes those waters flowing into the Brazos, Bosque, and Leon Rivers: Aquilla, Hackberry, Cobb, White Rock, Chambers, Cow Bayou, Castleman, Bull Hide, Hog, and Nolan Creeks.

PRECIPITATION

Precipitation within the Brazos River basin is uneven both areally and seasonally. Precipitation ranges from 18 inches in the semiarid area to 48 inches in the eastern subhumid area. Mean annual precipitation for the semiarid area is 17.66 inches and 38.69 inches for the subhumid area. Mean annual precipiation for the corridor is 34 inches. Mean average rainfall throughout the area shows a pattern of relatively light rainfall during the winter increasing to a maximum in the spring. Precipitation is so unevenly distributed in time that streamflow is not maintained in many of the streams in the area. Storage projects, therefore, are required to provide dependable quantities of water for municipal and industrial use.

RUNOFF

Runoff is that part of precipitation that does not infiltrate the surface but runs off toward the streams. It

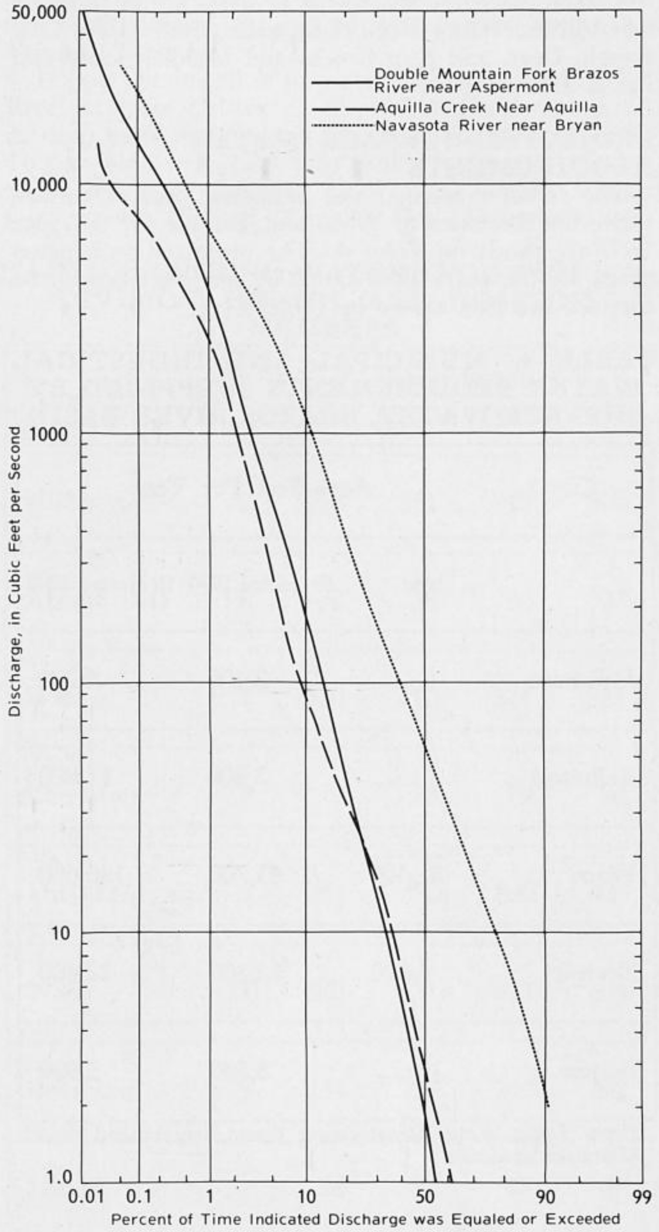


Fig. 27. Flow duration curve, Aquilla Creek. *From* Rawson 1967, The study and interpretation of chemical quality of surface waters in the Brazos River basin, Texas: Texas Water Development Board Report 55.

is the same as streamflow unaffected by diversions, storage, or other works of man in or on stream channels. The flow of the Brazos River is regulated by Whitney reservoir. Many of the tributaries are regulated by reservoirs, flood retarding structures, and farm ponds. It is necessary to adjust streamflow records for the effects of regulation before they can be used for runoff computations. Not all streams in the Brazos River basin are regulated by reservoirs. Therefore, the unregulated streams were used to show the general pattern of areal runoff within the basin. The period selected was 1960 through 1962.

Table 2 shows the average runoff from selected contributary areas within and adjacent to the studied area. This table does not show the magnitude or frequency of the high and low flows.

TABLE 2. AVERAGE DISCHARGE OF RIVERS IN THE I-35 CORRIDOR

Location	Average Discharge (cfs)	Observation Time (years)
Brazos River near Whitney	1690	26
Brazos River at Waco	2507	66
North Bosque River at Valley Mills	190	5
Bosque River near Waco	490	5
Middle Bosque River near McGregor	92.2	5
Aquilla Creek near Aquilla	108	25
Leon River near Belton	631	41

Records through September 1964. *From* U. S. Geological Survey (1964) Surface water records of Texas.

QUALITY

Water quality is generally defined in terms of chemical, physical, and biological characteristics. To these measurable water quality parameters may be added physiological and aesthetic properties, such as taste, color, and odor.

All water from natural sources contains dissolved minerals but amounts and kind of dissolved minerals will fluctuate widely. Some environmental factors that affect chemical quality of surface waters are variations in climate and geology; patterns and characteristics of stream flow; and activities of man such as impoundment and diversion, deposition of municipal and industrial wastes, and irrigation.

Water in the corridor area is classified with respect to dissolved-solid content, principal chemical constituents, and hardness (Table 3). On the basis of dissolved-solid content, water is classified as follows (Spencer, 1966, p. 40):

Classification	Dissolved Solids (ppm)
Fresh	less than 1,000
Slightly saline	1,000 - 3,000
Moderately saline	3,000 - 10,000
Very saline	10,000 - 35,000
Brine	more than 35,000

Water is classified on the basis of hardness as soft, moderately hard, hard, or very hard (Table 3).

TABLE 3. WATER HARDNESS CLASSIFICATION

Hardness (ppm)	Rating	Usability
0-60	Soft	Suitable for many uses without further softening.
61-120	Moderately hard	Usable except in some industrial applications.
121-180	Hard	Softening required by laundries and some other industries.
181+	Very hard	Softening desirable for most purposes.

After Spencer, 1966, Surface Waters of Waco *in* Urban Geology of Greater Waco, Part III, Water, Baylor Geol. Studies Bull. 10, p. 41.

SURFACE WATER DEVELOPMENT

It is apparent that considerable water from surface runoff is available for increased urbanization needs. Precipitation and runoff are highly variable; therefore, considerable development of surface water resources has taken place and watershed projects are in progress for Aquilla, White Rock, Castleman, Bull Hide, Cow Bayou, Deer, and Elm Creeks and Middle, South and North Bosque Rivers.

PROJECTED SURFACE WATER REQUIREMENTS

The actual municipal and industrial uses of surface water for the cities of Waco and Temple for the year 1960 are shown in Table 4. The projected anticipated usage for the years 1990 and 2020 for five cities in the corridor are also shown in Table 4.

TABLE 4. MUNICIPAL AND INDUSTRIAL WATER REQUIREMENTS SUPPPLIED BY SURFACE WATER, BRAZOS RIVER BASIN

City	Acre-Feet Per Year		
	1960	Projected 1990	Projected 2020
Hillsboro	[1]----	2,400	5,300
Bellmead	[1]----	3,500	11,800
Waco	21,400	61,700	130,600
Temple	4,800	12,300	22,400
Belton	[1]----	3,500	5,900

From Texas Water Development Board, unpublished report.
[1]Data not available.

GROUND WATER

PUBLIC SUPPLY

Population growth and urbanization along Interstate Highway 35 have created a steadily increasing demand for water. In 1967 approximately 16,816 acre-feet of ground water was pumped from the Trinity Group, the unit which contains the Hosston and Hensel Sands, the principal aquifers of the area.

Of the cities in the corridor, Hillsboro, in the extreme north section, uses the largest amount of ground water from the Trinity Group for its public supply. Using nine wells ranging in depth from 200 to 2,000 feet, the city pumps about 990 acre feet of ground water per year. Approximately 90 percent of this comes from Trinity aquifers in the corridor.

Belton is the second largest user of ground water from the Trinity Group in the corridor. In 1970, the city used 967 acre feet for public supply, or 25 percent of the total amount of water withdrawn from the Trinity aquifers. The water is pumped from four wells which range in depth from 1,140 to 1,293 feet. All of the wells are completed in the Hosston Formation.

Waco is the third largest user of ground water for public use in the corridor. As early as 1872 it obtained its water from an artesian well that tapped the Trinity Group. It now obtains most of its water from Lake Waco. Two wells, which range in depth from about 1,500 to 2,500 feet, are completed in the Hosston Formation of the Trinity Group. In 1970 these wells pumped 604 acre feet of water, which is 16 percent of the total amount of ground water used from the Trinity (Table 5).

Temple obtains all of its water supply from the Leon River at Lake Belton. It discontinued use of two of its deep wells in 1966 and the remaining well in 1968. To put these wells back into production would require the lowering of pumping heads (Leo Glaser, Water Department, City of Temple, Oral Communication, 12-71). Some, however, are in use by various public and private institutions.

In addition, numerous smaller water supply corporations, utilizing ground water, are located throughout the corridor.

TABLE 5. GROUND WATER FROM TRINITY DIVISION, HENSEL AND HOSSTON MEMBERS

City	No. of Wells	Acre feet used 1967	1968	1969	1970
Hillsboro	9	915	851	917	990
Abbott	1	32	34	36	37
West	3	330	312	331	321
Elm Mott	3	79	78	79	96
Lacy-Lakeview	3	361	353	399	435
Waco	33[1]	582	531	633	604
Robinson	3	254	252	292	302
Lorena	1	38	31	48	27
Bruceville	2	5	6	13	12
Eddy	2	22	22	27	31
Troy	2	91	58	64	61
Temple	3	61	Not used by city		
Belton	4	1140	1012	1230	967

[1]Only two active in 1972.

INDUSTRIAL SUPPLY

In 1967, approximately 3,659 acre-feet of ground water was pumped from the Trinity Division for industrial purposes. This is about nine percent of the total amount of ground water used from the Trinity Division in central Texas. Industrial pumpage has remained fairly constant with only minor fluctuations occurring from 1955 to 1970.

The largest single industrial user of ground water is the Rocketdyne Division of the North American Rockwell Corporation, located near McGregor. Although outside the corridor, Rocketdyne, which has five wells completed in the Hensel Formation, uses about 19 percent of the total amount of water withdrawn for industrial purposes from the Trinity Group.

The General Tire and Rubber Company, located in Waco, is the second largest industrial user of ground water from the Trinity Group. In 1967, General Tire and Rubber Company pumped 626 acre-feet of ground water, or about 17 percent of ground water used for industrial purposes from two wells completed in the Hosston Formation.

The third largest industrial user of ground water is the Ralph Wilson Plastics Company, located near Temple. The company has one well completed into the Hosston Formation and pumped 405 acre-feet in 1967, or about 11 percent of the total amount of water used for industrial purposes from the Trinity.

Other industries in the corridor which used large quantities of ground water from the Trinity Group in 1967 are: Belton Sand and Gravel Company, about 153 acre-feet; Certain-Teed Products Corporation, about 223 acre-feet; Plantation Foods, Inc., about 147 acre-feet; Taylor Bedding Manufacturing Company, about 129 acre-feet; and Pure Milk Company, about 80 acre-feet (Texas Water Development Board, unpub. report).

TABLE 6. PREDICTED WATER LEVEL DECLINES

City	Spring (1) 1967 - 1975	(2)	(1) 1967 - 1990	(2)	(1) 1967 - 2020	(2)
Hillsboro	354	131	354	220	354	418
Waco	250	114	250	312	250	770
Belton	51	115	51	173	51	242

From Texas Water Development Board, unpublished report.
1967-approximate water level in Spring 1967.
1975, 1990, 2020—projected decline in feet of water level from Spring 1967.

PREDICTED WATER LEVEL DECLINES

An aquifer simulation study of the Trinity aquifers projected to the year 2020 indicates water level declines of as much as 1000 feet will occur in areas of heavy pumpage (Texas Water Development Board, unpub. report). This will mean lifts of as much as 1600 feet for wells in Waco. In addition to increased lifting costs, this may also lead to a marked decline in water quality resulting from induced mixing with overlying Glen Rose waters.

The predicted water level declines for the periods spring 1967-1975, spring 1967-1990, and spring 1967-2020 are presented in Table 6.

HYDROGEOLOGY

INTRODUCTION

The two primary aquifers of the study area are the Hosston and Hensel Formations of the Trinity Group. These two formations supplied all the water needs of the corridor until the impoundment of surface waters by Lake Waco Dam and Lake Belton Dam.

Although the larger cities in the corridor, Temple and Waco, no longer depend upon ground water for public supply, the aquifers are important to the urbanization of the area because smaller communities and most industrial concerns will use ground water.

TRINITY GROUP

The Trinity Group consists of three units, each of which is divided into a basal clastic phase and an upper carbonate phase. The upper unit is divided into the upper Glen Rose Limestone and a lower Hensel Sand which is one of the two principal aquifers in the study area. The middle unit is designated the Pearsall Formation with the upper Cow Creek Limestone and the lower Hammett Shale. The lower unit is divisible into an upper Sligo Formation and a lower Hosston Formation which is the other principal aquifer (Holloway, 1959, p. 67).

HOSSTON FORMATION

The Hosston Formation is the lower sand unit of the Trinity Group and is situated between the underlying Paleozoic rocks and the overlying Pearsall Formation or the Hammett Member. The Hosston exists as a distinguishable unit throughout central Texas, except possibly in the west-central area where the Sycamore Formation is its equivalent. The Hosston is often referred to as the "Lower Trinity" by drillers and residents in central Texas. It is the most important aquifer in the corridor.

The Hosston Formation varies in thickness within the corridor from a maximum of 290 feet in the number one well of McCloskey Army Hospital in Bell County, in the southern part of the corridor to a minimum of 110 feet in well 16 in Hillsboro, located in Hill County in the northern section of the corridor. At West in McLennan County, the Hosston is 175 feet thick in well 3 and thickens eastward to 530 feet in the E. W. Barett well number 1 near Hubbard in southwestern Hill County. The thickness at Lorena in well 2, Community Water Supply Corporation, is 205 feet, which represents a gradual thickening to the east from McGregor where the thickness is zero in well number 4, City of McGregor, because of a pinch-out due to buried topography.

Near Belton the Hosston Formation is 85 feet thick in well number 1 of the Taylor Bedding Manufacturing Company, and thickens to the east where it is 290 feet in well number 1 of McCloskey Army Hospital near Temple.

The Hosston Formation has an eastward regional dip in northern, central, and western parts of the central Texas region and a southeastward dip in the area adjacent to and east of the Balcones fault zone. Locally the direction may vary due to the depositional structure and localized thickening or thinning of the Hosston. In the Hillsboro area the dip is 46 feet per mile. Southeast of Hillsboro and in the Balcones fault zone the dip is 86 feet per mile. South of Waco the dip is 85 feet per mile increasing to 90 feet per mile in the area east of Temple (Texas Water Development Board, unpub. report).

HENSEL FORMATION

The Hensel Formation, the upper sand unit of the Trinity Group, is overlain by the Glen Rose Formation and underlain by the Pearsall Formation or the Cow Creek Member. The Hensel is a mappable unit in the central Texas region, except in the west-central area, where the abundance of limestone in the Hensel makes difficult the differentiation between it and the underlying Cow Creek Member. The Hensel is commonly referred to as the "First Trinity" or "Upper Trinity Sand" by local drillers, engineers, and residents of central Texas. The Hensel is the second most important aquifer in central Texas. Most of the domestic and stock wells drilled into the Trinity Group are completed into the Hensel Formation.

The Hensel consists of pebbly sandy conglomerate, poorly sorted, crossbedded, poorly- to well-cemented with calcitic, opaline quartz, or clay; fine- to coarse-grained sand and sandstone, poorly- to well-cemented with calcitic and occasionally opaline quartz, gray green, buff to red-brown color, often unconsolidated in the subsurface; sandy to silty clay, occasionally waxy, green, gray, red, yellow or brown color, sometimes calcareous; gray to green shale; and lenses of limestone, often arenaceous. The conglomerates are often cross-bedded and occasionally the sands are cross-bedded, although they usually range from thin- to massively bedded. The sands and conglomerates are predominantly siliceous with pebbles consisting of chert or quartz. The conglomerates usually occur near the base of the Hensel and are found only in the area near or immediately adjacent to the outcrop. Grain size and amount of sand decrease in a southeastward direction becoming smaller and grading into silty and sandy shales in the subsurface.

Total thickness of the Hensel varies considerably in central Texas. At Hillsboro in Hill County (well number 16, City of Hillsboro) the Hensel is 55 feet thick; at Temple in Bell County, (well number 3, City of Temple) it is 50 feet thick. The general trend of decreasing thickness and increasing facies change from sand to shale is from west to east and northwest to southeast.

West of the Balcones fault zone the Hensel has a regional dip to the east. East of the fault zone the Hensel dips to the southeast.

The rate of dip in the vicinity of Hillsboro is 46 feet per mile increasing to 86 feet per mile near Hubbard in southeastern Hill County. The dip is 67 feet per mile near Waco and increases southeastward to 133 feet per mile east of Marlin in Falls County.

WASTE WATER REUSE AND RECLAMATION

INTRODUCTION

Additional sources of water can be obtained through the proper management of municipal, industrial, and agricultural waste water. These return flows must be considered in the overall water budget.

RATIO OF RETURN FLOW TO WATER USE

The ratio of municipal return flow to water use depends upon such factors as total population, population density, economic base, and cost and quality of the supply, with climate the most important single factor. In general the return-flow water-use ratios in most municipalities range between 0.4 and 0.7, the weighted mean being 0.6 (Texas Water Development Board, 1971, p. 11-16).

Waco discharges about 300 million gallons of treated sewage effluent into the Brazos River every month. This represents a flow ratio of 0.5 for the city. The chemical analysis of effluent is shown in Table 7.

DIRECT USE OF WASTE WATER

Municipal waste water can be used for irrigation of parks, golf courses, and cemeteries. Irrigation of nonedible crops with these effluents contributes to agriculture yields which are generally greater than those realized from conventional irrigation without fertilization. No known incidence of disease directly related to these uses has been documented, although detailed epidemiological studies have not been conducted (Texas Water Development Board, 1971, p. 11-19).

TABLE 7. CHEMICAL ANALYSIS OF FINAL SEWAGE EFFLUENT, WACO, TEXAS

Substance	Concentration in ppm
Specific conductance (micromhos)	960
Total dissolved solids	574
Chloride	72
Sulfate	65
Chlorine demand	1.5
Dissolved Oxygen	0[1]
River above outfall	9.6
River below outfall	9.3
B. O. D.	26
River above outfall	2.1
River below outfall	2.3
Ammonia	14
Nitrate Nitrogen	0.1
P. alkalinity	0.0
Total alkalinity	262
Total suspended solids	34
Volatile suspended solids	33
Fixed suspended solids	1

From Spencer, 1966, Surface Waters of Waco *in* Urban Geology of Greater Waco, Part III, Water, Baylor Geol. Studies Bull. 10, p. 29.

[1]Analysis made several hours after collection. Analysis November 18, 1965, Texas State Department of Health and Waco Water Department.

ECONOMIC GEOLOGY

INTRODUCTION

Economic geology is closely related to urban geology. Without deposits of suitable earth materials within economic distances urbanization would proceed at a very slow rate and possibly not occur at all. Abandoned rock quarries along Interstate Highway 35 are mute testimony to the need for low cost earth material in highway construction.

Development and production of these resources brings a responsibility for environmental protection by the producer and must be considered in planning for exploitation of resources. Planning should be undertaken by regional or city planners prior to licensing of any extractive operation. A sequential multiple use (Flawn, 1970b, p. 3) should be the rule rather than the exception. If this principle is accepted, the solution to the problem of mineral resource and multiple land use can be stated in terms of three elements:

1. Creation of a legal structure that will require industry-wide performance in land-use practices on an equitable basis.
2. Creation of an economic structure that will not only permit but encourage the mineral industry to reclaim and restore the surface, prevent subsidence, and prevent deleterious environmental effects from solid, liquid, and gaseous wastes.
3. Creation of a social attitude that includes a long-term sequential view of land use and recognizes that in certain areas containing mineral deposits needed by society, exclusive land use is required during the extractive period (Flawn, 1970b, p. 3).

The corridor has abundant deposits of earth materials, such as (1) sand and gravel, (2) stone, and (3) shale, which are suitable for construction and other urban needs.

SAND AND GRAVEL

Great quantities of sand and gravel can be found throughout the area in Brazos alluvium, Brazos terraces, Bosque terraces, and the Quaternary terraces of the Leon River.

The flood plain and lower Brazos terraces (20 to 50 feet above the low water level of the Brazos River) are the major source areas in the central section of the study area. Industrial users in the southern section secure these materials from the Quaternary terraces of the Leon River and the terraces of the Lampasas River, 20 miles south of Temple.

Brazos terrace gravels consist of well-rounded siliceous pebbles composed of quartz, quartzite, chert, and jasper and some limestone gravels in a quartz-sand matrix. Bosque terrace gravels are composed of limestone pebbles in a sandy clay matrix; gravels of the Leon terraces are composed of quartz, quartzite, chert, jasper, and large quantities of limestone and shell with varying amounts of clay and sand. Limited amounts of sand and gravel occur along major creeks within the study area.

STONE

Crushed stone is obtained from the Edwards Formation. The Mainstreet Member of the Georgetown Formation is sometimes used as base material for secondary streets and highways. The lower Austin Formation can be used if crushed as coarse as possible.

Both the Edwards and Georgetown Formations crop out in the area around Belton. There are no outcrops of these two formations within the corridor north of Temple. However, outcrops of both occur within economical hauling distances (30 miles) in the central section. None of the formations are uniform in lithology, therefore, on-site testing is required.

The Austin Chalk is the principal ingredient for regionally-produced cement. It is used for cement produced at the Universal Atlas Cement Plant near Waco. The massive chalk beds have a $CaCO_3$ content in excess of 85 percent. The reserves at Waco are in excess of 100 years. High purity limestone is also available from the Edwards Limestone exposed near Belton.

SHALE

Expanded light-weight aggregate is produced from shales found in the study area and supplies a rapidly expanding market. At present the Eaglelite Aggregate Company is the only producer of this product in the corridor.

The Waco Brick Company manufactures bricks from shale taken from the Pepper Formation and mixed with Brazos River sand and silt. The Universal Atlas Cement Plant uses shale from the South Bosque Formation to manufacture cement.

As a result of ready availability of raw materials, many small and medium sized industries using products derived from earth resources have developed within the area. These industries depend on the continued development and production of the earth's resources. To insure that we continue to receive economic stimulus and job opportunities from these companies, we must plan now for sequential multiple use of our lands.

RECOMMENDATIONS

INTRODUCTION

The study of any limited area cannot be divorced from the problems of the region in which that area lies. Regional urbanization has a direct effect on physical and environmental factors of smaller areas within the region. For this reason recommendations have been divided into two categories: (1) those that are regional in nature and (2) those that are based on the physical limitations of the growth corridor.

REGIONAL RECOMMENDATIONS

1. Creation of a state-supported environmental commission which would be responsible for the development of master land-use plans, master zoning codes, and development of environmental controls. This commission would be responsible for implementation of these plans, codes, and controls on a regional basis and the comprehensive re-education of the public in environmental awareness, responsibilities of land ownership, and limitations of land use.

2. Establishment of regional solid waste disposal plants. These plants would serve a number of purposes, such as: (a) recycling of much needed raw materials (Table 8), (b) providing additional income to cities by the sale of solid wastes to these plants thereby offsetting any necessity for tax increases, (c) revitalizing the public's pride in the community when visual and financial proof of environmental concern can be seen, (d) elimination of sanitary landfills, since in most cases these are not operated properly and also building over them may be hazardous due to stability and shrink-swell changes caused by effluent or leachate reactions with the clays.

TABLE 8. PROBLEMS AND ENFORCEMENT OF SOLID WASTE DISPOSAL

Item	Use	Problems	Enforcement
Paper	Recycling	Special inks and coatings	Collection centers; fines, pulp industry pay special tax.
Cans	Recycling	Tin coatings	Manufacture of cans from resin coated steel, separation at source, ban on aluminum cans.
Bottles	Reuse and recycling	Colored glass	Deposit on bottles, special collection centers, deposit centers
Automobiles	Scrap metal	Non-metallic material	Centers for collection and reclamation, design of autos for easy reclamation.
Tires	Recapping and raw material for other products	None	Old tire must be turned in in order to purchase a new tire.

From Wagner, 1971, Environment and Man, p. 412-17.

3. Interpretive mapping on a large scale (1/1,200) of the land areas bordering Interstate Highway 35. The interpretive maps useful in this area are as follows:

(a) Suitability of soils for homesites based on plasticity index and shrink-swell.
(b) Suitability of soils as source of sand and gravel.
(c) Suitability of soils for growing trees and other vegetation.
(d) Suitability of soils for roads.
(e) Relation of soils to surface runoff.
(f) Relation of soils to underground structures.

4. Geological evaluation of landfill sites within economical hauling distances. It would be advantageous for every community to identify geologically secure sites for sanitary land fills and acquire them now. This would be a temporary measure until regional solid waste disposal plants are operable.

5. Public acquisition of low lands bordering all streams so that these areas can be developed as recreational areas, limiting losses due to flooding.

LOCAL RECOMMENDATIONS

Geology and Soils

Zoning within the growth corridor should be based upon all environmental factors such as geology, soils, hydrology, and climatic information.

On the basis of geology and soils the area has been divided into six "Land Capability Groups." These groups, correlated with hydrologic and climatic data, are the basis for the zoning recommendations on Plates V and VI.

These recommendations do not constitute the only solution to urbanizing the growth corridor. They do represent a plan that is based upon the physical potential of the area.

Generally, the land capability groups I, II, III, IV can be zoned for residential usage. The zoning would be influenced by degree of limitation as found in Plates III, IV, VI and the climatic section of this report.

Corrective actions for some of the most troublesome engineering problems found within the growth corridor are given in Plate VI along with information on placement of sanitary landfills and absorption area requirements for private residences.

Land capability group V should be zoned for recreational use. Any construction in this area will encounter serious engineering problems (Plates II, IV, VI). Group VI shows the floodplains of the area which can be zoned agricultural, recreational, or parkland, as well as industrial, when it will not be harmed by flooding. Usually parkland and recreational facilities are little damaged by flooding.

These recommendations do not replace site evaluation and testing. They should give the regional planner an overview of the environmental control factors which govern the degree of testing and sampling needed to allow for safe and economical engineering design.

Climate

1. Residential areas should be built on the western side of the area to take advantage of the prevailing wind directions (Figs. 12-17). Industry should be located on the east side. Interstate Highway 35 is the median line dividing the area into eastern and western sides.

2. Parks should be built at right angles to north-south roads. This will in some instances act as an air shed and sound breaks, cool the wind, and reduce wind velocity in the park area. Parks should be planned north of cities in capability groups V and VI (Plate VI).

3. Major streets should be aligned in a north-south direction. This will allow the passage of prevailing winds.

4. Where possible, streets should have center medians with vegetation. This will tend to keep streets cooler and to reduce overall radiation and heating effects on adjacent buildings.

5. Where terrain is hilly, residential areas should be built on the south and southeast slopes and parks on hilltops. Valleys should be left as parkland.

6. Buildings should be designed to take advantage of minimal energy requirements from mid-September through October and from mid-April to early June (Figs. 25, 26).

7. Construction schedules should, when possible, take advantage of dry seasons to avoid difficulties encountered in clayey soils.

8. Solar energies average 2450 BTU per cubic foot on July 15 and 2100 BTU per cubic foot on January 15 (Barry Eaton, S.M.U. Institute of Technology, Oral Communication, 2-75). Therefore, a low cost solar energy is available for the operation of solar heating and air-conditioning. This energy can also be used in solar batteries if initial capital outlays are not prohibitive.

9. Control of natural sunlight is desirable for economy and general efficiency of people. Prior to construction, solar angles should be considered so building orientation and general design configuration (as overhangs, glass surfaces, and exposure angles) can adequately provide a method for introducing natural light and controlling its distribution.

Generally, north slopes of hills or the south wall of a ditch will not receive as much solar radiation as the sides open toward the south. While solar radiation intensity will be highest for a southern exposure, the highest temperatures usually occur on slopes with a southwest direction.

Ground and Surface Water

1. By the year 2020 only smaller cities will be using ground water from sands of the Hosston and Hensel Formations. Their requirements are estimated to be approximately 6,000 acre-feet per year. The two formations of the Trinity Group will probably be able to supply this amount.

2. Proposed surface water development in the Brazos River basin must be carried out to provide water for the larger cities.

3. Extensive use should be made of municipal and industrial waste water.

APPENDIX I

INTERPRETATION OF PLATE IV[1, 2]

Column 1. Percentage of Soil Series in Associations

Association-Series	*Percentage in Association*
Austin-Eddy-Stephen	
Austin	83%
Eddy	7
Stephen	10
Axtell-Irving	
Axtell	61
Irving	9
Hortman	2
Ivanhoe	8
Riesel	9
Vanos	8
Brewer	3
Wilson Burleson	
Wilson	56
Burleson	44
Kaufman	0
Denton-Purves	
Denton	1
Purves	99
Houston Black-Heiden	
Houston Black	69
Heiden	29
Ferris	0.2
Bastrop	0.2
Travis	1.4
Lewisville	0
Venus	0
Houston Black-Heiden-Austin	
Houston Black	43
Heiden	0
Austin	57
Miller-Norwood-Yahola	
Miller	8
Norwood	13
Yahola	13
Asa	66
Brazos	0
San Saba-Crawford	
San Saba	50
Crawford	50
Tarply-Brackett-Tarrant-Purves	
Tarrant	29
Brackett	13
Altoga	0
Purves	29
Tarply (Speck)	29
Trinity-Frio-Bosque	
Bastrop	0.2
Trinity	0
Frio (Catalpa)	19
Bosque	56
Venus	19
Payne	2
Travis	2
Trinity-Pursley	
Trinity	100
Frio (Catalpa)	0

[1]All columns except column 1 are from U. S. Soil Conservation Service, 1971b, Guide for interpreting engineering uses of soils (unedited interim report). Published Nov. 1971.

[2]See glossary for definitions.

COLUMN 2. DEPTH TO HARD ROCK

The depth of loose material to "rock which requires drilling and blasting for its economical removal" (A.G.I. Glossary, 1957).

	Classes	*Inches*
vs	Very shallow	Less than 10
s	Shallow	10 to 20
md	Moderately deep	20 to 36
d	Deep	36 to 50
vd	Very deep	50 inches to 20 feet
rf	Rock free	More than 20 feet

COLUMN 3. PERMEABILITY

Soil permeability is that quality of the soil that enables it to transmit water and air. This rate of flow is principally downward and is divided into the following classes:

Permeability class	*Grouping for report*
very slow	less than 0.06"/hr.
slow	0.06 to 0.2
moderately slow	0.2 to 0.6
moderate	0.6 to 2.0
moderately rapid	2.0 to 6.0
rapid	6.0 to 20.0
very rapid	over 20.0"/hr.

COLUMN 4. NATURAL SOIL DRAINAGE

Natural soil drainage is an overall evaluation of the drainage characteristics of the soil, considering both the internal porosity of the soil and the slope on which it is found. Three classes are used:

Good—drainage is adequate under all conditions.

Fair—drainage may be restricted for short periods of heavy rainfall or inundation.

Poor—drainage restricted except during protracted dry periods.

COLUMN 5. POTENTIAL VERTICAL RISE (PVR)

PVR is the latent or potential ability of a soil material (at a given density, moisture, and loading condition) when exposed to capillary or surface water to swell and thereby increase the elevation of its upper surface together with anything resting upon it. PVR is expressed in inches (Font and Williamson, 1970, p 33).

Adjective ratings of PVR	
Low	0.5
Moderate	0.5 - 1.25
High	1.35 - 2.0
Very high	2.0

Structures located on soils with PVR rating over 1.5 are considered to be in a damage area. Serious engineering problems will be encountered.

COLUMN 6. SOIL LIMITATION CLASSES FOR LOCAL ROADS AND STREETS

Items affecting use	Degree of soil limitations: Slight	Moderate	Severe
Soil drainage class	Excessively, somewhat excessively, well, and moderately well	Somewhat poorly	Poorly and very poorly
Flooding	None	Once in 5 years	More than once in 5 years
Slope (percent)	0 - 8	8 - 15	More than 15
Depth to bedrock[1]	More than 40 inches	20 to 40 inches	Less than 20 inches
Subgrade[2]			
a. AASHO Group Index[3]	0 to 4	5 to 8	More than 8
b. Unified soil classes	GW, GP, SW, SP, GM, GC,[7] SM, SC[7]	CL with PI[4] Less than 15. ML	CL with PI[4] 15 or more. CH, MH,[5] OH, OL, Pt
Shrink-swell potential	Low	Moderate	High
Susceptibility to frost heave[6]	Low	Moderate	High
Stoniness	Classes 0, 1, 2	Class 3	Classes 4, 5
Rockiness	Class 0	Class 1	Classes 2, 3, 4, 5

[1]If bedrock is soft enough so that it can be dug with light power equipment and is rippable by machinery, reduce moderate and severe limitations by one class.

[2] Use AASHO Group Index values if available from laboratory tests; otherwise use the estimated Unified classes.

[3]Use Group Index values according to AASHO Designation M 145-49 and M 145-661; for most soils with group index values below about 8, both designations (method) give results nearly enough alike to be considered alike for the purposes of this guide.

[4]PI means plasticity index.

[5]Upgrade to moderate if MH is largely kaolinitic, friable, and free of mica.

[6]Use this term only where frost penetrates below the paved or hardened surface layer and moisture transportable by capillary movement is sufficient to form ice lenses at the freezing front. See section "Potential Frost Action" for guidance to classes.

[7]Downgrade to moderate if content of fines is greater than about 30 percent.

COLUMN 7. SOIL LIMITATION CLASSES FOR SHALLOW EXCAVATIONS

Items affecting use	Degree of soil limitation		
	Slight	Moderate	Severe
Soil drainage class	Excessive, somewhat excessive, and well drained	Moderately well drained	Somewhat poorly, poorly, and very poorly drained
Seasonal water table	Below 60 inches	Between 30 and 60 inches	Above 30 inches
Flooding	None	None	Subject to flooding
Slope (Percentage)	0 to 8	8 to 15	More than 15
Texture of depth to be excavated[1, 2]	fsl, sl, l, sil, sicl, scl	si,[3] cl, sc, all gravelly types	c,[4] sic,[4] s, ls, organic soils, all very gravelly types
Depth to bedrock[5]	More than 60 inches	40 to 60 inches	Less than 40 inches
Stoniness (classes)	0, 1	2	3, 4, 5
Rockiness (classes)	0	1	2, 3, 4, 5

[1]Texture is used here as an index of workability and sidewall stability.
[2]If soil contains a thick fragipan, duripan, or other material difficult (but not impossible) to excavate with handtools, increase the limitation rating by one class unless it already is severe.
[3]If soil will stand in vertical cuts, like loess, reduce rating to slight.
[4]If friable, like that in some kaolinitic Paleudults, reduce rating to moderate.
[5]If bedrock is soft enough so that it can be dug out with ordinary handtools, or light equipment, such as back hoes, reduce moderate and severe ratings by one class.

COLUMN 8. CORROSIVITY

Corrosion of uncoated steel is a physical-biochemical process converting iron into its ions. Soil moisture is needed to form solutions with soluble salts before the process can operate. This constitutes a corrosion cell. Any factors influencing the soil solution or the oxidation-reduction reactions taking place in the soil will influence the operation of the corrosion cell. Some of these factors are soil moisture content, conductivity of soil solution, hydrogen ion activity of soil solutions (pH), oxygen concentration (aeration), and activity of organisms capable of causing oxidation-reduction reactions. The corrosivity of soil for untreated steel pipe is commonly estimated by (1) electrical resistivity or resistance to flow of current, (2) total acidity, (3) soil drainage, and (4) soil texture.

The criteria used here are from National Bureau of Standards, Dept. of Commerce Circ. 579 as *cited in* U. S. Soil Conservation Service (1907b).

Over 10,000 ohms/cc	very low
5,000-10,000	low
2,000-5,000	moderate
1,000-2,000	high
1,000	very high

COLUMN 9. SOIL LIMITATION CLASSES FOR DWELLINGS[1]

Item affecting use	Degree of soil limitation[2]		
	Slight	Moderate	Severe
Soil drainage class[3]	*With basements:* Excessively, somewhat excessively, well	*With basements:* Moderately well	*With basements:* Somewhat poorly, poorly, very poorly
	Without basements: Excessively, somewhat excessively, well, moderately well	*Without basements:* Somewhat poorly	*Without basements:* Poorly, very poorly
Seasonal water table (Seasonal means 1 month or more)	*With basements:* Below 60 in.	*With basements:* Below 30 in.	*With basements:* Above 30 in.
	Without basements: Below 30 in.	*Without basements:* Below 20 in.	*Without basements:* Above 20 in.
Flooding	None	None	Occasional to frequent
Slope[4] (percent)	0 to 8	8 to 15	More than 15
Shrink-swell potential	Low	Moderate	High
Unified soil group	GW, GP, SW, SP, GM, GC, SM, SC	ML, CL	CH, MH,[5] OL, OH, Pt
Potential frost action[6]	Low	Moderate	High
Stoniness	Classes 0 to 1	Class 2	Classes 3, 4, and 5
Rockiness[7]	Class 0	Class 1	Classes 2, 3, 4, and 5
Depth to bedrock[7]	*With basements:* 60 in.	*With basements:* 40 to 60 in.	*With basements:* Less than 40 in.
	Without basements: More than 40 in.	*Without basements:* 20 to 40 in.	*Without basements:* Less than 20 in.

[1]By reducing the slope limits 50 percent, this table can be used for evaluating soil limitations for shopping centers and for small industrial buildings with foundation requirements not exceeding those of ordinary three-story dwellings.
[2]Some soils rated as having moderate or severe limitations may be good sites from an aesthetic or use standpoint but require more preparation or maintenance.
[3]U.S. Soil Conservation Service (1951) Soil Survey Manual, pp. 169-72.
[4]Reduce slope limits 50 percent for those soils susceptible to hillside slippage.

[5]Upgrade to moderate if MH is largely kaolinitic, friable, and free of mica.

[6]Use this item only where frost penetrates to assumed depth of footings and soil is moist during freezing weather. See section "Potential Frost Action" for guidance to classes.

[7]If bedrock is soft enough so that it can be dug out with light power equipment such as backhoes, reduce the moderate and the severe ratings by one class.

Column 10. Soil Limitation Classes for Septic Tank Absorption Fields

Soil Properties	Soil Ratings in Terms of Limitations		
	Slight	Moderate	Severe
Permeability[1] class	Rapid,[2] moderately rapid, and upper end of moderate	Lower end of moderate	Moderately slow and slow[3]
Hydraulic conductivity rate (Uhland core method)	More than 1.0 inch/hr.[2]	1.0 to 0.60 inch/hr.	Less than 0.60 inch/hr.
Percolation rate (Auger hole method)	Faster than 45.0 min./inch[2]	45 to 60 min./inch	Slower than 60 min./inch
Depth to water table[4]	More than 72 inches	48 to 72 inches	Less than 72 inches
Flooding hazard	Not subject to flooding	Not subject to flooding	Subject to flooding
Slopes	0 to 8%	8 to 15%	More than 15%
Depth to hard rock,[4] bedrock, or other impervious material	Over 72 inches	48 to 72 inches	Less than 72 inches

[1]Class limits are the same as those suggested by the Work-Planning Conference of the National Cooperative Soil Survey. The limitation ratings should be related to the permeability of soil layers at and below depth of the tile line.

[2]Indicate by footnote where pollution to water supplies is a hazard.

[3]In arid or semiarid areas soils with moderately slow permeability may have a moderate limitation.

[4]Based on assumption of tile depth of 2 feet in the soil.

Column 11. Soil Limitation Classes for Lagoons

Soil Properties	Limitation Class		
	Slight	Moderate	Severe
Depth to water table (seasonal or normal)	Over 60 inches	40 to 60 inches	Less than 40 inches
Permeability	Less than 0.60 inch/hr.	0.60 to 2.0 inch/hr.	Over 2.0 inch/hr.
Depth to bedrock	More than 60 inches	40 to 60 inches	Less than 40 inches
Slope (percent)	Less than 2	2 to 7	Over 7
Reservoir site material[1] (Unified grouping)	GC, SC, CL, and CH	GM, ML, SM, and MH	GP, GW, SW, SP, OL, OH, and Pt
Coarse fragments, under 10" in diameter, by percent volume	Less than 20	20 to 50	Over 50
Percent of surface area covered by coarse fragments over 10" diameter	Less than 3	3 to 15	Over 15
Organic matter (percent)	Less than 2	2 to 15	Over 15
Flooding hazard	Not subject to flooding	Not subject to flooding	Subject to flooding

[1]Mainly for lagoon floor.

COLUMN 12. SOIL LIMITATIONS FOR SANITARY LANDFILL TRENCH TYPE[1]

Soil Property	Degree of soil limitation		
	Slight[2]	Moderate[2]	Severe
Depth to seasonal high water table	Not class determining		Less than 60 inches
	More than 60 inches		
Soil drainage classes	Excessively, somewhat excessively, well and somewhat[3] moderately well-drained	Somewhat poorly and somewhat[3] moderately well-drained	Poorly- and very poorly-drained
Flood hazard	None	None	Soils subject to flooding
Permeability[4]	Less than 2.0 ins. per hour	Less than 2.0 ins. per hour	More than 2.0 ins. per hour
Slope (percent)	0 to 15	15 to 25	More than 25
Soil texture[5] (dominant to a depth of 60 inches)	Sandy loams, loam, silt loam, sand clay loam	Silty clay loam,[6] clay loam, sandy clay, loamy sand	Silty clay, clay, muck, peat, gravel, sand
Depth to Bedrock :Hard	More than 72 inches	More than 72 inches	Less than 72 inches
Depth to Bedrock :Rippable	More than 60 inches	Less than 60 inches	Less than 60 inches
Stoniness	0, 1	2	3, 4, 5
Rockiness	0	0	1, 2, 3, 4, 5

[1]Based on soil depth (5-6 ft.) commonly investigated in making soil surveys.
[2]If the probability is high that the soil material to a depth of 10 to 15 feet will not alter a rating of slight or moderate, indicate that by an appropriate footnote such as "Probably slight to 12 feet," or "Probably moderate to 12 feet."
[3]Soil drainage classes do not correlate exactly with depth to seasonal water table. The overlap of the moderately-well drained soils into two limitation classes allows some of the wetter moderately-well drained soils (mostly in the northeast) to be given a moderate limitation.
[4]Reflects ability of soil to retard movement of landfill leachate. May not be a factor in arid and semiarid areas.
[5]Reflects ease of digging and moving soil material (workability) and trafficability in the immediate area of the trench that may not have surfaced roads.
[6]Soils high in expanding clays may need to be rated as severe.

COLUMN 13. SOIL LIMITATIONS FOR INTENSIVE CAMP AREAS[1]

These soil ratings apply to areas suitable for tent and camp trailer sites and the accompanying activities for outdoor living. They are used frequently during the camping season. These areas require little site preparation and should be suitable for unsurfaced parking for cars and camp trailers and heavy foot traffic by humans or horses or vehicular traffic. The soils should be free of coarse fragments and rock outcrops. Suitability of soil for supporting vegetation is a separate item to be considered in the final evaluation of selecting sites for these uses.

Rating guide: Soils such as swamps, marsh, rock outcrops, and the like are considered as having a very severe limitation and should not be classified as severe. These soils should be listed in a separate grouping.

Degree of Soil Limitation

Items Affecting Use	None to Slight	Moderate	Severe
Wetness hazard	Well and moderately well drained soils with no ponding and with water table below 3 feet	Moderately well drained soils with water table less than 3 feet and somewhat poorly drained soils with no ponding	Well drained, moderately well drained and somewhat poorly, with occasional ponding of short duration and poorly, and very poorly drained soils
Flooding hazard	None	----	Subject to flooding
Permeability[2]	Very rapid to moderate	Moderately slow and slow	Very slow
Slope	0 - 6%	6 - 15%	15% +
Surface soil texture	sl, fsl, vfsl, l, and ls with text. B horizon. Not subject to soil-blowing	cl, scl, sicl, ls, and sand other than loose sand	Organic, sc, sic, c, and sand subject to soil blowing
Coarse fragments < 10"	Less than 15%	15 - 50%	Over 50%
Stoniness or rockiness	None	Classes 1 and 2	Classes 3 and 4

[1]Based on soil limitations during use season.
[2]In low rainfall areas soil limitations imposed by permeability may be reduced one class.

COLUMN 14. SOIL LIMITATIONS FOR PICNIC AREAS SUBJECT TO INTENSIVE USE

Soil ratings are based on three classes for degree of soil limitation—slight, moderate, or severe. These ratings are based on soil features only and do not include other features such as presence of trees or lakes which may affect the desirability of a site. Suitability of soil for supporting vegetation is a separate item to be considered in the final evaluation of selecting sites for these uses.

Degree of Soil Limitation

Items Affecting Use	None to Slight	Moderate	Severe
	Well and moderately well drained soils not subject to ponding	Well drained, moderately well drained soil subject to occasional ponding. Somewhat poorly drained not subject to ponding	Poorly drained and very poorly drained soils. Somewhat poorly drained soils subject to ponding. Too wet for use for periods of 1 week or more
Flooding hazard	None during season of use	May flood 1 or 2 times for short periods during season of use	May flood more than twice during season of use
Slope	0 - 6%	6 - 15%	15% +
Surface soil texture	sl, fsl, vfsl, l and ls with textural B. Not subject to blowing.	cl, scl, sicl, sil, ls, and sand other than loose sand[1]	sc, sic, c, organic and sand subject to soil blowing
Stoniness	Classes 0, 1, and 2	Class 3	Classes 4 and 5
Rockiness	Classes 0, 1, and 2	Class 3	Class 4

[1]In arid and subhumid climates fine textured soils may be classified as having a moderate limitation.

COLUMN 15. SOIL SUITABILITY CLASSES AS SOURCE OF TOPSOIL

Item	Degree of soil suitability		
	Good	Fair	Poor
Moist consistency	Very friable, friable	Loose, firm	Very firm, extremely firm
Texture	fsl, vfsl, l, sil; sl; sc if 1:1 clay is dominant	cl, scl; sicl; sc if 2:1 clay is dominant; c and sic if 1:1 clay is dominant	s, ls; c and sic if 2:1 clay is dominant
Thickness of material (usually top part of profile)	More than 16 inches	8 to 16 inches	Less than 8 inches
Coarse fragments (percent)	Less than 3	3 to 15	More than 15
Soluble salts; conductivity of saturation extract (mmhos/cm)	Less than 4	4 to 8	More than 8
Surface stoniness	Class 0	Class 1	Classes 2, 3, 4, 5
Slope (percent)	Less than 8	8 to 15	More than 15
Drainage class	Drainage class not determining if better than poorly drained		Poorly drained, very poorly drained

Column 16. Soil Suitability Classes As Sources of Road Fill

Items Affecting Use[1]	Soil suitability classes		
	Good	Fair	Poor
Engineering soil class: Unified	GW, SP, SW, SP, GC,[2] SM,[2] SC[2]	ML, CL, with PI[3] less than 15	CL with PI[3] more than 15, CH, MH,[4] OL, OH, Pt
Engineering soil class: AASHO group index[5]	0 to 4	5 to 8	More than 8
Shrink-swell potential	Low	Moderate	High
Susceptibility to frost action[6]	Low	Moderate	High
Slope (percent)	0 to 15	15 to 25	More than 25
Stoniness class	0, 1, 2	3	4, 5
Rockiness class	0, 1	2	3, 4, 5
Soil drainage class	Excessively to moderately well	Somewhat poorly	Poorly, very poorly

[1]The first three items are predictions about the soil after it is placed in a fill; the last four items pertain to the soil in the natural condition before excavation for road fill.
[2]Downgrade to fair if content of fines is greater than about 30 percent.
[3]PI means plasticity index.
[4]Upgrade to fair if MH is largely kaolinitic, friable, and free of mica.
[5]Use only where laboratory data are available for the kind of soil being rated; otherwise use Unified classes.
[6]Use this item only where frost penetrates below the paved or hardened surface layer and moisture transportable by capillary movement is sufficient to form ice lenses at the freezing front. See section "Potential Frost Action" for guidance to classes.

APPENDIX II

GLOSSARY

AASHO—American Association of State Highway Officials.
Duripan—a horizon cemented by silica or aluminum silicate.
Fissility—a property of splitting easily along closely spaced parallel planes.
Fragipan—very compact soil horizon rich in silt, sand or both and usually relatively low in clay. They interfere with water and root penetration. When dry they appear to be indurated, but the apparent induration disappears when wet.
Friable—easily crumbled.
Group Index Values:

0-1	Good
2-4	Fair
5-9	Poor
10-20	Very Poor

Montmorillonite—a group of clay minerals whose formulas may be derived by substitution in the general formula $Al_2Si_4O_{10}(OH)_2$. These clays are characterized by swelling in water.
PVR—Potential Vertical Rise.

Rockiness[1]—refers to the relative proportion of bedrock exposures, either rock outcrops or patches of soil too thin over bedrock for use, in a soil area. "Rocky" is used, perhaps arbitrarily, for soils having fixed rock (bedrock), and "stony" for soils having loose detached fragments of rock. Classes of rockiness are as follows:

Class 0: No bedrock exposures or too few to interfere with tillage. Less than 2 percent bedrock exposed.
Class 1: Sufficient bedrock exposures to interfere with tillage but not to make intertilled crops impracticable. Depending upon how the pattern affects tillage, rock exposures are roughly 100 to 300 feet apart and cover about 2 to 10 percent of the surface.
Class 2: Sufficient bedrock exposures to make tillage of intertilled crops impracticable, but soil can be worked for hay crops or improved pasture if the other soil characteristics are favorable. Rock exposures are roughly 30 to 100 feet apart and cover about 10 to 25 percent of the surface, depending upon the pattern.
Class 3: Sufficient rock outcrop to make all use of machinery impracticable, except for light machinery where other soil characteristics are especially favorable for improved pasture. May have some use for wild pasture or forests, depending on the other soil characteristics. Rock exposures, or patches of soil too thin over rock for use, are roughly 10 to 30 feet apart and cover about 25 to 50 percent of the surface, depending upon the pattern.
Class 4: Sufficient rock outcrop (or of very thin soil over rock) to make all use of machinery impracticable. The land may have some value for poor pasture or for forestry. Rock outcrops are about 10 feet apart or less and cover some 50 to 90 percent of the area.
Class 5: Land on which over 90 percent of the surface is exposed bedrock (Rock outcrop).

[1]*From* U.S. Soil Conservation Service, 1971b, Guide for interpreting engineering uses of soils.

Soil Texture:

- c = clayey
- cl = clayey loam
- fsl = fine sandy loam
- l = loam
- ls = loamy sand
- s = sand
- scl = sandy clay loam
- sic = silty clay
- sicl = silty clay loam
- sil = silty loam
- sl = sandy loam

Stoniness[1] classes:

Class 0: No stones or too few to interfere with tillage. Stones cover less than 0.01 percent of the area.

Class 1: Sufficient stones to interfere with tillage but not to make intertilled crops impracticable. (If stones are 1 foot in diameter and about 30 to 100 feet apart, they occupy about 0.01 to 0.1 percent of the surface, and there are about 0.15 to 1.5 cubic yards per acre-foot.)

Class 2: Sufficient stones to make tillage of intertilled crops impracticable, but the soil can be worked for hay crops or improved pasture if other soil characteristics are favorable. (If stones are 1 foot in diameter and about 5 to 30 feet apart, they occupy about 0.1 to 3 percent of the surface, and there are about 1.5 to 50 cubic yards per acre-foot.)

Class 3: Sufficient stones to make all use of machinery impracticable, except for very light machinery or hand tools where other soil characteristics are especially favorable for improved pasture. Soils with this class of stoniness may have some use for wild pasture or forests, depending on other soil characteristics. (If stones are 1 foot in diameter and about 2.5 to 5 feet apart, they occupy about 3 to 15 percent of the surface, and there are about 50 to 240 cubic yards per acre-foot.)

Class 4: Sufficient stones to make all use of machinery impracticable; the land may have some value for poor pasture or for forestry. (If stones are 1 foot in diameter and are about 2.5 feet or less apart, they occupy 15 to 90 percent of the surface, and there are more than about 240 cubic yards per acre-foot.)

Class 5: Land essentially paved with stones that occupy more than 90 percent of the exposed surface (Rubble).

Unified Soil Classes:

Group Symbols	Typical Names
GW	Well graded gravels, gravel-sand mixtures, little or no fines.
GP	Poorly graded gravels, gravel-sand mixtures, little or no fines.
GM	Silty gravels, poorly graded gravel-sand-silt mixtures.
GC	Clayey gravels, poorly graded gravel-sand-clay mixtures.
SW	Well graded sands, gravelly sands, little or no fines.
SP	Poorly graded sands, gravelly sands, little or no fines.
SM	Silty sands, poorly graded sand-silt mixtures.
SC	Clayey sands, poorly graded sand-clay mixtures.
ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity.
CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.
OL	Organic silts and organic silt-clays of low plasticity.
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.
Pt	Peat and other highly organic soils.

REFERENCES

Adhern, V. P. (1964) Land use planning and the sand and gravel producer: National Sand and Gravel Assoc., 30 p.

Adkins, W. S. (1923) Geology and mineral resources of McLennan County: Univ. Texas Bur. Econ. Geol. Bull. 2340, 202 p.

——— and Arick, M. B. (1930) Geology of Bell County, Texas: Univ. Texas Bur. Econ. Geol. Bull. 3016, 92 p.

——— and Lozo, F. E., *eds.* (1951) Stratigraphy of the Woodbine and Eagle Ford, Waco area *in* the Woodbine and adjacent strata of the Waco area of central Texas: Southern Methodist Univ., Fondren Sci. Ser. no. 4, p. 105-165.

Allen, P. M. (1972) Urban Geology along Interstate 35 growth corridor from Hillsboro through Ellis County, Texas: Unpub. Master's thesis, Baylor Univ. (in press).

Ambrose, J. E. (1967) Building structures primer: John Wiley, New York, 123 p.

American Geological Institute (1957) Glossary of Geology and related sciences: A.G.I., Washington, D. C., 325 p.

American Society for Testing Materials (1950) Special Tech. Pub. 113.

Aschman, F. T. and Engelen, R. E. (1962) ABC's of community planning: The Community Planning Division of Sears, Roebuck and Co., Chicago, Illinois, 32 p.

Baidyuk, B. V. (1967) Mechanical properties of rocks at high temperatures and pressures: Consultants Bureau, New York, 75 p.

Beall, A. O., Jr. (1964) Stratigraphy of the Taylor Formation (Upper Cretaceous), east-central Texas: Baylor Geol. Studies Bull. 6, 35 p.

Berry, F. A.; Bollay, E.; and Beers, N. R. (1945) Handbook of meteorology, McGraw-Hill, New York, 1068 p.

Boyd, C. and Janek, R. (1958) Geology of the West quadrangle, Texas: Unpub. student paper 148, Baylor Univ.

Bronaugh, R. L. (1950) Geology of Brazos River terraces in McLennan County, Texas: Unpub. Master's thesis, Univ. of Texas, Austin.

Brown, J. B. (1963) The role of geology in a unified conservation program, Flat Top Ranch, Bosque County, Texas: Baylor Geol. Studies Bull. 5, 28 p.

Brown, T. E. (1971) Stratigraphy of the Washita Group in central Texas: Baylor Geol. Studies Bull. 21, 43 p.

Brown, W.; Montgomery, G.; and Reynolds, M. (1956) Geology of the Austin Chalk along North Cow Bayou: Unpub. student paper No. 57B, Baylor Univ.

Burkett, J. M. (1965) Geology of Waco *in* Urban Geology of Greater Waco, Part I, Geology: Baylor Geol. Studies Bull. 8, p. 9-46.

Capper, P. L.; Cassie, W. F.; and Geddes, J. D. (1966) Problems in engineering soils: E. & F. N. Spon Ltd., London, 183 p.

Chamness, R. S. (1963) Stratigraphy of the Eagle Ford Group in McLennan County, Texas: Unpub. Master's thesis, Baylor Univ.

Christiansen, E. A., *ed.* (1970) Physical environment of Saskatoon: Saskatechewan Research Council, The National Research Council of Canada, Ottawa, Canada, 68 p.

Clarke, G. R. (1957) The study of the soil in the field: Oxford Univ. Press, New York, 202 p.

Conrad, V. C. and Pollack, L. W. (1950) Methods in climatology: Harvard Univ., Cambridge, Mass., 459 p.

Crichfield, H. J. (1966) General climatology: Prentice Hall, Englewood Cliffs, New Jersey, 420 p.

Cuyler, R. H. (1931) Vegetation as an indicator of geologic formations: Am. Assoc. Petrol. Geol. Bull. v. 15, n. 1, p. 67-78.

Davis, S. N. and DeWiest, R. J. M. (1966) Hydrogeology: John Wiley, New York, 463 p.

Dixon, J. W., Jr. (1967) Georgetown Limestone, central Texas: Including discussion of *Kingena Wacoensis* in Comanchean (Lower Cretaceous) stratigraphy and paleontology of Texas: Soc. Econ. Paleont. Mineralog. (Permian Basin Sec.) Pub. 67-8, p. 241-255.

Durham, C. O. (1957) Austin Group in central Texas: Unpub. Ph.D. dissertation, Columbia Univ., New York, N.Y.

Eckel, E. B., *ed.* (1958) Landslides and engineering practice: NAS-NRC Pub. 544, Washington, D. C., 232 p.

Elder, W. R. (1965) Soils and urban development of Waco *in* Urban Geology of Greater Waco, Part II, Soils: Baylor Geol. Studies Bull. 9, 66 p.

Environmental Data Service (1968) Climatic atlas of the United States: U.S. Dept. of Commerce, Washington, D. C., 80 p.

Fandrich, J. W. (1968) Studies of bentonites and related rocks in the Eagle Ford Group, central Texas: Unpub. Master's thesis, Baylor Univ.

Felt, E. L. (1950) Soil series names as a basis for interpretive soil classification, for engineering purposes: Symposium on the identification and classification of soils: Am. Soc. for Testing Materials, Spec. Tech. Pub. 113, p. 62-79.

Flawn, P. T. (1965) Geology and urban development: Texas Town & City, v. 52, n. 7, p. 9-10.

———— (1966) Geology and the new conservation movement: Science, v. 151, n. 3709, p. 409-412.

———— (1970a) Environmental geology: Harper & Row, New York, 307 p.

———— (1970b) Mineral resources and conservation in Texas: Univ. Texas Bur. Econ. Geol. Circ. 70-1, 20 p.

————; Turk, L. J.; and Leach, C. H. (1970) Geological considerations in disposal of solid municipal wastes in Texas: Univ. Texas Bur. Econ. Geol. Circ. 70-2, 22 p.

Foley, F. C. (1968) A pilot study of land-use planning and environmental geology: Kansas Geol. Survey, Lawrence, Kansas, 63 p.

Font, R. L. (1969) Engineering geology of the greater Waco area: Unpub. Master's thesis, Baylor Univ.

———— and Williamson, E. F. (1970) Geologic factors affecting construction in Waco *in* Urban Geology of Greater Waco, Part IV, Engineering: Baylor Geol. Studies Bull. 12, 34 p.

Frost, J. G. (1963) The Edwards Limestone in central Texas: Unpub. Master's thesis, Baylor Univ.

Gillott, J. E. (1968) Clay in engineering geology: Elsevier, New York, 296 p.

Hackett, J. E. (1968) Geologic factors in community development at Naperville, Illinois: Illinois Geol. Survey Env. Geol. Notes 22, June 1968, 16 p.

Handin, J.; Hager, R. V., Jr.; Friedman, M. W.; and Feather, J. N. (1963) Experimental deformation of sedimentary rocks under confining pressure: pore pressure tests: Am. Assoc. Petrol. Geol. Bull. v. 47, n. 5, p. 717-755.

Happ, S. C. (1955) Engineering geology reference list: Geol. Soc. Am. Bull., v. 66, p. 993-1030.

Harr, M. E. (1966) Foundations of theoretical soil mechanics: McGraw-Hill, New York, 391 p.

Haurwitz, B. and Austin, J. M. (1944) Climatology: McGraw-Hill, New York, 410 p.

Hayward, O. T. (1957) The structural significance of the Bosque escarpment, McLennan County, Texas: Unpub. Ph.D. dissertation, Univ. of Wisconsin, Madison, Wis.

———— and Brown, L. F., Jr. (1967) Comanchean rocks of central Texas in Comanchean (Lower Cretaceous) stratigraphy and paleontology of Texas: Soc. Econ. Paleont. Mineralog. (Permian Basin Sec.) Pub. 67-8, p. 31-48.

Hem, J. D. (1970) Chemical characteristics of natural water: U. S. Geol. Survey Water Supply Paper 1473, 363 p.

Henningsen, E. R. (1962) Water diagensis in Lower Cretaceous Trinity aquifers of central Texas: Baylor Geol. Studies Bull. 3, 38 p.

Hill, R. T. (1901) Geography and geology of the Black and Grand Prairies, Texas: U. S. Geol. Survey 21st Ann. Rept., 666 p.

Hilpman, P. L. and Stewart, G. F. (1968) Environmental geology and urban land-use planning: Univ. of Kansas Pub., Lawrence, Kansas.

Holloway, H. D. (1961) The Lower Cretaceous Trinity aquifers, McLennan County, Texas: Baylor Geol. Studies Bull. 1, 32 p.

Hough, B. K. (1957) Basic soils engineering: Ronald Press, New York, 513 p.

Howell, G. D. and Thomas, R. (1969) The urban geology of Hillsboro, Texas: Unpub. student paper 631, Baylor Univ.

Hughes, L. S. (1967) Selection of refuse disposal sites in northern Illinois: Env. Geol. Notes Series 17, Illinois State Geol. Survey, Urbana, Illinois, 15 p.

Jenny, H. (1941) Factors of soil formation: McGraw-Hill, New York, 281 p.

Johnson, C. F. (1964) Stratigraphy of the Del Rio Clay, central Texas; Shale environments of the mid-Cretaceous section, central Texas—field guide: Baylor Geol. Soc. Pub., p. 4-12.

Johnson, E. E. (1966) Ground water and wells: Johnson Division: St. Paul, Minnesota, 440 p.

Johnson, J. H. (1968) Urban geography: Pergamon, New York 188 p.

Judd, W. R. (1964) State of stress within the earth's crust: Am. Elsevier, New York, 732 p.

Krynine, D. P. (1947) Soil mechanics: McGraw-Hill, New York, 511 p.

Landsberg, H. (1958) Physical climatology: Gray Printing, Dubois, Pennsylvania, 446 p.

Legget, R. F. (1962) Geology and engineering: McGraw-Hill, New York, 884 p.

Leonards, G. A. (1962) Foundation engineering: McGraw-Hill, New York, 1136 p.

Leopold, L. B. (1968) Hydrology for urban land planning—a guidebook on the hydrologic effects of urban land use: U. S. Geol. Survey Circ. 554, 18 p.

Logan, K. H. (1948) Corrosion by soils *in* Corrosion Handbook, Uhlig, H. H., *ed.*: John Wiley, New York, 1188 p.

Lozo, F. E., *ed.* (1951) The Woodbine and adjacent strata of the Waco area of central Texas, a symposium: Southern Methodist Univ., Dallas, Texas, 165 p.

———— (1959) Stratigraphic relations of the Edwards Limestone and associated formations in north-central Texas: Univ. Texas Bur. Econ. Geol. Pub. 5905, p. 1-19.

Lung, R. C. and Proctor, R. L. *eds.* (1969) Engineering geology in Southern California: Assoc. Eng. Geol. Spec. Pub., Arcadia, California, 389 p.

McDougal, M. S. (1947) The case for regional planning: Yale Univ. Press, New Haven, Connecticut, 94 p.

McGill, J. T. (1964) Growing importance of urban geology: U. S. Geol. Survey Circ. 487, 4 p.

McHarg, I. L. (1969) Design with nature: The Natural History Press, New York, 197 p.

McLean, W. G. and Nelson, E. W. (1962) Engineering mechanics: Schaum, New York, 300 p.

Moore, T. H. (1970) Water geochemistry, Hog Creek basin, central Texas: Baylor Geol. Studies Bull. 18, 43 p.

National Bureau of Standards (19__) Underground corrosion: U. S. Dept of Commerce, Circ. 579, Washington, D. C. *Cited in* U. S. Soil Conservation Service (1971b).

Orton, R. B. (1964) The climate of Texas and the adjacent gulf waters: U. S. Govt. Printing Office, Washington, D. C., p. 194.

Pace, L. (1921) Geology of McLennan County, Texas: The Baylor Bulletin, Baylor Univ. v. 24, n. 1, 25 p.

Paige, S. (1950) Application of geology to engineering practice: Geol. Soc. Am. Berkey Volume, 327 p.

Proctor, C. V. (1969) The north Bosque watershed, inventory of a drainage basin: Baylor Geol. Studies Bull. 16, 40 p.

Rawson, J. W. (1967) The study and interpretation of chemical quality of surface waters in the Brazos River basin, Texas: Texas Water Development Board Report 55, Austin, Texas, 118 p.

Ray, J. R. (1964) Stratigraphy of the Buda Limestone in central Texas: Unpub. student paper 309, Baylor Univ.

Savini, J. and Kammerer, J. C. (1961) Urban growth and the water regimen: U. S. Geol. Survey Water Supply Paper 1591 A, 42 p.

Schellie, K. L. and Rogier, D. A. (1963) Site utilization and rehabilitation practices for sand and gravel operations: National Sand and Gravel Assoc., 80 p.

Schroeder, E. E. (1971) Flood stages and discharges for small streams in Texas: U. S. Geol. Survey, Water Resources Division, Austin, Texas, 319 p.

Sellards, E. H.; Adkins, W. S.; and Plummer, F. B. (1932) The geology of Texas, Vol. 1, Stratigraphy: Univ. Texas Bur. Econ. Geol. Bull. 3232, 1007 p.

Seewald, K. O. (1959) Stratigraphy of the Austin Chalk: Unpub. Master's thesis, Baylor Univ.

Seullin, C. M. (1966) History, development and administration of excavation and grading codes *in* Engineering geology in southern California: Assoc. Eng. Geol. Spec. Pub., p. 227-236.

Silver, B. A. (1963) The Bluebonnet Member, Lake Waco Formation (Upper Cretaceous), central Texas—A lagoonal deposit: Baylor Geol. Studies Bull. 4, 46 p.

Slossan, J. E. (1969) Engineering geology—its importance in land development: The Urban Land Institute Tech. Bull. 63, 20 p.

Soil Survey Staff (1951) Soil Survey manual: U. S. Dept. of Agriculture, Agriculture Handbook 18, 503 p.

Spencer, J. M. (1966) Surface waters of Waco *in* Urban Geology of Greater Waco, Part III, Water: Baylor Geol. Studies Bull. 10, 42 p.

Stagg, K. G. and Zienkiewicz, O. C., *eds.* (1969) Rock mechanics in engineering practice: John Wiley, New York, 442 p.

Stephenson, L. W. (1937) Stratigraphic relations of the Austin, Taylor and equivalent formations in Texas: U. S. Geol. Survey Prof. Paper 186-G, p. 1-17.

Stricklin, F. L., Jr. (1961) Degradational stream deposits of the Brazos River, central Texas: Geol. Soc. Am. Bull., v. 72, p. 19-36.

Swenson, H. A. and Baldwin, H. L. (1965) A primer on water quality: U. S. Geol. Survey, Washington, D. C., 27 p.

Taylor, D. R. (1962) The geology of the Gholson and Aquilla quadrangles of McLennan and Hill Counties, Texas: Unpub. Master's thesis, Baylor Univ.

Taylor, D. W. (1960) Fundamentals of soil mechanics: John Wiley, New York, 700 p.

Terzaghi, K. (1960) From theory to practice in soil mechanics: John Wiley, New York, 425 p.

———— and Peck, R. B. (1968) Soil mechanics in engineering practice: John Wiley, New York, 729 p.

Texas Water Development Board (1968) The Texas Water Plan, 215 p.

———— (no date) Water resources of central Texas, unpub. report, 300 p.

Tipps, C. W. (1964) Corrosion causes and control, Soil Handbook for soil survey, metropolitan area, San Antonio, Texas: U. S. Soil Conservation Service, U. S. Dept. of Agriculture, 193 p.

Trask, P. D. (1950) Applied sedimentation: John Wiley, New York, 707 p.

Trefethen, J. M. (1959) Geology for engineers: D. Van Nostrand, Princeton, New Jersey, 632 p.

Tyner, C. G. (1964) Geology of the Abbott and Peoria quadrangles, Hill County, Texas: Unpub. Master's thesis, Baylor Univ.

U. S. Bureau of Soils (1921) Soils map of Bell County, Texas: U. S. Dept. of Agriculture.

U. S. Geol. Survey (1964) Surface water records of Texas, 1964, 479 p.

U. S. Soil Conservation Service (1951) Soil Survey Manual: U. S. Dept. of Agriculture.

———— (1958) Soil Survey, McLennan County, Texas: U. S. Dept of Agriculture, Series 1942, n. 17, 124 p.

———— (1964) Soil Survey, Ellis County, Texas: U. S. Dept. of Agriculture, Series 1961, no. 7, 76 p.

———— (1971a) Established series: Unpub. soil descriptions: U. S. Dept. of Agriculture.

———— (1971b) Guide for interpreting engineering uses of soils: U. S. Dept. of Agriculture (unedited interim report). Published Nov. 1971.

U. S. Study Commission (1961) The climate of central Texas and coastal watersheds: U. S. Dept. of Commerce, Weather Bureau, National Weather Records Center, Asheville, North Carolina, p. 14.

Vann, B. (1969) Geology of the Moody quadrangle: Unpub. student paper 729, Baylor Univ.

Wagner, A. A. (1957) The use of the unified soil classification system by the Bureau of Reclamation, Proc. 4th. Inter. Conf. Soil Mech. Found. Eng. (London), Vol. I, p. 125.

Wagner, R. H. (1971) Environment and man: W. W. Norton, New York, 491 p.

Williamson, E. F. (1967) Urban geology of Temple, Bell County, Texas: Unpub. Master's thesis, Baylor Univ.

Yong, R. N. and Warkentin, B. P. (1966) Introduction to soil behavior: McMillan, New York, 451 p.

INDEX

BAYLOR GEOLOGICAL PUBLICATIONS*

Baylor Geological Studies

1. Holloway, Harold D. (1961) The Lower Cretaceous Trinity aquifers, McLennan County, Texas: Baylor Geological Studies Bull. No. 1 (Fall). Out of print.
2. Atlee, William A. (1962) The Lower Cretaceous Paluxy Sand in central Texas: Baylor Geological Studies Bull. No. 2 (Spring). $1.00 per copy. Out of print.
3. Henningsen, E. Robert (1962) Water diagenesis in Lower Cretaceous Trinity aquifers of central Texas: Baylor Geological Studies Bull. No. 3 (Fall). $1.00 per copy. Out of print.
4. Silver, Burr A. (1963) The Bluebonnet Member, Lake Waco Formation (Upper Cretaceous), central Texas—A lagoonal deposit: Baylor Geological Studies Bull. No. 4 (Spring). $1.00 per copy.
5. Brown, Johnnie B. (1963) The role of geology in a unified conservation program, Flat Top Ranch, Bosque County, Texas: Baylor Geological Studies Bull. No. 5 (Fall). $1.00 per copy. Out of print.
6. Beall, Arthur O., Jr. (1964) Stratigraphy of the Taylor Formation (Upper Cretaceous), east-central Texas: Baylor Geological Studies Bull. No. 6 (Spring). $1.00 per copy.
7. Spencer, Jean M. (1964) Geologic factors controlling mutation and evolution—A review: Baylor Geological Studies Bull. No. 7 (Fall). $1.00 per copy. Out of print.

Urban geology of Greater Waco. A series on urban geology in cooperation with Cooper Foundation of Waco.

8. Part I: Geology (1965) Geology and urban development by Peter T. Flawn; Geology of Waco by J. M. Burket: Baylor Geological Studies Bull. No. 8 (Spring). $1.00 per copy.
9. Part II: Soils (1965) Soils and urban development of Waco by W. R. Elder: Baylor Geological Studies Bull. No. 9 (Fall). $1.00 per copy.
10. Part III: Water (1966) Surface waters of Waco by Jean M. Spencer: Baylor Geological Studies Bull. No. 10 (Spring). $1.00 per copy.
11. Part III: Water (1966) Subsurface waters of Waco by H. D. Holloway: Baylor Geological Studies Bull. No. 11 (Fall). $1.00 per copy.
12. Part IV: Engineering (1967) Geologic factors affecting construction in Waco by R. G. Font and E. F. Williamson: Baylor Geological Studies Bull. No. 12 (Spring). $1.00 per copy.
13. Part V: Socio-Economic Geology (1967) Economic geology of Waco and vicinity by W. T. Huang; Geology and community socio-economics—A symposium coordinated by R. L. Bronaugh: Baylor Geological Studies Bull. No. 13 (Fall). $1.00 per copy.
14. Part VI: Conclusions (1968) Urban geology of greater Waco—Summary and recommendations by Editorial Staff: Baylor Geological Studies Bull. No. 14 (Spring). $1.00 per copy.

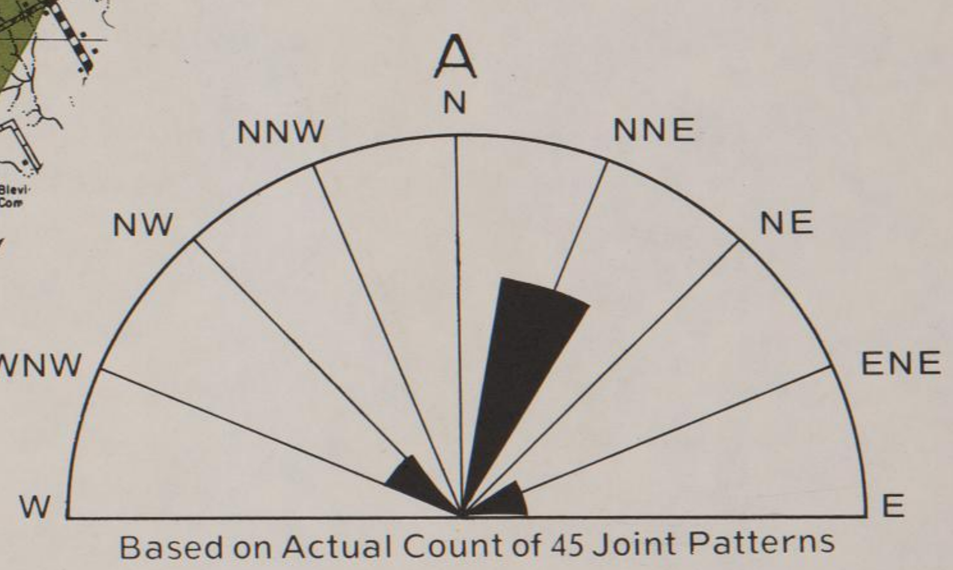
---

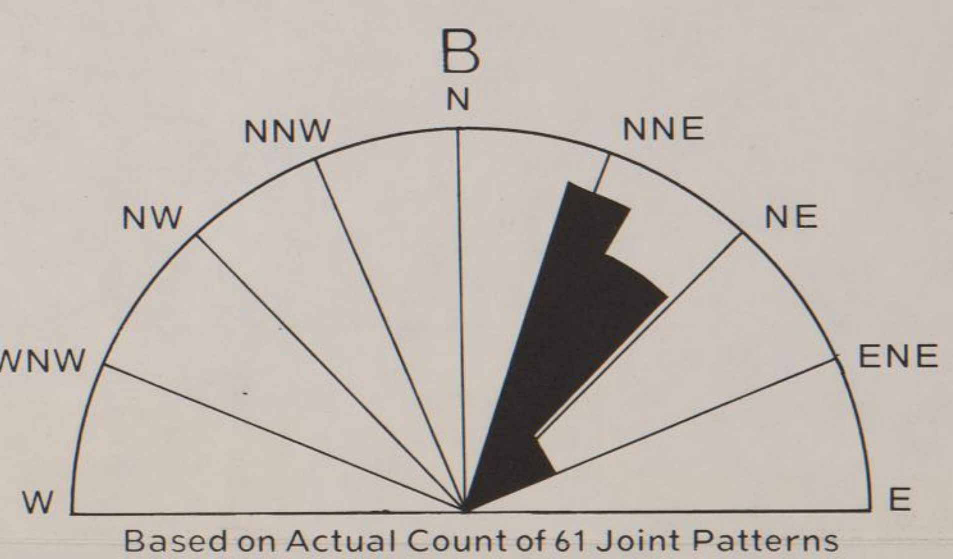
15. Boone, Peter A. (1968) Stratigraphy of the basal Trinity (Lower Cretaceous) sands, central Texas: Baylor Geological Studies Bull. No. 15 (Fall). $1.00 per copy.
16. Proctor, Cleo V. (1969) The North Bosque watershed, Inventory of a drainage basin: Baylor Geological Studies Bull. No. 16 (Spring). $1.00 per copy.
17. LeWand, Raymond L., Jr. (1969) The geomorphic evolution of the Leon River system: Baylor Geological Studies Bull. No. 17 (Fall). $1.00 per copy.
18. Moore, Thomas H. (1970) Water geochemistry, Hog Creek basin, central Texas: Baylor Geological Studies Bull. No. 18 (Spring). $1.00 per copy.
19. Mosteller, Moice A. (1970) Subsurface stratigraphy of the Comanchean Series in east central Texas: Baylor Geological Studies Bull. No. 19 (Fall). $1.00 per copy.
20. Byrd, Cilfford Leon (1971) Origin and history of the Uvalde Gravel of central Texas: Baylor Geological Studies Bull. No. 20 (Spring). $1.00 per copy.
21. Brown, Thomas E. (1971) Stratigraphy of the Washita Group in central Texas: Baylor Geological Studies Bull. No. 21 (Fall). $1.00 per copy.
22. Thomas, Ronny G. (1972) The geomorphic evolution of the Pecos River system: Baylor Geological Studies Bull. No. 22 (Spring). $1.00 per copy.
23. Roberson, Dana Shumard (1972) The paleoecology, distribution and significance of circular bioherms in the Edwards Limestone of central Texas: Baylor Geological Studies Bull. No. 23 (Fall). $1.00 per copy.
24. Epps, Lawrence Ward (1973) The geologic history of the Brazos River: Baylor Geological Studies Bull. No. 24 (Spring). $1.00 per copy.
25. Bain, James S. (1973) The nature of the Cretaceous-pre Cretaceous contact in north-central Texas: Baylor Geological Studies Bull. No. 25 (Fall). $1.00 per copy.
26. Davis, Keith W. (1974) Stratigraphy and depositional environments of the Glen Rose formation, north central Texas: Baylor Geological Studies Bull. No. 26 (Spring). $1.00 per copy.
27. Baldwin, Ellwood E. (1974) Urban geology of the Interstate Highway 35 growth corridor between Belton and Hillsboro, Texas: Baylor Geological Studies Bull. 27 (Fall). $1.00 per copy.

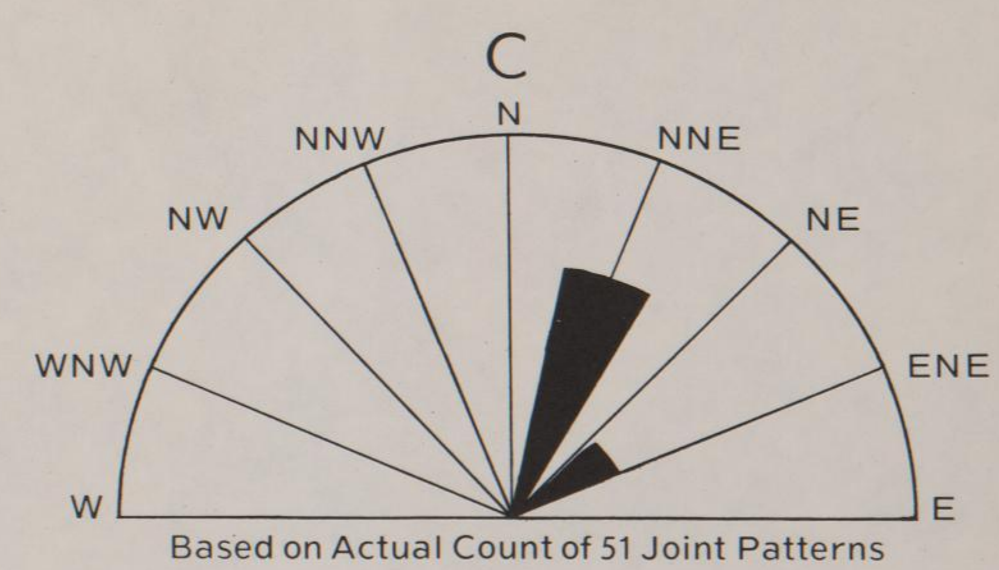
Baylor Geological Society

101. Type electric log of McLennan County. 1″-100′; 1″-50′-$2.00.
102. Reptile charts—Comparison of flying and swimming reptiles. $0.10 each. Comparison of the dinosaurs. $0.10 each.
103-114. Out of print. For titles see earlier Baylor Geological Studies Bulletins.
115. Why teach geology? A discussion of the importance and cost of teaching geology in high schools, junior colleges and smaller 4-year institutions. Free upon request. 27 pp. (1961).
116. Popular geology of central Texas: The hill country—McLennan, Coryell and Bosque counties, 1963. $1.00 per copy. Revised. Out of print.
117. Shale environments of the mid-Cretaceous section, central Texas—A field guide. Leaders—Beall, A. O.; Johnson, C.F.; and Silver, B. A.; 1964. $2.00 per copy.
118. Geology and the city of Waco—A guide to urban problems, 1964. $2.00 per copy. Out of print.
119. The Bosque watershed. Geology of the Bosque River basin, 1966. Out of print.
120. Valley of the giants. Lower Comanchean section of the Paluxy River basin, 1967. Out of print.
121. The Hog Creek watershed. Environmental study of a watershed, 1968. $1.00 per copy. Out of print.
122. The Waco region. Geologic section of the area around Lake Waco, McLennan County, Texas, 1968. $1.00 per copy. Out of print.
123. Mound Valley. A physiographic study of central Texas, 1969. Out of print.
124. The Bosque watershed (revised). Geology of the Bosque River basin, 1969. Out of print.
125. Lampasas Cut Plain. Geomorphic evolution of the Lampasas Cut Plain, southwest of Gatesville, 1970. $1.00 per copy. Out of print.
126. Middle Bosque Basin. Geology of the Middle Bosque drainage basin, 1970. $1.00 per copy. Out of print.
127. Geology of the Trinity Group in the type area. A professional level guide, 1970. $4.00 per copy.
128. The Walnut Prairie, 1971. $1.00 per copy.
129. Urban Geology, 1972. $6.00 per copy.
130. Geology in the city. Urban geology of Waco, 1973. $1.50 per copy. Out of print.
131. Exploration of a delta—65 million years ago. Study of a Tertiary delta, 1973. $1.50 per copy. Out of print.
132. Valley of the giants (revised). Lower Comanchean section of the Paluxy River basin, 1973. $1.50 per copy.
133. Whitney Reservoir. Geology of the Whitney Reservoir Area, 1974. $1.50 per copy.
134. The Black and Grand Prairies. A physiographic study of two central Texas Prairies, 1974. $1.50 per copy.
135. The Hill Country (revised). Geology of McLennan, Coryell, and Bosque Counties, 1972. $1.50 per copy.
136. The Bosque Watershed (2nd revision). Geology of the Bosque River basin, 1974. $1.50 per copy.

*Publications available from Baylor Geological Studies or Baylor Geological Society, Baylor University, Waco, Texas 76703.
Texas residents add five cents per dollar for state tax.





LEGEND

Base Map, Texas State Highway Department, Revised 1973.

ALLUVIUM
Calcareous silts and clays with high organic content.

TERRACES
Clayey limestone gravels from bed load deposits.

TAYLOR MARL
Fine-grained, massive, uniformly bedded marl.

AUSTIN CHALK
Alternating beds of chalk and marl with bentonite seams in marl at base.

SOUTH BOSQUE FORMATION
Blocky shale which grades from calcareous at base to non-calcareous at top. Limestone flags occur in lower part.

LAKE WACO FORMATION
Calcareous bentonitic shales interbedded with thin dense limestone beds.

PEPPER SHALE
Non-calcareous, black, dense pyritic shale.

DEL RIO CLAY
Blocky clay with rare thin lenticular beds of highly calcareous siltstone and limestone.

GEORGETOWN LIMESTONE
Nodular limestone interbedded with thin marl beds.

EDWARDS LIMESTONE
Massive, dense, high purity limestone.

Baylor Geological Studies
Bulletin No. 27

PLATE I

GEOLOGY

I-35 CORRIDOR, CENTRAL TEXAS

Ellwood E. Baldwin

1974

Plate No. II

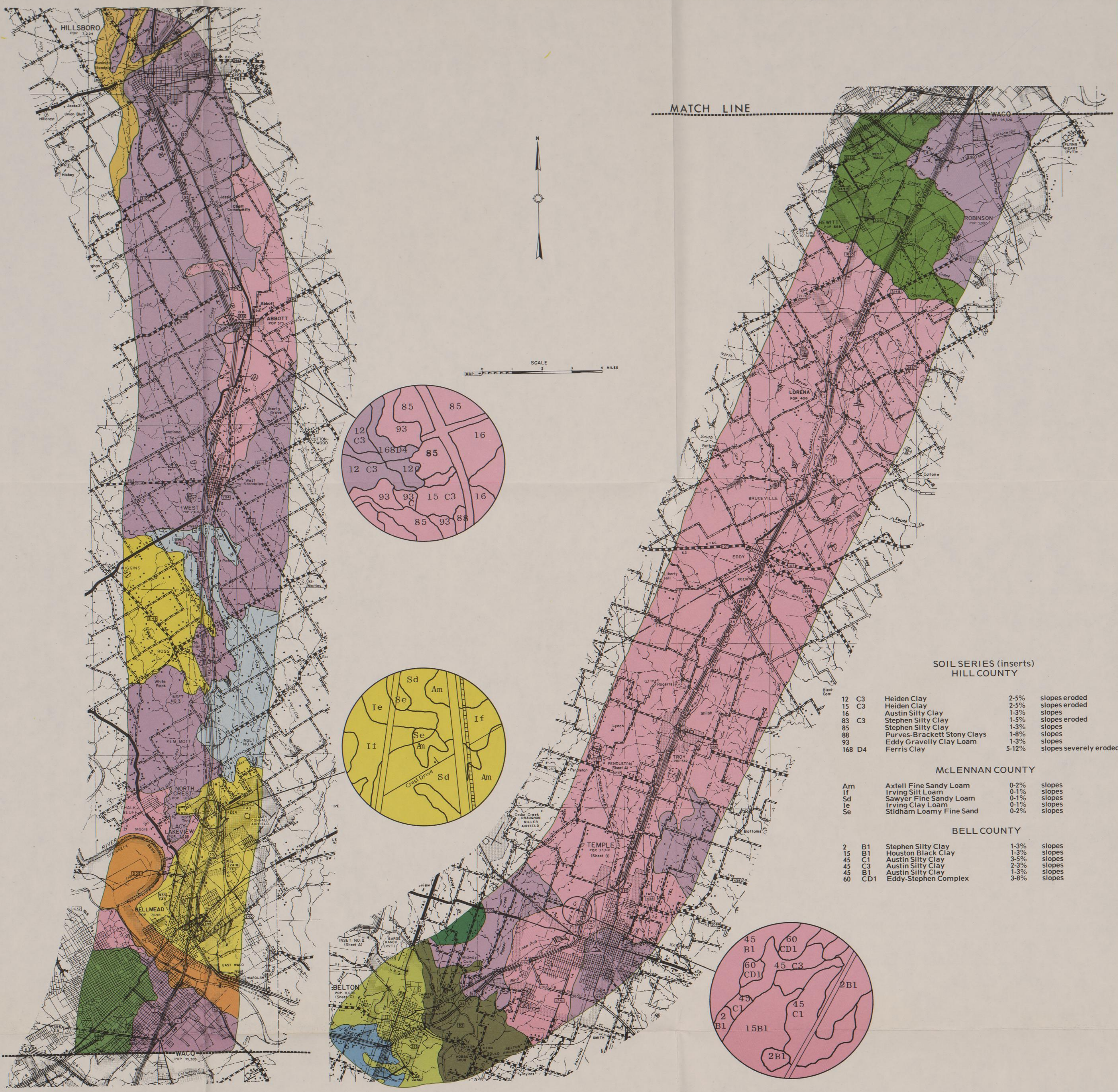
GEOLOGIC FACTORS AFFECTING URBAN DEVELOPMENT

Baylor Geological Studies Bulletin No. 27 Ellwood E. Baldwin

SYSTEM	SERIES OR GROUP	FORMATION OR MEMBER	1 DESCRIPTION	2 DISTRIBUTION	3 VEGETATIVE INDICATOR	4 MINERALOGICAL COMPOSITION
QUATENARY	RECENT	Alluvial silts and clays	Calcareous silts and clays, loosely compacted. Organic content generally high. Color in unweathered material is brown to black. Weathered material ranges from buff to tan to red. Good agricultural land. Foundations fail readily if not designed properly.	Alluvial silts and clays are found in the bottom lands of the Brazos, Bosque, and Leon rivers. Alluvium appears in the drainage systems of the following creeks: Aquilla, Williams, Tehuacana, Tradinghouse, Waco, Cottonwood, North and South Cow Bayou, Bullhide, Pepper, Bird, Little Elm, and Morgan.	Native growth of deciduous trees, such as cottonwood, elm, pecan, and oak.	clays
QUATENARY	PLEISTOCENE	Leon River Terraces	Leon River Terraces were derived from bed load river deposits during the early history of the river. The limestone gravels are too clayey to be used as concrete aggregate.	Leon River Terraces occur east of the river and are indicated on the geologic map by a tan color. The highest terrace occuring in the area is at Temple at an elevation of 100 to 115 feet above the present river bed.	deciduous trees	Quartz, quartzite, chert, jasper, limestone and shell gravels and reddish brown clay.
QUATENARY	PLEISTOCENE	Brazos River Terraces	Brazos River Terraces are divided into two groups: a lower terrace group varying 20 to 50 feet above the river and a higher group varying 70 to 200 feet above mean low water level. Sand and gravel from bedload deposits of the early history of the river.	East of the river and throughout southeast Waco; West of the river in south and north Waco.	Extensive growth of deciduous trees	Quartz, quartzite, jasper, chert, and limestone gravels
QUATENARY	PLEISTOCENE	Bosque River Terraces	Bosque terraces are composed chiefly of clay and limestone gravels deposited by the Bosque River which have cut into Lower Cretaceous shales and limestones west and north of Waco.	Along the Bosque Rivers and on the north and west sides of Lake Waco.	Extensive growth of deciduous trees	Limestone and shell gravels with varying amounts of reddish-brown clay.
CRETACEOUS	GULF SERIES	Taylor Marl	The Lower Taylor Marl is a fine-grained, massive, uniformly bedded marl. It is usually grey but weathers buff and grades rapidly to the dark rich soils of the Texas Blacklands. It is fissile where the $CaCO_3$ cement is leached.	The Taylor Marl unconformably overlies Austin Chalk. It has been eroded from most of the area west of the alluvial valley of the Brazos River and is now exposed chiefly in the region east of the Brazos River in the Waco area and east of the Temple area. It is in fault contact with the Austin Chalk over the southern half (Waco to Belton) of the area. Five miles north of Waco it is in fault contact with the South Bosque Shale of the Eagle Ford Group.	Mesquite trees and cactus	Clay minerals chiefly illite and montmorillonite compose approximately 69 to 70 percent of the lower Taylor Marl. $CaCO_3$ cement and minor amounts of silt, calcite, pyrite, hematite, glauconite, and calcium phosphate compose the remaining 30 to 40 percent.
CRETACEOUS	GULF SERIES	Austin	The Austin Chalk is composed of alternating beds of chalk and marl. The color of this material is blue-grey. Bentonites are sometimes found in the marl layers above the base of the formation. It is faulted out about 4 miles north of Waco and reappears at West.	The Austin forms a north-south trending belt 3 to 4 miles wide through the study area paralleling I-35. It is faulted out about 4 miles north of Waco reappears at West.	Large Live Oaks	The chalk beds contain 85 percent $CaCO_3$ including microcrystalline calcite, as well as aluminum and magnesium mostly in the form of clay minerals.
CRETACEOUS	GULF SERIES / EAGLE FORD GROUP	South Bosque	Dark grey to black, blocky shale. Weathers blue-grey to tan. It contains a few thin buff colored limestone flags which occur in the lower part. The upper 30 to 50 feet contain bentonitic shale beds which tend to slump when wet. Low carbonate content (2 to 8 percent) contributes to this plastic behavior. The transition from calcareous (lower part) to non-calcareous (upper part) occurs within a few feet vertically.	The South Bosque Shale forms a narrow outcrop along the west side of the Austin Chalk paralleling I-35. It is widest in the northern part of the study area between Waco and Hillsboro.	Mesquite	Pyrite, glauconite, $CaCO_3$ and phosphate nodules.
CRETACEOUS	GULF SERIES / EAGLE FORD GROUP	Lake Waco	The Lake Waco Formation is composed of calcareous bentonitic shales interbedded with thin dense limestone beds. The formation which is dark gray-blue, varies from buff to tan on weathered surfaces. The Lake Waco Formation is more calcareous, fissile, and resistant to erosion than the overlying South Bosque Shale. The formation is divided into three members, in descending order they are: Bouldin, Cloice, and Bluebonnet.	The Lake Waco Formation appears in small patches along the western edge of the study area. Regionally it crops out along the Bosque Escarpment from Moody to Lake Waco. It thickens eastward into the East Texas Basin. Two miles northwest of Troy the Lake Waco Formation is in fault contact with the Austin Chalk. In the northern part of the study area the Lake Waco Formation is exposed in Alligator, Cobb, and Hackberry Creeks.	Mesquite	The Bouldin and Bluebonnet members contain 50 percent $CaCO_3$. The Cloice member is less calcareous. Other minerals are montmorillonite, bentonite, quartz, and Kaolinite.
CRETACEOUS	GULF SERIES	Pepper Shale	The Pepper Formation is noncalcareous, black, dense, pyritic shale. Weathered Pepper Shale has a lighter color than the overlying Lake Waco Formation. Selenite crystals and jarasite are weathering products found in joints and on the surface.	The Pepper Shale lies directly below the Blue Bonnett member of the Lake Waco Formation which is composed of thin-bedded limestone beds. The Pepper Shale outcrops in the banks of Pepper Creek north of I-35 and Bird Creek south of I-35. Both of these outcrops are in the Temple area. It is a subsurface formation in most of the study area.	None. Note flora above and below formation. Due to acid nature very little vegetation is noted.	20% montmorillonite, 20-25% illite, 20-25% kaolinite, 10-15% quartz, and 20-25% amorphous material. Some siderite and pyrite.
CRETACEOUS	GULF SERIES	Woodbine	Strata of porous, crumbly to friable, locally indurated, furruginous sandstones. Interfingers with the Pepper Shale and disappears southward into the Pepper Shale.	The Woodbine does not outcrop in the study area. It outcrops west of the area trending north along Aquilla Creek in the Gholson area. It interfingers with the Pepper Shale north of Waco.	not applicable	not applicable
CRETACEOUS	COMMANCHE SERIES / WASHITA GROUP	Buda	The Buda Limestone is a hard massive, buff to grey, dense limestone containing numerous fossil pelecypods.	Buda Limestone does not crop out within the study area. A small band trending north-south is found in the Temple-Belton area roughly parallel with Hwy. 317.	Elm trees	85% $CaCO_3$, pebbles and grains of Fe_2O_3, FeS_2 (pyrite, and $FeCO_3$ (siderite).
CRETACEOUS	COMMANCHE SERIES / WASHITA GROUP	Del Rio	The Del Rio Formation is a blue-grey, blocky clay with rare thin lenticular beds of highly calcareous siltstone and limestone composed predominantly of pelecypods. Hcl test will identify this formation from the overlying non calcareous Pepper Shale.	The Del Rio crops out north of Belton and disappears under the high terraces of the Leon River.	Mesquite	10% montmorillonite, 20% illite, 20% Kaolinite, 10% quartz, 30% calcite, and 10% amorphous material. Pyrite is present. Calcite is considerably less in the middle of the formation.
CRETACEOUS	COMMANCHE SERIES / WASHITA GROUP	Georgetown	Nodular limestone interbedded with thin marl beds. The Georgetown Formation is divided into seven members. From older to younger they are: Kiamichi Shale, Duck Creek Limestone, Fort Worth Limestone, Denton Shale, Weno Limestone, Pawpaw Shale, and Main Street Limestone.	The Main Street Limestone, Pawpaw Shale, Weno Limestone, Denton Limestone, Fort Worth Limestone, and Duck Creek Limestone crop out from Midway Drive in the south western section of Temple to the end of the study area south of Belton.	Mountain Cedar and Skunk Bush	High $CaCO_3$ content in limestone members.
CRETACEOUS	COMMANCHE SERIES / FREDERICKSBURG GROUP	Edwards	Massive dense high purity limestone of variable thickness due to reef patch build-ups.	The Edwards is exposed in the Leon River bank beneath the bridges of I-35 and in the northern part of the study area around Belton. It is in the subsurface from Temple to Hillsboro.	Scrub Oak	High $CaCO_3$ content
CRETACEOUS	COMMANCHE SERIES / FREDERICKSBURG GROUP	Commanche Peak	Composed of alternating layers of dark grey, nodular, earthy limestone and calcareous clay.	sub-surface	not applicable	not applicable
CRETACEOUS	COMMANCHE SERIES / FREDERICKSBURG GROUP	Walnut	The Walnut Clay is composed of an upper shale unit and a lower unit of coquinoid (oyster limestone) and thin dense limestone beds.	sub-surface	not applicable	not applicable
CRETACEOUS	COMMANCHE SERIES / FREDERICKSBURG GROUP	Paluxy	Thin fine-grained, calcareous sandstone beds.	sub-surface	not applicable	not applicable
CRETACEOUS	COMMANCHE SERIES / TRINITY GROUP	Glen Rose	Dense, buff-colored, alternating limestones and shales with some anhydrite.	sub-surface	not applicable	not applicable
CRETACEOUS	COMMANCHE SERIES / TRINITY GROUP	Hensel	The Hensel Sand is white, fine to coarse-grained, sub-rounded to sub-angular unconsolidated sand.	sub-surface	not applicable	not applicable
CRETACEOUS	COMMANCHE SERIES / TRINITY GROUP	Pearsall	The Pearsall Formation is composed of an upper Cow Creek Limestone member and a lower Hammett Shale member.	sub-surface	not applicable	not applicable
CRETACEOUS	COMMANCHE SERIES / TRINITY GROUP	Sligo	The Sligo Formation consists of brown to grey oolitic to crystalline limestone.	sub-surface	not applicable	not applicable
CRETACEOUS	COMMANCHE SERIES / TRINITY GROUP	Hosston	The Hosston Sand is composed of fine to coarse, red to white, silty porous sand.	sub-surface	not applicable	not applicable
		Pre-Cretaceous	Pre-Cretaceous rocks are probably, slates, metaquartzites, and schists.	sub-surface	not applicable	not applicable

FORMATION OR MEMBER	5 BEARING CAPACITY	6 SHEARING STRENGTH	7 SLOPE STABILITY	8 EXCAVATION DIFFICULTY	9 PROPERTIES WHEN USED AS FILL
Alluvial silts and clays	Bearing capacity ranges from 0.7 to 1.8 tons/ft_2 it will vary with thickness, moisture content, clay-silt composition, and nature of the underlying formation.	Shearing strength is low. This is indicated by the low angle of slope on natural slopes. No actual quantitative data is available and on site testing is necessary. Soil stabilization with lime will help.	Unstable. The material is too plastic with high porosity and moisture content. Retaining walls must be used to maintain oversteepened slopes. Heavy structures must be supported below grade.	Easily excavated with light machinery. Shoring and cribbing are necessary to support open cuts. Extreme hazard in unsupported material.	When used as a general fill the material must be stabilized with lime and compacted.
Leon River Terraces	Bearing capacity is dependent upon the cohesiveness of the material, water content, confining pressure, and whether the load is static or dynamic. The clayey sands range from 1.0 to 6.5 tons/ft_2. Gravels range from 2.5 to 8.5 tons/ft_2. Shallow foundations or slab construction will encounter minimum bearing capacity due to the absence of confining pressure.	No quantitative data available.	The terraces may maintain steep slopes because of the clay binder. In addition, limestone cementation of the gravel has resulted in development of durable conglomerate which will maintain low vertical faces.	Easily excavated with light machinery (loader, backhoe, dragline). Where conglomerates are located blasting or ripping may be required. Water may be encountered at 15 to 20 feet.	Sands and gravels good to usable above grade fill. The quality depends in part on the clay content. Excessive clay content and clay free content are both undesirable.
Brazos River Terraces	Bearing capacity is low to intermediate depending upon cohesiveness, water content, and depth. The Barzos sands range from 1.1 to 2.5 tons/ft_2. The compacted sands range from 4 to 8 tons/ft_2. Testing is required at each site. Values for bearing capacity may be different from site to site. Shallow foundations or slab construction will encounter minimum bearing capacity due to lack of confining pressure.	Shearing strength of the Brazos terraces is low.	Slopes are stable especially on indurated, dense, cemented conglomerates.	Readily excavated with light machinery. Where cementation of gravels have produced conglomerates, it may be necessary to blast or rip. Shallow groundwater is frequently encountered at 10 to 15 feet.	Brazos sands and gravels; poor when used as above grade fill, due to lack of clay binder. Very good on below grade fill.
Bosque River Terraces	Low to intermediate depending upon cohesiveness, water content, and depth. Testing is required at each site. Values for bearing capacity may value from site to site.	Shear strength of the Bosque terraces is intermediate to high.	Slopes are normally stable due to clay binder. $CaCO_3$ cementation of the gravel has resulted in the development of conglomerates that will maintain low vertical faces. In uncemented sands and gravels, maintain gentle slopes from 10 to 15 degrees to insure stability. Sometimes shoring is necessary.	Readily excavated with light equipment. In dense hard conglomerates blasting or ripping may be necessary.	Bosque terrace material is excellent above grade fill except when excessive clay binder is present, or when too little is present.
Taylor Marl	The bearing capacity is variable; usually intermediate to low. It increases with depth because of increased confining pressure and natural clay stabilization below the weathered soil zone. Bearing capacity in tons per square foot is 3.5 at 10 to 15 feet and 15 tons/ft_2 at 40 to 50 feet. These values can vary widely within the same site. On site testing is required.	Shearing strength is low. Ranging from 3.79 lbs/in² at zero lateral pressure to 29.15 lbs/in² at 15 lbs. lateral pressure.	Slope stability is low. Excavated slopes of less than 10 feet will fail when wet. Continuous shoring is required in all excavations. The maximum natural slope is 10 degrees throughout the outcrop area. Because of climatic conditions northwest facing slopes are usually steeper (2 to 4 degrees) than southwest facing slopes. When excavating this material, wall supports or gentle slopes (3½:1) should be maintained. During wet periods sealing against moisture is advisable.	The Taylor Marl when dry can be easily excavated with light machinery. When wet it becomes sticky and may cause trouble. Excavations for footings and piers should be filled quickly since bentonitic clay beds are present in the marl.	This material is usually unstable when used as a fill. It fails readily when oversteepened or wet. It erodes easily when used in this manner and provides little support strength.
Austin	The bearing capacity is high varying from 14 to 25 tons/ft_2. Lower 50 feet (clay righ zone) will be lower. Although bearing capacity is high, in areas where the formation is thin, problems will arise. In areas where the South Bosque Shale is exposed beneath the chalk, the Austin may fail due to slope failure in the shale. On site testing may be necessary.	Shearing strength is high varying from 9.75 lbs/in² at zero lateral pressure to 109.5 lbs/in² at 15 lbs. lateral pressure.	Slope stability is high. This material can support vertical slopes without shoring. Near the basal contact shoring is required. The Austin will slump if the shale beneath is disturbed.	The Austin Chalk is difficult to excavate. However, it can be excavated by mechanical means due to friable nature of the material. Weakness along joint and fault planes permits easier excavation by blade or ripper when direction of force is applied at right angles to the dominant north-south fracture system.	The Austin Chalk makes an excellent fill material. The marl beds within the formation should be avoided due to high PVR. When used as fill the material should be sealed against filtration to avoid decomposition of the chalk.
South Bosque	Bearing capacity is intermediate to low. The values increase with depth. Values range from 3.5 tons/ft_2 at 5 to 12 feet to 18 tons/ft_2 at 30 to 40 feet. Near the surface these can drop to 2 tons/ft_2.	Shearing strength is low.	Unstable. The natural slope ranges from zero to 20 degrees with stability at less than 10 degrees. Stability in this material depends upon moisture content, height of slope, type of vegetation on the slope, and weight added on top of the slope. Construction problems are to be expected in this material.	Easily excavated with light equipment when dry. Sticky when wet and difficult to manage.	The material is unstable as fill. When used as fill should be stabilized, compacted, drained, and only gentle slopes maintained.
Lake Waco	Bearing capacity is intermediate and increases with depth. The limestone beds in the Bouldin and Bluebonnet members have the highest foundation strength. These beds will fail when underlain by bentonites. Near the surface the values are 4.5 tons/ft_2. At 30 feet they are 25 tons/ft_2. Testing at each site is recommended.	Shearing strength is low in bentonitic beds and high in limestone beds.	Slope stability is moderate in more calcareous Bouldin and Bluebonnet members; low in less calcareous Cloice member. Natural slope angles range from zero to 40 degrees depending upon the type of vegetation present, the type and weight of overburden, and the height of the slope.	Moderately easy to excavate. However, the thin limestone beds may cause some difficulty when light equipment is used. When wet these clays are sticky and hard to manage. Work should be completed when material is dry. Blasting is not necessary because of fractures in the limestone beds.	This formation is a poor fill material. Recompaction of the shale and limestone beds should be undertaken with close moisture and density control. Bentonitic beds should be stabilized with lime or other suitable agent.
Pepper Shale	Bearing capacity of the Pepper Shale is low. It varies with depth and moisture content. It ranges from 1.5 ton/ft_2 near the surface to 8 tons/ft_2 at about 25 feet in depth.	This formation fails under its own weight when wet.	Very unstable. Slopes should never exceed 10 degrees unless adequately supported. In excavations continuous shoring is necessary to maintain slopes. Controlled compaction and stabilization should be carried out on this formation.	The Pepper Shale is easily excavated when dry, but very difficult to work with when wet. Exposure of cuts to weather should be avoided.	Poor, very unstable. Erodes easily. The small clay particles are layered in such a way that each of them acts as a lubricated sliding surface.
Woodbine	not applicable	not applicable	not applicable	not applicable	not applicable
Buda	30 to 35 tons/ft_2 in thich sections.	No data available. However, based on other properties probably very high.	Too thin and discontinuous to affect stability of slopes in most places. The Buda does support an escarpment 2.5 miles east of the Temple airport on state highway 36.	Difficult; heavy equipment is necessary for removal and blasting for fracturing purposes.	Not enough material available to be used as fill.
Del Rio	The bearing capacity ranges from one ton/ft_2 near the surface to about 6.5 tons/ft_2 at depths of about 20 feet.	Moderate to low. With the addition of lime, the shearing strength of the clay increases.	Slopes in the Del Rio Clay tend to be unstable because of the plastic clay content. The natural slopes range from 0 to 15 degrees. Slope failure is caused by: lack of confining pressure, excess moisture, height or steepness of slope, and undercutting by stream erosion.	Moderate to easy. Difficult to work when wet. Limestone and siltstone beds which occur throughout the formation may require medium to heavy duty equipment. Rippers may be used to cut channels for ditches, etc.	Poor; the material is unstable. The upper and lower parts of the formation have a higher $CaCo_3$ content than the middle and therefore are better than the latter zone when used as fill material.
Georgetown	The Mainstream Limestone is excellent founding material. The founding strength ranges from 15 to 25 tons/ft_2 in most areas. However, the shale members tend to be weak.	No data available. Should be high.	Stable to moderate. Limestone beds substain stable slopes. Shale beds do not.	Difficult; blasting may be necessary to loosen the material. Ripper and blade may be used, especially along the joint planes.	Excellent; Main Street Limestone is excellent. Clayey facies should be avoided.
Edwards	Excess of 35 tons/ft_2	Probably very high in view of the high bearing capacity.	Highly stable. Edwards Limestone will maintain nearly vertical slopes.	Very difficult. Blasting is needed then crushing.	Excellent, but not very practical due to the high cost of removal.
Commanche Peak	not applicable	not applicable	not applicable	not applicable	not applicable
Walnut	not applicable	not applicable	not applicable	not applicable	not applicable
Paluxy	not applicable	not applicable	not applicable	not applicable	not applicable
Glen Rose	not applicable	not applicable	not applicable	not applicable	not applicable
Hensel	not applicable	not applicable	not applicable	not applicable	not applicable
Pearsall	not applicable	not applicable	not applicable	not applicable	not applicable
Sligo	not applicable	not applicable	not applicable	not applicable	not applicable
Hosston	not applicable	not applicable	not applicable	not applicable	not applicable
Pre-Cretaceous	not applicable	not applicable	not applicable	not applicable	not applicable

FORMATION OR MEMBER	10 POTENTIAL SWELL	HYDROLOGIC PROPERTIES: 11 FREE GROUNDWATER	HYDROLOGIC PROPERTIES: 12 PERMEABILITY-INFILTRATION	13 ASSOCIATED SOILS	14 ECONOMIC PROPERTIES
Alluvial silts and clays	2 to 7 percent by volume. This volume change depends on moisture content and clay mineralogy.	There is a moderate amount of water at shallow depths. Water is probably polluted.	Permeability is low to moderate because of high water content. Large drainage fields are necessary for septic sewage disposal.	Soil series associated with alluvium are: Asa, Frio, Miller, Norwood, Yahola, Pledger, Brazos, Trinity, Bosque, and Kaufman.	Alluvial soils are good lands for agriculture. They are major sources for sand and gravel. Future use of these lands should be confined to sand and gravel resources and then recreational areas.
Leon River Terraces	Expanding clays in the gravel deposits are accommodated within the pore structure of the material. Trouble from swelling should not be encountered when building on the terraces.	Polluted water is present in most of the larger areas. Water occurs most abundantly in the lower terraces. It is seasonal in the high terraces.	Readily accepts infiltration and induced fluids. Lower terraces pose disposal problems because of the shallow water table.	Axtell, Bastrop, Bell, Burleson, Irving, Lewisville, and the Travis series.	Major source of sand and gravel. Lower terraces produce some water, however, it is polluted.
Brazos River Terraces	None in the parent material. However, on site testing should be carried out. Values may vary from site to site.	Free water is abundant in low terraces. Seasonal in the high terraces. Mostly polluted.	Permeability is high. High terrace sands and gravels readily accept infiltration of fluid. However, pollution is an ever present danger.	Axtell, Bell, Irving, Lewisville, and Travis series.	Principal source of sand and gravel in the Waco area.
Bosque River Terraces	None in parent material.	Bosque terraces generally do not have as much free water as the Brazos terraces. What water is available is probably polluted.	Both permeability and infiltration is high. However, pollution is a danger.	Axtell, Bell, Irving, and Lewisville series.	Good farm soils. Gravel pits, fill and road material. Source of good top soil.
Taylor Marl	The material has a high potential swell. It may reach values of 8 to 15 inches. Protection against damage from swelling clays include: sealing of ground from moisture; backfilling excavations with non-swelling material (caution must be exercised here because of the corrosion cell set up between two different materials); deep footings below the zone of moisture penetration; the use of heavy grade beams and foundations.	The lower Taylor Marl produces no potable ground water within the study area.	Intermediate to moderate permeability when dry; impermeable when wet. This low permeability facilitates storage of surface water by building storage ponds. Infiltration is low because of the low permeability and the sealing effect of the bentonitic clays. Sewage disposal requires large drainage fields. During excessively wet periods sewage will find its way to the surface causing pollution.	Heiden series and Ferris series.	Good farm soils. Possibility of some marginal economic ceramic clays.
Austin	PVR is low in chalk beds. However, the marl beds have high PVR and will cause foundation failure. If the top soil contains many limestone fragments and is light in color the danger of swell is at its minimum. If the soil is deep and grey to black a potential danger exists and corrective measures taken. Either removal of soil or deep footings into bedrock.	The Austin produces a moderate amount of free water which is usually polluted. Excavations during wet seasons may require extensive pumping.	Permeability is moderate due to the highly fractured nature of the material. Infiltration is moderate. However, during wet periods infiltration will be reduced due to sealing by the bentonitic clays in the marl layers.	Austin, Eddy, Stephen, Houston Black, Heiden, and Ferris series.	The Austin provides excellent material for cement production. Effective disposal fields can be installed in areas of 100 by 125 feet for private residences. Low sub-base materials for roads. Potential value as a fertilizer due to high $CaCo_3$ content.
South Bosque	High, particularly in the noncalcareous upper part of the formation. When testing for potential swell, consideration must be given to the moisture conditions at the time of the test, additional weight which tends to counterbalance swell, and depth of potential swelling material.	No free ground water because of tight compaction of material.	Impermeable; infiltration capacity is low. When dry the shale cracks and fluffs, providing temporary adequate drainage. Water that percolates through the overlying Austin Chalk drains out on top of the underlying shale. Extremely large drainage fields are required to provide adequate sewage disposal. Infiltration is reduced by clay expansion during periods of high saturation. During wet periods, septic waste may find its way to the surface and contaminate South Bosque soils.	Houston Black, Austin, and Ferris series.	Good agricultural soil. Excellent raw material for cement production and expanded aggregate.
Lake Waco	Potential swell is high. This is due to the high shrink-swell of the bentonitic beds. This property will cause problems with foundations, buried structures, and excavations. It can be minimized by proper drainage and surface sealing. In thicker bentonitic beds, complete removal is necessary.	No free ground water in this formation. Uncased wells produce small amounts of water from surface seepage.	Generally impermeable. Permeability increases along bedding planes and fractures of limestone beds. Infiltration capacity is low.	Heiden series.	Well suited as cropland.
Pepper Shale	High-PVR commonly equal to 10-14 inches.	None	The Pepper Shale is impermeable. Infiltration capacity is low.	Houston Black and Heiden series.	None
Woodbine	not applicable	not applicable	not applicable	not applicable	not applicable
Buda	Probably very low.	No water	The Buda Limestone lies between beds of impervious shales, therefor, preventing fluids from infiltrating. In the subsurface of northern Falls County, the formation is an oil reservoir.	The Buda will be covered by colluvial soils derived from the overlying Pepper and Eagle Ford Formations.	Excellent building stone.
Del Rio	High; PVR values of 1.5 to 2.5 inches. Sometimes these approach the values of Pepper Shale.	No water	Impermeable. Low infiltration capacity.	Heiden, Houston Black, and San Saba series.	Good agricultural soils. No other commercial use.
Georgetown	Low in limestone due to high $CaCO_3$ content. In marl beds and shale beds potential swell is usually high.	None	Permeable; However, it occurs between impermeable shales which prevent fluid infiltration. Infiltration capacity is low.	Denton, San Saba, and Tarrant series.	Excellent base material. Cement when combined with shale.
Edwards	None	Edwards Limestone contains water west of the study area.	Permeable; fluids migrate through the formation easily.	Brackett, Crawford, Denton, and San Saba series.	Crushed aggregate for road base material. Riprap material. Excellent building stone.
Commanche Peak	not applicable	no water	not applicable	not applicable	not applicable
Walnut	not applicable	no water	not applicable	not applicable	not applicable
Paluxy	not applicable	no water	not applicable	not applicable	not applicable
Glen Rose	not applicable	very limited water in Temple area	not applicable	not applicable	not applicable
Hensel	not applicable	Some water for limited use in Temple area.	not applicable	not applicable	not applicable
Pearsall	not applicable	no water	not applicable	not applicable	not applicable
Sligo	not applicable	no water	not applicable	not applicable	not applicable
Hosston	not applicable	Principal aquifer in study area	not applicable	not applicable	not applicable
Pre-Cretaceous	not applicable	no water	not applicable	not applicable	not applicable



SOIL SERIES (inserts)

HILL COUNTY

12	C3	Heiden Clay	2-5%	slopes eroded
15	C3	Heiden Clay	2-5%	slopes eroded
16		Austin Silty Clay	1-3%	slopes
83	C3	Stephen Silty Clay	1-5%	slopes eroded
85		Stephen Silty Clay	1-3%	slopes
88		Purves-Brackett Stony Clays	1-8%	slopes
93		Eddy Gravelly Clay Loam	1-3%	slopes
168	D4	Ferris Clay	5-12%	slopes severely eroded

McLENNAN COUNTY

Am	Axtell Fine Sandy Loam	0-2%	slopes
If	Irving Silt Loam	0-1%	slopes
Sd	Sawyer Fine Sandy Loam	0-1%	slopes
Ie	Irving Clay Loam	0-1%	slopes
Se	Stidham Loamy Fine Sand	0-2%	slopes

BELL COUNTY

2	B1	Stephen Silty Clay	1-3%	slopes
15	B1	Houston Black Clay	1-3%	slopes
45	C1	Austin Silty Clay	3-5%	slopes
45	C3	Austin Silty Clay	2-3%	slopes
45	B1	Austin Silty Clay	1-3%	slopes
60	CD1	Eddy-Stephen Complex	3-8%	slopes

LEGEND

Base Map, Texas State Highway Department, Revised 1973.

AUSTIN-EDDY-STEPHEN
Shallow stony soils. Gently sloping to moderately steep. Shallow to moderately deep clayey soils over chalk, on uplands.

TARPLY-TARRANT-BRACKETT-PURVES
Gently sloping to steep shallow and very shallow clayey soils containing small to large limestone fragments over limestone; on uplands.

WILSON-BURLESON
Shallow to moderately deep sandy loam to clay loam over firm blocky calcareous mottled clay. On nearly level to gently sloping stream terraces.

AXTELL-IRVING
Shallow sandy soils over firm blocky clay. Nearly level to gently sloping old stream terraces. Shallow clayey soils over blocky firm clay.

DENTON-PURVES
Gently sloping to sloping silty clay soils that are moderately deep to shallow over limestone or limestone interbedded with marly clays on uplands.

SAN SABA-CRAWFORD
Nearly level to gently sloping clayey soils that are moderately deep over limestone on uplands.

HOUSTON BLACK-HEIDEN
Gently sloping to sloping clayey soils that are deep over marl and chalk, on uplands.

TRINITY-PURSLEY
Nearly level, deep clayey and loamy soils on floodplains.

HOUSTON BLACK-HEIDEN-AUSTIN
Gently sloping to undulating to moderately rolling calcareous clays over marl and chalk.

TRINITY-FRIO-BOSQUE
Nearly level, deep, calcareous clayey and loamy soils on floodplains.

MILLER-NORWOOD-YAHOLA
Dark calcareous clays, silty clays, and sand loam developed on well drained nearly level floodplains.

Baylor Geological Studies
Bulletin No. 27

PLATE III
SOIL ASSOCIATIONS
I-35 CORRIDOR, CENTRAL TEXAS

Ellwood E. Baldwin

1974

	PHYSICAL FACTORS					DEGREE OF LIMITATION AND FACTORS AFFECTING USE FOR:													HAZARDS	
	1	2	3	4	5	6	7		8	9		10	11	12	13	14	15	16		
							PONDS										SOURCE MATERIAL			
SOIL ASSOCIATION	DOMINANT SOIL and PROPORTION OF ASSOCIATION	DEPTH TO PARENT MATERIAL	PERMEABILITY RATE IN./HR.	NATURAL SOIL DRAINAGE	POTENTIAL VERTICAL RISE	HIGHWAY and STREET LOCATION	RESEVOIR	EMBANKMENT	CORROSION UNCOATED STEEL	BUILDING SITES	LIGHT INDUSTRY	SEPTIC TANK FILTER FIELDS	SEWAGE LAGOONS	SANITARY LAND FILLS	CAMP AREAS	PICNIC AREAS	TOPSOIL	GENERAL FILL	EXCAVATION HAZARDS	FLOOD HAZARD
AUSTIN-EDDY-STEPHAN	Austin 83%	16" to 40"	0.2 to 2.5	Good	High	Severe High shrink-swell	Severe Depth to chalk Permeability	Moderate Stability	High	Severe High shrink-swell	Severe High shrink-swell Corrosivity	Severe Slow permeability Depth to chalk	Severe Depth to chalk	Severe Clayey texture Depth to chalk	Severe Clayey texture	Severe Clayey texture	Poor Clayey texture	Poor High shrink-swell	Difficult	None
AXTELL-IRVING	Axtell 61%	70"	0.05 to 2.0	Fair	Moderate	Severe Shrink-swell Traffic supporting capacity	None to slight	Moderate Stability	High	Severe High shrink-swell	Severe High shrink-swell Corrosivity	Severe Permeability	0-2% slopes slight 2-7% " Mod. 7-12% " severe	Severe Permeability	Severe Permeability	0-8% slope slight 8-12% " Mod.	Poor Clayey texture	Poor Shrink-swell	None	None
WILSON-BURLESON	Wilson 56%	36"	0.01 to 1.0	Fair	High	Severe Shrink-swell Traffic supporting capacity	None to slight	Moderate Stability	Very high	Severe High shrink-swell	Severe High shrink-swell Corrosivity	Severe Permeability	0-2% slopes slight 2-5% " Mod.	Severe Clayey texture	Severe Permeability Wetness	Moderate Wetness Texture	Poor Texture	Poor Shrink-swell Traffic supporting capacity	None	None
	Burleson 44%	70"	0.05 to 0.15	Fair	Very high	Severe Shrink-swell Traffic supporting capacity	None to slight	Moderate	High	Severe High shrink-swell	Severe High shrink-swell Corrosivity	Severe Permeability	0-2% slopes slight 2-5% " Mod.	Severe Clayey texture	Severe Permeability Clayey texture	Severe Clayey texture	Poor Clayey texture	Poor Very high shrink-swell	None	None to slight
DENTON-PURVES	Purves 99%	20"	0.20 to 0.63	Good	High	Severe Shrink-swell	Severe Depth to bedrock	Severe Thickness of burrow material	High	Severe High shrink-swell Depth to bedrock	Severe High srink-swell Depth to bedrock	Severe Depth to bedrock	Severe Depth to bedrock	Severe Clayey texture Depth to bedrock	Severe Clayey texture	Severe Texture	Poor Texture Coarse fragments	Poor High shrink-swell	Bedrock at 20"	None
HOUSTON BLACK-HEIDEN	Houston Black 69%	60"	0.05 to 0.15	Fair	Very high	Severe Shrink-swell Poor stability	None to slight	Severe Shrink-swell Poor stability Erodible	Very high	Severe High shrink-swell	Severe High shrink-swell Corrosivity	Severe Slow permeability	0-2% slope slight < 2% " Mod.	Severe	Severe Permeability Clayey texture	Severe Permeability Clayey texture	Poor Clayey texture	Poor High shrink-swell Stability	None	None to slight
	Heiden 29%	60"	0.05 to 0.15	Good	Very high	Severe Shrink-swell Traffic supporting capacity	None to slight	Moderate Stability	Very high	Severe High shrink-swell	Severe High shrink-swell Corrosivity	Severe Permeability	0-2% slope slight 2-7% " Mod. 7-20% " severe	Severe	Severe Permeability Clayey texture	Severe Clayey texture	Poor Clayey texture	Poor High shrink-swell	None	None
HOUSTON BLACK-HEIDEN-AUSTIN	Austin 57%	See Austin-Eddy-Stephan Association																		
	Houston Black 43%	See Houston Black-Heiden Association																		
MILLER-NORWOOD-YAHOLA	Asa 66%	60"	0.1 to 1.5	Good	Low	Moderate Traffic supporting capacity	Moderate Permeability	Moderate Permeability	High	Moderate Bearing capacity (If area is protected from flooding)	Moderate If protected from flooding	None to slight	Moderate Permeability	Moderate (If protected from flooding)	Moderate (If protected from flooding)	Moderate (If protected from flooding)	Fair	Fair	None	Floods every 10 to 15 years unless protected
SAN SABA-CRAWFORD	San Saba 50%	24" to 40"	< 0.06	Fair	Very high	Severe High shrink-swell	Severe Bedrock is permeable	Moderate Stability	High	Severe Bearing capacity and shrink-swell	Severe Bearing capacity Shrink-swell	Severe Permeability Bedrock	Severe Bedrock	Severe Depth to bedrock	Severe Permeability Texture	Severe Texture	Poor Clayey texture	Poor Shrink-swell	Rock at 24"	None
	Crawford 50%	20" to 40"	< 0.06	Good	Very high	Severe High shrink-swell Depth to bedrock	Severe Depth to bedrock	Moderate	High	Severe High shrink-swell	Severe Very high shrink-swell	Severe Slow permeability	Severe Depth to bedrock	Severe Depth to bedrock	Severe Slow permeability	Severe Clayey texture	Poor Clayey texture	Poor Very high shrink-swell	Rock at 20"	None
TARPLY-BRACKETT-TARRANT-PURVES	Tarrant 29%	12"	0.02 to 1.0	Good	Low	Severe Stones Depth to bedrock	Severe Permeable Fractures in bedrock	Severe Stones Thickness of material	High	Severe Shrink-swell Depth to bedrock	Severe Stoniness and shrink-swell	Severe Depth to bedrock	Severe Depth to bedrock	Severe	Severe Stones Texture	Severe Stones Texture	Poor Stones	Poor Stones Thin soils Shrink-swell	Bedrock at 12"	None
	Purves 29%	See Denton-Purves Association																		
	Speck 29%	14" to 20"	0.06 to 0.2	Good	Low to moderate	Severe Depth to bedrock	Severe Bedrock	Severe Thickness of material	High	Severe Bedrock	Severe Bedrock and Corrosivity	Severe Permeability Bedrock	Severe Bedrock	Severe Permeability Depth to bedrock	Moderate Permeability Texture	Moderate Texture	Fair Texture Thickness of material	Poor Thickness of material	Bedrock at 20 "	None
TRINITY-FRIO-BOSQUE	Bosque 65%	60"+	0.63 to 2.0	Fair	Low	Severe Flooding	Moderate Permeability	Moderate Stability	High	Severe Flooding	Severe Flooding and corrosivity	Severe Flooding	Moderate Permeability	Severe Flooding	Severe Flooding	Moderate Flooding	Good	Fair	Banks unstable when wet	Flooding 1 to 5 years for at least 2 days
TRINITY-PURSLEY	Trinity 100%	80"+	< 0.06	Fair	Very high	Severe Shrink-swell Flooding	None to slight	Moderate	Very high	Severe Wetness, flooding Shrink-swell	Severe Wetness, flooding, shrink-swell, and corrosivity	Severe Permeability Flooding	Moderate	Severe Flooding	Severe Permeability Flooding	Severe Texture	Poor Clayey texture	Poor Shrink-swell	Banks unstable when wet	Floods once a year unless protected

HOW TO USE SOIL MAP AND SOIL INTERPRETATIONS

This chart is to be used in conjunction with the General Soil Map (Plate III). The map shows the soil associations in the growth area. A soil association is a landscape that has distinctive proportional patterns of soils. It normally consists of one or more major soils for which it is named, although several minor soils may be included.

This map is useful to people who want a general idea of the soils in the area, who want to compare different parts of the area or who want to determine suitability of soils to certain land uses for general planning. More specific interpretations should be based on a detailed soil survey and on-site examination. The soils within one association may differ widely in slope, drainage, texture and other characteristics that affect use and management.

This chart lists the degree of limitation and principal factors affecting use for major soils within each association. The chart lists only the principal adverse factors affecting uses. The soils of small acreage within the association are not rated in the table.

DEFINITIONS OF SOIL LIMITATIONS

Slight — Soils have properties favorable for the rated use. Limitations are so minor that they can be easily overcome. Good performance and low maintenance can be expected from these soils.

Moderate — Soils have properties moderately favorable for the rated use. Limitations can be overcome or modified with planning, design, or special maintenance.

Severe — Soils have one or more properties unfavorable for the rated use. Limitations are difficult and costly to modify or overcome, requiring major soil reclamation, special design, or intense maintenance.

Very severe — Soils have one or more properties so unfavorable for a particular use that overcoming the limitations is most difficult and costly. Reclamation is extreme, requiring the soil material be removed, replaced, or completely modified.

NOTE:

Numbers found at the top of each column refer to tables of interpretive properties in the appendix.

Rockiness and stoniness classifications are given in the glossary.

URBAN GEOLOGY INTERSTATE-35 BELTON, TEXAS TO HILLSBORO, TEXAS

Baylor Geological Studies
Bulletin No. 27

PLATE IV

SOIL FACTORS AFFECTING URBANIZATION

Ellwood E. Baldwin

LEGEND

Base Map, Texas State Highway Department, Revised 1973.

GROUP I-AUSTIN CHALK

- Austin-Eddy-Stephen
- Houston Black-Heiden-Austin

GROUP II-EDWARDS-GEORGETOWN

- Denton-Purves
- Tarpley-Tarrant-Brackett

GROUP III-TERRACES

- Axtell-Irving
- Trinity-Frio-Bosque

GROUP IV-TAYLOR MARL-EAGLE FORD

- Houston Black-Heiden
- San Saba-Crawford
- Wilson-Burleson

GROUP V-PEPPER SHALE-DEL RIO CLAY

- Houston Black-Heiden

GROUP VI-ALLUVIUM

- Trinity-Pursley
- Miller-Norwood-Yahola
- Trinity-Frio-Bosque

Baylor Geological Studies
Bulletin No. 27

PLATE V

LAND CAPABILITY GROUPS

I-35 CORRIDOR, CENTRAL TEXAS

Ellwood E. Baldwin

1974

LAND CAPABILITY GROUP	RECOMMENDED ZONING	LIMITATIONS	CORRECTIVE ACTION
Group I A-middle Austin B-lower Austin This group is located on the Austin-Eddy-Stephen and Houston Black-Heiden associations and covers 45% of the studied area. Soils in these associations have developed on the middle and lower units of the Austin Chalk. Soils are thin (12-15 inches) to deep (40-60 inches). The dominant soil series are the Austin (16-40 inches) and the Houston Black (60 inches). Topography is gently sloping with rounded divides, flatlands, and predominantly grasslands with vegetation confined to floodplains.	A-industrial B-residential	A- middle Austin Bearing capacity values will be at the lower end of the 14 to 25 tons/ft^2 range. This unit erodes easily because of the marly beds. Soils on this unit have high shrink-swell values because of bentonite seams in the marl beds. Serious septic system problems will be encountered, therefore large drainage fields will be required. B-lower Austin Bearing capacity values will be on the upper end of the 14 to 25 tons/ft^2 range. Problems will be encountered near the contact of this unit with the underlying South Bosque Shale. Excavations will be difficult, blasting may be necessary. The lower 50 feet of this unit, which contains bentonite seams will cause problems in support strength and septic sewage disposal.	1. Where soil is shallow removal is necessary. Where this is impractical, foundations should be anchored in rock beneath soils. 2. In areas near the Austin-South Bosque contact, buildings should be set back 100 to 200 feet. 3. Surface drainage must be controlled in the middle unit and in areas near the Austin-South Bosque Contact. This will minimize erosion. 4. Shoring will be necessary near the basal contact of the Austin Chalk and the South Bosque Shale. 5. Excavations by mechanical means should be made with force applied at right angles to the north-south fracture system. 6. Drains should be properly bedded with gravel. 7. Structures and foundations should be constructed at right angles to fracture alignments to minimize foundation damage due to transmitted energy. 8. Exposed banks in the middle unit or marl beds of the lower unit should be gentle slopes or capped by properly anchored surface seal. 9. On site testing may be required.
Group II This group is located on the Denton-Purvis and Tarply-Tarrant-Brackett associations and covers 10% of the studied area. These soils have developed on the Edwards Limestone and the Georgetown Formation. Soils are thin (0-12 inches) to moderately deep (14-20 inches). The dominant soil series are the Purvis (20 inches), Tarrant (12 inches), and Speck (14-20 inches). Topography is gently sloping to steep with good natural drainage. The area is heavily urbanized.	Residential Industrial	Bearing capacity for the Main Street member of the Georgetown Formation ranges from 15 to 25 tons/ft^2. Shale members are very weak. The Edwards Limestone has a very high bearing capacity. Excavation will be difficult and blasting may be necessary. Large septic fields will be necessary.	1. Shale horizons should be avoided for construction purposes. 2. Excavation difficulties can be lessened by use of ripper and blade along jointing planes. 3. Proper drainage near contacts with shale members will minimize slope failure due to undermining.
Group III This group is located on the Quaternary Terraces of the Leon and Brazos rivers. It consists of the Axtell-Irving and Trinity-Frio-Bosque soil associations and covers 20% of the area. Soils are deep (60-70 inches) with the dominant series the Axtell (70 inches) and Bosque (60 inches). Relief is low and the area is frequently flooded.	Residential Industrial	Bearing capacities range from 1.1 to 8.5 tons/ft^2, depending upon cohesiveness, water content, and depth. Pollution is a hazard because of high permeability.	1. On site testing is required. 2. Shallow or slab foundations will encounter minimum bearing capacities. 3. Maintain slopes of 10-15^0 in uncemented sands and gravels. 4. Shoring will be required in slopes over 15^0.
Group IV Three soil associations make up the area. These are: Houston Black-Heiden, San Saba-Crawford, and Wilson-Burleson. This group covers 20% of the studied area. These soils have developed on the lower Taylor Marl, South Bosque Formation, and the Eagle Ford Group. Soils are moderately deep (20-40 inches) to deep (60-70 inches). The dominant soil series are the Wilson (36 inches), Burleson (70 inches), Houston Black (60 inches), Heiden (60 inches), San Saba (20-40 inches), and Crawford (20-40 inches). Topography is level to gently sloping. The most of the area is under cultivation. However, some sections are heavily urbanized.	Residential Industrial	Bearing capacities range from 3.5 to 18 tons/ft^2 depending upon stratigraphic position. Excavation is easy except when wet. Soil movement, because of high shrink-swell, amounts to several inches. Permeability is very low and the presence of bentonite beds add to the problems of septic sewage disposal.	1. Testing should be performed at each individual site. 2. Foundations should extend down into the unweathered shale by means of piers or footings. 3. The bases of piers or footings should be horizontal or slightly inclined away from the hill slope. Foundations of this type transfer the loads to more massive sections of the formation (South Bosque Shale). 4. To protect foundations ground should be sealed from moisture fluctuations. 5. Excavations should be filled rapidly before surface water expands clays. 6. Excavations should be back-filled with non-swelling material. 7. Use of heavy beams and foundations. 8. All heavy structures should be pier supported. 9. Removal of soils where possible. Artificial slopes should have the following protection: 1. Retaining walls. 2. Proper compaction and stabilization. 3. Maintenance of gentle slopes (not more than 10^0).
Group V This group is located at the southern end of the studied area, northeast of Belton along Pepper Creek. It covers about 1% of the area. Soils are deep (60 inches) and consist of the Houston Black and Heiden series. Relief is gently rolling to steep. This area is presently under cultivation but, urbanization is becoming more prevalent.	Recreation	Bearing capacity will generally be less than 8 tons/ft^2 depending on confining pressure. At the surface bearing capacity is 1.5 tons/ft^2. The Pepper Shale and Del Rio Clay which are in this group will erode easily. Some calcareous sections of the Del Rio Formation will have support strength of 6.5 tons/ft^2. These formations are highly plastic when wet. Corrosive values are very high. Both formations are impermeable making disposal systems impractical.	1. Foundation design can be improved by the following: (a) Foundations should extend well into the unweathered surface. In the Pepper Formation they should extend into the more stable Del Rio Clay. (b) Compaction or stabilization with lime or other stabilizing agent. (c) Deep piers or flotation support should be employed. 2. In highway and street construction, stabilization and compaction of shales is needed. Well-drained base material should be provided, and flexible paving should be employed. 3. Maintenance of artificial slopes: (a) Slopes should be no greater then 10^0. (b) Controlled compaction and stabilization of the shale. (c) Provide adequate drainage.
Group VI This group is located on three soil associations: Trinity-Pursley, Miller-Norwood-Yahola, and Trinity-Frio-Bosque. The group covers 5% of the studied area. The soils are deep (60-80 inches); composed of the following dominant series: Asa (60 inches), Bosque (60 inches), and Trinity (80 inches). They are flatlands used for range and pasture with some cultivation. There is a large percentage of high transpiration plants, such as, pecan and oak.	Recreational Parkland	Bearing capacity ranges from 0.7 to 1.8 tons/ft^2. It will vary with thickness, moisture content, clay-silt composition, and nature of the underlying formation. The material is very unstable due to high porosity and moisture content. Flooding and ponding are very common hazards in this group.	1. Foundations can be protected by: (a) Stabilizers, such as $CaCO_3$, should be used to improve low shearing strength. (b) On site testing is required. (c) Heavy structures should be supported below grade. 2. Slope retention in excavations: (a) Shoring and cribbing are necessary. (b) Excavations should be closed immediately. 3. Extensive excavations should be performed during dry seasons.

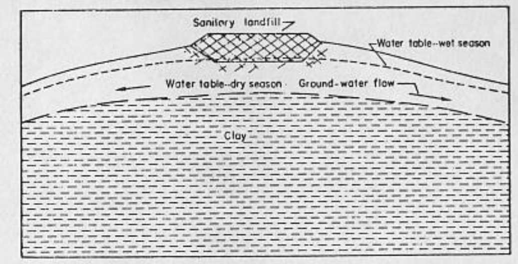
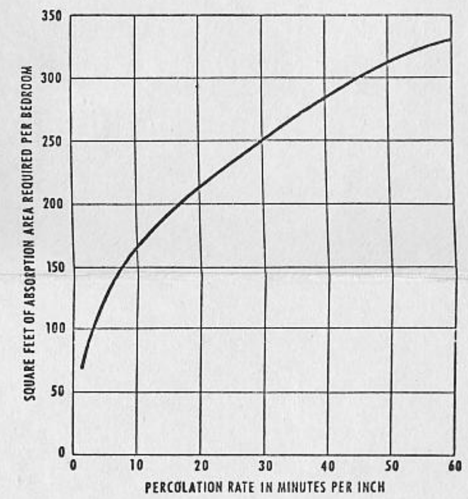


Figure 3. Low permeability host, moderate climate. (Example: clay in Taylor Formation, near Austin, Travis County.) Fill placed on a topographic rise (preferably on a broad, relatively flat area) is secure. In wet season, if water table intersects the landfill, contamination of a small area around the landfill occurs, but the low permeability of the host prevents extensive movement of the contaminants. Typical rates of ground-water movement away from the fill would be less than 1 foot per year.

CAUTION:

Building over old land fill areas may be hazardous due to stability and shrink-swell changes caused by effluent or leachates reactions with clays; sites should be examined prior to construction to determine new physical properties. Long life of effluent and leachates (4 to 5 years) should be considered before building operations which may cause consolidation and flow of these fluids.



Absorption area requirements for private residences. (From U. S. Dept. Health, Education and Welfare, 1963, p. 7.)

URBAN GEOLOGY
INTERSTATE-35
BELTON, TEXAS TO HILLSBORO, TEXAS

Baylor Geological Studies
Bulletin No. 27

PLATE VI

LAND CAPABILITY GROUPS

Ellwood E. Baldwin

BAYLOR UNIVERSITY

GEOLOGY