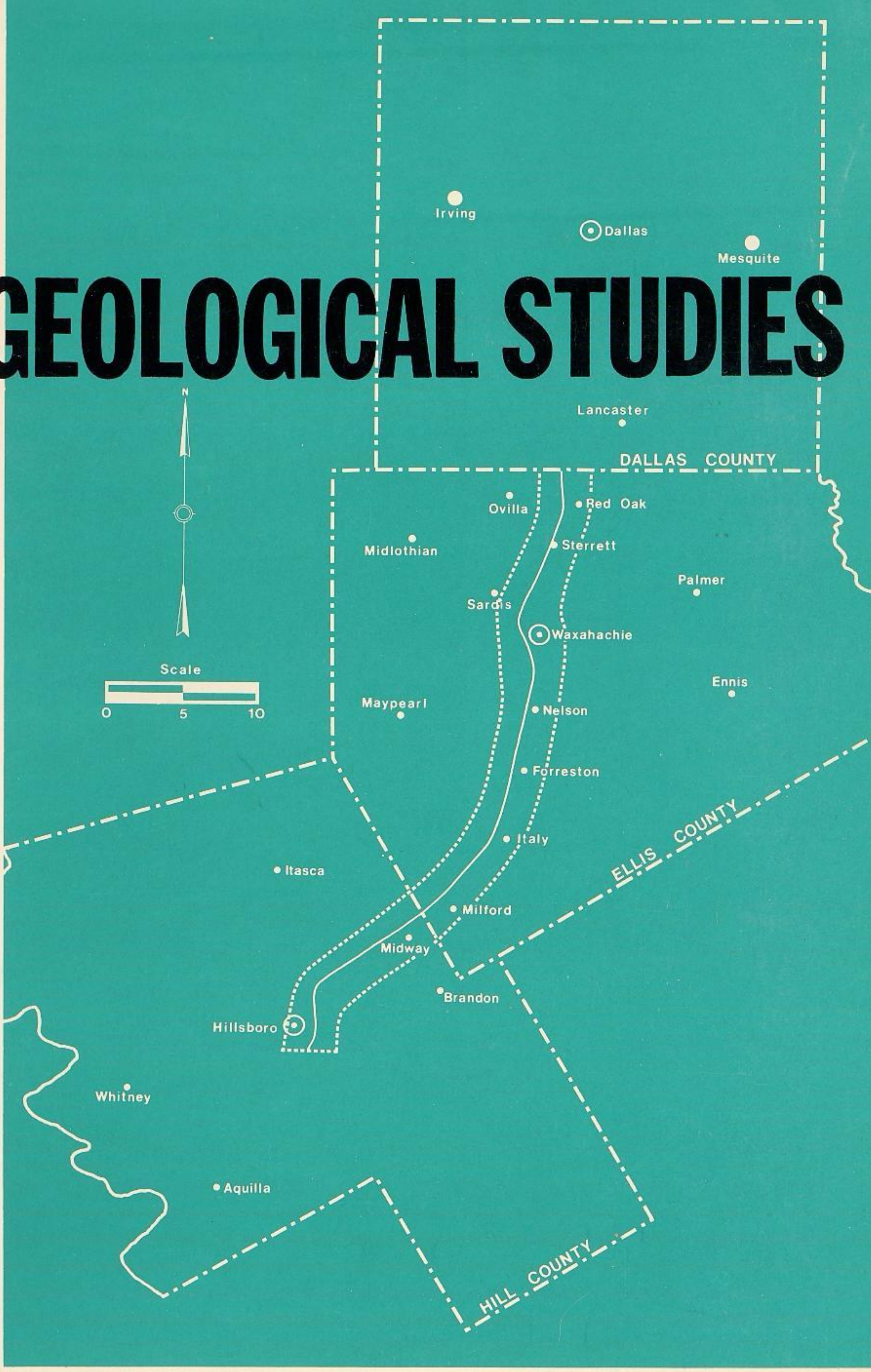
BAYLOR GEOLOGICAL STUDIES



SPRING 1975

Bulletin No. 28

Urban Geology of the Interstate Highway 35 Growth Corridor from Hillsboro to Dallas County, Texas

Peter M. Allen

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

FRANK CARNEY, PH.D.
PROFESSOR OF GEOLOGY
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1929-1934

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Arlington, Texas 76019

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Peter M. Allen

BAYLOR UNIVERSITY
Department of Geology
Waco, Texas
Spring, 1975

Baylor Geological Studies

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ISSN 0005-7266

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Peter M. Allen

ABSTRACT

Urban expansion southward from the City of Dallas is presently occurring within a narrow corridor centered on Interstate Highway 35. An assessment of corridor land for most efficient future development can be derived only through knowledge of long term capabilities and potentials. The purpose of this study is to evaluate systematically the geology, soils, climate, and hydrology of the growth corridor in relation to future urbanization.

The formations that crop out in the corridor include Holocene alluvium; Quaternary terrace deposits; and Cretaceous Taylor Marl, Austin Chalk, and Eagle Ford Shale. The Taylor Marl consists of a fine-grained, uniformly laminated, calcareous, montmorillonitic shale. This formation has low foundation support strength, low permeability, and high potential swell or expansion potential. The Austin Chalk is divisible into three lithologic units within the study area: in ascending order, the "lower" chalk, "middle" marl, and "upper" chalk. Although minor variations in engineering properties exist among these units, the Austin Formation has high bearing capacity, and moderate to excessive permeability along fractures or joints. Stratigraphic position of the Austin Chalk relative to the Taylor Marl and Eagle Ford Shale is critical for proper structural design. The Eagle Ford Group is divided into two formations: the South Bosque and the underlying Lake Waco. This Group has low permeability and large septic drainage fields will be required. The high potential swell and low bearing capacity properties of this shale necessitate clay stabilization procedures and well-engineered foundations. Depending upon topographic position, the Taylor Marl and Eagle Ford shales are adequate sanitary landfill sites.

Most soils indigenous to the study area possess the same engineering properties: high corrosion potential, high potential swell, moderate to slow permeability, and relatively good agricultural productivity.

Slopes are particularly steep and soils thin along the crests and faces of the Austin Chalk-Eagle Ford escarpment, and along the north-facing slopes of present river systems. Gravel deposits are typically found to the north of streams under 80 percent of the mapped area of Lewisville series soils.

Knowledge of soil depth to contrasting bedrock is useful for foundation design, sanitary landfill sites, and septic tank limitations. Minimal soil depths are found over areas of outcrop of "lower" Austin Chalk and along the crests of south slopes along major river systems. Maximum soil depths occur along the north side of present river systems and over areas of outcrop of "middle" Austin Chalk, Eagle Ford Shale, and Taylor Marl.

Five design groups were mapped and described utilizing geologic and soil series information. Mapped areas have the detail routinely included in soil maps and at the same time retain the dimension of depth from the geologic study.

The study area is enclosed in the drainage basin of the Trinity River. About 15 percent of the precipitation or about five inches per year becomes runoff of hard, calcium bicarbonate water suitable for most industrial and agricultural purposes. In the future, additional surface water will conceivably be available from return flows from municipal and industrial use and additional reservoir construction.

Groundwater is principally obtained from the Woodbine and Hosston aquifers. Small additional supplies of above standard groundwater are presently available. The current water resources within the area are sufficient to satisfy all water requirements until after the year 2000.

The study area lies within the extreme northern part of the humid subtropical belt that extends northward from the Gulf of Mexico. The climate has both maritime and continental features. Quantification of selected climatic elements (solar angles, solar radiation, temperature, wind direction and velocity, precipitation extremes, humidity values, heating and cooling degree days), in charts, tables, and text allows for practical construction within the growth corridor.

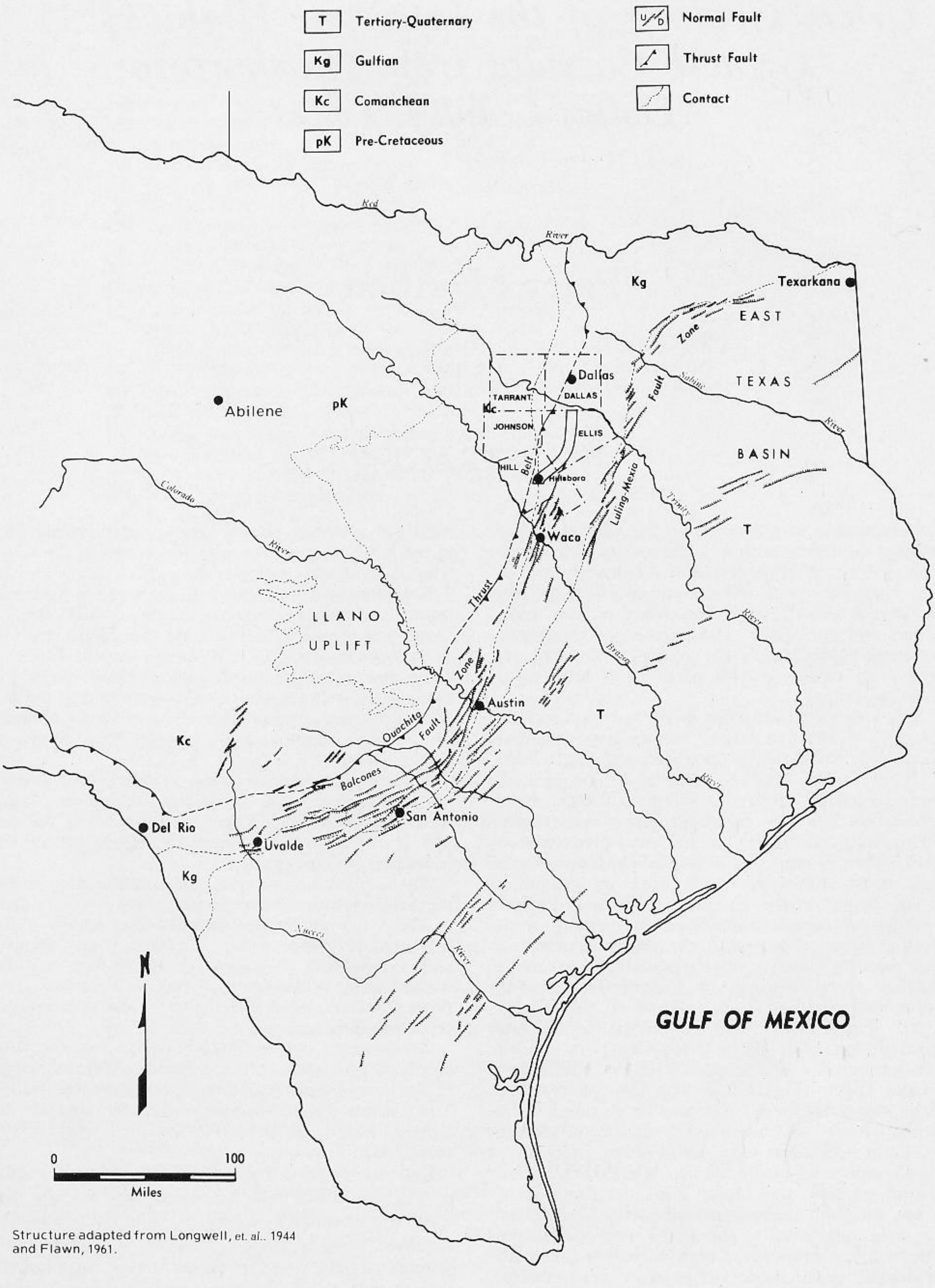

Fig. 1. Index map showing location of the Interstate Highway 35 corridor of this study. This is a northward extension of the area described in Baylor Geological Studies Bulletin 27 (Fall, 1974).

INTRODUCTION*

Major urban growth southward from the City of Dallas, Texas, is occurring within a triangular-shaped growth corridor centered along Interstate Highway 35. The southern apex of this triangle, located at the Dallas-Ellis County Line, marks the southern extension of urbanization. East-west urbanization increases proportionally as one moves to the north along the interstate from this point.

Based on the general realization that the physical limitations of the earth's crust and its resources are relatively permanent entities, planning should precede the projected southward extension along this growth corridor. The first essential in assessing land for urban use is to determine the physical potential for development within a region and to undertake a comparative economic assessment of alternative possibilities based on an objective study of environmental limitations.

The present study is an evaluation of the physical environment of a segment of the corridor of projected growth immediately south of the Dallas-Ellis County line. It includes data from geology, soils, hydrology, and climate. Descriptions, engineering interpretations and recommendations are based on data from these areas and are presented in text, maps, and tables.

Utilization of this information should allow more realistic economic appraisal of natural environs, allow evaluation of the effect of development upon the environment, and aid in planning for "most efficient use." The physical environment along the Interstate Highway 35 growth corridor must be viewed as a dynamic system of limited flexibility to which man must adjust rather than as a static system of infinite variability which we may thoughtlessly adjust to our immediate needs.

LOCATION

The Interstate Highway 35 urban growth corridor (hereafter referred to as the corridor) is a strip of land four miles wide, centered on Interstate Highway 35, and extending from Hillsboro on the south to the Dallas County line on the north (Fig. 1). The corridor includes an area of 160 square miles bounded by latitudes 31° 56′ and 32° 33′ N and longitudes 96° 45′ and 97° 07′ W in north-central Texas.

The corridor parallels the northwestern margin of the West Gulf Coastal Plains (Fenneman, 1938, p. 102-8; Duessen, 1924, Fig. 2), and closely follows the White Rock escarpment within the Blackland Prairies (Fenneman, 1938, p. 7) (Plate I).

The corridor is located in the northern third of the most populous region in Texas. This is a triangular area with apices at Dallas, Houston, and San Antonio which now contains nearly half the population of the state.

METHOD

Though the purpose of this study is wholly utilitarian, and the conclusions and recommendations are presented as interpretative text and displays, the factual basis upon which interpretations rest are sound scientific data. These data include geologic and soils information, climatic and hydrologic data, land use, and engineering data.

Surface and subsurface geologic work is based on literature survey, field mapping, utilizing air photo control (1 : 60,000), and electric well log interpretation. Field data were compiled on 1 : 24,000 topographic maps (U.S.G.S.) and subsequently transferred to Plate I. Classical geologic units were used for two basic reasons: (1) interpretation of their boundaries based on proven stratigraphic techniques most accurately defines the areal extent and physical properties of the rock, and (2) these maps represent broad groups of integrated information and permit a variety of interpretations; new interpretations are not limited by the bias of previous interpretations or lack of pertinent data.

Engineering properties of rocks described in this text are based on studies by Font (1969) and Williamson (1967) on similar formations further south; and from R. L. McKinney, District 9 Laboratory Engineer and Geologist for the Texas State Highway Department.

Soil maps were prepared from Soil Conservation Services field sheets (1 : 20,000 aerial photographs), transferred by photographic methods to 1 : 24,000 topographic maps (U.S.G.S.) and then to Plate II. Mapped soil associations (Plate II) were selected because of internally consistent properties. Soil maps were checked in the field. Representative profiles of soil series were studied in detail, and conclusions were checked in the field by C. A. Brooks, Soil Scientist, U. S. Soil Conservation Service. Detailed study of the soil and rock section exposed along a pipeline excavation which transected the corridor contributed substantially to knowledge of soil and bedrock conditions. Knowledge of the general engineering properties of soils (Plate III) was obtained from the Soil Survey of Ellis County, Texas, Report (1964), and from engineering test data on borings done by the Texas Highway Department in areas of similarly mapped soils.

Hydrological data on groundwater and information regarding surface water are based on literature review, electric well log interpretation, field work, and personal communication with R. Preston, Geologist, Texas Water Development Board.

Climatic data were compiled from literature about central Texas largely from the U. S. Weather Bureau. These data are shown in Figures 20-43.

For greater convenience, much of the data in this report has been expressed in table form. Descriptions and engineering properties basic to the interpretation of soils and geologic units in the corridor are given (Plates III and IV) and illustrated (Plates I, II). Recommended land-use options and conclusions based on soils and geologic information are shown in Plate V.

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

Because more detailed information than is presented in the tables is often needed for proper analysis of specific design problems, descriptions and soil relationships to slope, parent material, and urban growth are also presented. Detailed descriptions of outcropping geologic units, interrelationships between engineering properties and probable service conditions, and locations of representative outcrops are also included.

Hydrologic information is considered as surface water and groundwater. Quantity and quality of available surface water are described, and its relationship to potential urban growth noted in Plate V. Design considerations involving surface and groundwater are also given in Plate V.

Climatic data are presented in Figures 20 through 43 and supporting text. Design considerations for urban planning involving climatic factors are given in Plate V.

ACKNOWLEDGEMENTS

Many sources supplied subject matter for this study. The author hopes that suitable acknowledgement has been given to all of them and assumes full responsibility for the representation of the contents of this Bulletin.

Dr. O. T. Hayward, Professor of Geology, Baylor University, suggested this problem and aided in field work. Dr. J. Namy, Professor of Geology, Baylor University, assisted in manuscript preparation and gave personal support and interest throughout the study. Dr. V. Mayes, Professor of Mathematics, Baylor University, gave generously of time, interest, and understanding. Particular acknowledgement is due Mr. C. A. Brooks, U. S. Soil Conservation Service Soil Scientist, for providing soils information, and for aiding in the field work; and Mr. R. Preston, Geologist, Texas State Water Development Board, for providing information on the subsurface hydrology of the area.

My special thanks go to Captain E. Leach and Mr. R. Belcher for aid in photographic work, to Mrs. A. Mize for manuscript preparation, and to the National Science Foundation for funding through a summer assistantship (1971).

A special note of appreciation is extended to Mr. R. L. McKinney, District 9 Laboratory Engineer and Geologist, Texas State Highway Department, for use of Highway Department information, for personal consultation, and for kindly reviewing the manuscript before publication. Appreciation is also extended to the Texas Real Estate Research Center, College Station, Texas, for graciously providing funds to publish this work.

PREVIOUS WORKS

Knowledge of urban geology along the Interstate Highway 35 growth corridor is derived from six interrelated disciplines: geology, hydrology, soils, engineering, climatology, and regional planning. Literature from all areas was used in the preparation of this study.

GEOLOGY

Two classes of geologic information proved useful: (1) specific works on the stratigraphy of the area and (2) general works which aided in stratigraphic mapping and interpretation of formational boundaries.

Though various works pertaining to the geology of central Texas were published prior to 1900, none of these has more than historical significance today. The first truly significant geologic study was the epic work *Geography and Geology of the Grand and Black Prairies* by R. T. Hill (1901) which has become a standard for central Texas geology and is still widely used as a geological reference.

The geologic structure of Dallas County was described in 1918 by W. E. Shuler. His work was followed by that of Lula Pace in 1921 whose report *Geology of McLennan County, Texas* gives brief descriptions of the Gulfian formations that crop out in Hill County. In 1932, E. H. Sellards, W. S. Adkins, and F. B. Plummer's work on the stratigraphy of Texas was published. This bulletin describes in detail the Cretaceous Gulfian strata and serves as a basic reference for general stratigraphy.

L. W. Stephenson (1937) briefly described the Austin and Taylor Formations in the central Texas area.

Dallas Petroleum Geologists' (1941) report *The Geology of Dallas County, Texas* was used extensively as a reference. Descriptions of the Austin, Taylor, and Eagle Ford Formations, and Quaternary terrace deposits are particularly applicable to this study.

The Woodbine Symposium (Adkins and Lozo, editors, 1951) provided information on the stratigraphy of the Eagle Ford, Washita, and Woodbine Groups in Hill County.

O. T. Hayward's (1957) study on the Balcones fault system was useful in relating air photo interpretations and regional characteristics of the Balcones fault system to stratigraphic and structural relationships within the study area. Durham's (1957) work on the Austin Chalk within the southern third of the corridor was useful in differentiating the various chalk units and facilitated correlation of these units with those in the Dallas County area.

Stratigraphic descriptions and structural relationships of the Austin Chalk and Taylor Marl were aided by several reports. Detailed studies of the Lancaster (Ingels, 1957), Waxahachie (Peabody, 1958), Midlothian (Reed, 1958), and Forreston (Dooley, 1960) quadrangles were particularly useful in interpreting Austin stratigraphy within the mapped area.

Seewald's (1959) study on the stratigraphy of the Austin Chalk in McLennan County aided in interpretation of the stratigraphy near the southern border of the mapped area.

Geology of the Eagle Ford Group was considered in detail in works by Silver (1963), Chamness (1963) and Fandrich (1969) for the southern part of the mapped area.

Stratigraphy and clay petrology of the Taylor Marl in central Texas were described by Beall (1964).

General works on geology consulted for this study included Cuyler's (1931) discussion of vegetational indicators useful in mapping outcropping formations and *Aerial Photographs in Geologic Interpretation and Mapping* by Ray (1960).

SOILS

Three classes of information on soils proved useful in this study: (1) studies of soils in the corridor, (2) aid in the field from soil experts, and (3) general works dealing with soil genesis and soil behavior. Basic soil series information was provided by the Soil Survey of Ellis County (1964) and by C. A. Brooks (U. S. Soil Conservation Service, 1972, personal communication).

Other unpublished soil series information used in preparation of soil charts was obtained from the Hillsboro office of the U. S. Soil Conservation Service.

Brady, Buckman, and Lyon's (1952) text provided excellent introduction to soil genesis and physical properties of soils.

HYDROLOGY

Three classes of information proved useful in interpretation of the hydrology of the area: (1) specific articles published on groundwater hydrology, (2) specific articles on the surface water hydrology and, (3) basic texts in hydrology.

Sundstrom (1948) described results of pumping tests on wells in Waxahachie. Thompson (1967) described groundwater conditions in Ellis County, including water quality, groundwater usage, depth to major aquifers, and pumping rates for wells. Other aquifer tests by Myers (1969) aided assessment of groundwater potentials in the area. Geologic information on aquifer depths was obtained from logs and from published works by Plummer and Sargent (1931), Holloway (1961), and Mosteller (1970).

Chemical quality of groundwater was described by Sundstrom, Hastings, and Broadhurst (1948); Henningsen (1962); and Peckham, Souders, Dillard, and Baker (1963). Groundwater geology of Hill County was compiled from log studies and personal aid from Richard Preston (Texas Water Development Board, 1972, personal communication).

Surface water resources were evaluated in a regional study of the Trinity River Basin by the U. S. Army Corps of Engineers (1962). Chemical quality of surface waters was considered by Leifeste and Hughes (1967), also for the Trinity basin. Quality and quantity of municipal and industrial waste water entering streams in the corridor were evaluated by Wells and Gloyna (1966). Chemical composition of surface water in Chambers Creek (near Corsicana) and for Richland Creek (near Fairfield) was described by Hughes and Shelby (1963). Data on discharge of major rivers within the area were derived from a survey of surface water records in Texas by Manford (1957).

General works on hydrology consulted for this study included those by Todd (1959) and Linsley and Franzini (1961). Factors contributing to differences in chemical quality of subsurface water were reviewed by Hem, White, and Waring (1963). Hydrologic effects of urbanization were evaluated by Savini and Kammerer (1961). Runoff potential from urbanized areas was considered by Vandertulip (1966) and Leopold (1968).

CLIMATE

Climatic information included specific studies of climatic factors in central Texas and general works on climatology. Climatic data were derived from reports on central Texas by Visher (1954), the U. S. Study Commission (1961), Orton (1964), the Environmental Data Service (1968), and Department of the Interior (1970).

Basic references useful in interpretation of climatic data were those by Berry, Bollay, and Beers (1945), Conrad and Pollack (1950), Landsberg (1958), Geiger (1959), and Critchfield (1966).

ENGINEERING DATA

Engineering data were derived from a number of different sources. Shearing strengths and bearing capacities of geologic formations in central Texas were described by Williamson (1967) and Font (1969). Additional data were obtained from McKinney (Texas Highway Dept., 1971, personal communication). Specific soils engineering data were derived from work done on similar mapped soil series by the U. S. Soil Conservation Service (1964) and from the Texas Highway Department.

General information on engineering geology was obtained from works by Paige (1950), Eckel (1958), Trefethen (1959), Lung and Proctor (1969), Stagg and Zienkiewicz (1969), and Flawn (1970). General works on soil mechanics consulted for this study include those by Yong and Warkentin (1966), Gillott (1968), and Terzaghi and Peck (1968).

URBAN PLANNING

Fundamental to a study of the geological impact on urban development along the corridor were works by McHarg (1969) on ecological design, Christiansen (1970) on physical environment of Saskatoon, Canada, Burkett (1965), Elder (1965), Flawn (1965), Spencer (1966), and Font and Williamson (1970) on the geology, soils, water, and their related engineering properties in Waco, Texas.

Coordination of soils and geology for land-use planning was based on work by Thomas and Associates; Stewart (1968); and Hinkley, Kempton, and McComas (1969).

GEOLOGY OF THE GROWTH CORRIDOR

All materials that comprise the corridor exist in a geological environment. Their present physical and chemical properties are the product of their mode of origin and subsequent geological processes that have acted on them.

Rocks are anisotropic and vary in characteristics vertically from bed to bed and laterally within a given bed. Even uniform homogeneous rock masses will deviate from expected service conditions due to weathering, jointing, and faulting. Knowledge of lateral and vertical variations in rock properties and structural attitudes is necessary for the location, design, construction, operation, and maintenance of engineering works.

Geologic information has become necessary for the establishment of a safe, economical urban development:

> (1) Geologic data made available during original real estate appraisal allow for more realistic estimates of natural environs and their effects on land value and estimated development costs.
>
> (2) Possibly even more important at the present time is an evaluation of the effect of a development upon the environment and, in partciular, what factors should be considered in a design to allow the retention of ecological preserves while still creating a safe and economical project.
>
> (3) A complete analytical geological survey prior to design of a master plan will not only avoid the possibility of an unsafe and/or unstable condition, but in almost every situation it will aid in the creation of the most economical and efficient construction criteria (Rold, 1969, p. 8).
>
> (4) In Colorado, non-use of geologic data prior to 1952 resulted in percentage failure of engineering works slightly greater than 10% as compared to 0.15% in recent projects with adequate soils and geologic information (Rold, 1969).
>
> (5) For sand and gravel transportation costs for distances greater than 16 miles raise the cost of transportation above the original value of the resource; planners must be cognizant of available resources for proper design considerations.

Outcropping geological units within the corridor are shown in Plate I. General descriptions of these units, their engineering properties, and representative electric logs are given in Plate IV for general design considerations.

Additional data including: (1) detailed descriptions of outcropping formations, their structural relationships, and geomorphic expression, (2) air photo characteristics of formations, and (3) interrelationships between physical properties to probable service conditions are given for more specific design problems.

Design considerations based on combined soils and geologic information are included in Plate V and illustrated in Plate VI.

Rocks outcropping in the corridor can be basically divided into four main types: river deposits in the present floodplains, ancient river deposits well above present day floodplains, chalks, and shales. These are described individually in the sections which follow and are shown in block diagram.

QUATERNARY SYSTEM

Holocene Alluvium

General Description

Deposits consist of brown to black waxy clays along present river systems in the corridor. Locally, deposits are more than twenty feet in thickness and are often underlain (at depths from 5 to 15 feet) by stratified sand and gravel. Vegetation along these floodplains consists of pecan, oak, and other large deciduous trees with high transpiration rates.

Relation to Urban Geology

Due to seasonal flooding and high potential swell, construction on alluvial deposits is particularly hazardous. River-deposited sediments are typically loosely packed and have low bearing capacities. "Rapid deposition from streams heavily charged with debris results in arching effects, which, aided by the buoying effect of water, result in open packing" (Trefethen, 1959, p. 104), making such sediments susceptible to consolidation when loaded.

Septic sewage disposal in alluvial areas often results in pollution of streams and adjacent shallow domestic and agricultural water wells. Waste disposal systems in alluvial areas should be constructed above the maximum level of the water table (Burkett, 1965, p. 20), and at least 300 feet from area streams (Leopold, 1968).

Trinity, Frio, and Lewisville series soils are mapped in the floodplains of the corridor (Plates II, III).

Pleistocene

General Description

Typically, terraces which consist of basal limestone pebble conglomerate are about two feet in thickness and are made up of fossil fragments, well rounded pebbles of chalk, limestone and quartzite in a calcuim-carbonate cemented sand matrix (Loc. 1). Larger areas of outcrop of terrace deposits (as those near Waxahachie and South Prong Creeks in Plate I) are as much as two miles wide and in places up to thirty feet thick.

Relation to Urban Geology

Engineering problems related to drainage and shrink-swell of soils may be alleviated to some extent over areas of terrace deposits. Where terrace gravels are several feet thick below the foundations, swelling of clays is generally minimal (Burkett, 1965, p. 19). Designers of heavy foundations requiring piles should disregard lower shrink-swell effects created by the terraces and consider only data obtained from borings, knowledge of subsurface geologic conditions, and recent soil surveys in the area.

In the corridor terraces are typically veneered by Houston Black terrace soils. Soil maps aid in delineating the areal extent of these deposits and thus should be consulted prior to construction for spacing and location of boring localities and for analysis of potential areas of springs or seasonal perched water tables.

CRETACEOUS DEPOSITS

Taylor Marl

General Description

The Taylor Formation is divided into four members in Ellis and Hill Counties. In ascending order these are the lower Taylor Marl, the Wolf City Sand Member, the Pecan Gap Member, and the upper Marl (Beall, 1964, p. 10-11). The formation strikes approximately N 12°-16° E with an average dip of 91 feet per mile (Beall, 1964, p. 18).

Only the calcareous shale of the lower Marl Member occurs within the corridor. It occurs in normal sequence and in downfaulted blocks in fault contact with the Austin Chalk along the eastern border of the corridor (Fig. 2). From its contact with the Austin Formation, the Taylor Formation thickens eastward to 330 feet in McClain #1 in the north (well 2) to 345 feet in T. W. Christian #3 in the south (well 6).

Representative outcrops of the lower Taylor Marl occur at Locality 1 in the north and Localities 2 and 3 in the south (Plate I), though generally the member is concealed under black waxy clay soils, Quaternary terrace deposits, and Holocene alluvium. Geologic structure has little control over physiography in the Taylor Marl. Streams on the Taylor occupy mature valleys separated by broad, gently rounded divides.

The lower Taylor Marl is soft, incompetent, easily eroded, and maintains low rounded slopes ranging from one to ten degrees. North-facing slopes are generally two to five degrees steeper than south-facing slopes, apparently because of microclimatic differences. Rills and gullies in slopes of exposed Taylor Marl (Loc. 16) illustrate Taylor erodability (Fig. 3).

The lower Taylor Marl consists of fine-grained, uniformly laminated calcareous marine shale. The fresh, blocky shale displays conchoidal fractures but develops fissility upon weathering. Fresh exposures are bluish black or gray, which is similar in color to unweathered Austin Chalk. While similarities in unweathered color exist, lithology and bedding are sufficiently different to allow the Austin and Taylor to be distinguished. The weathered Taylor Marl is typically a darker gray and more fissile than the light-tan weathered chalk.

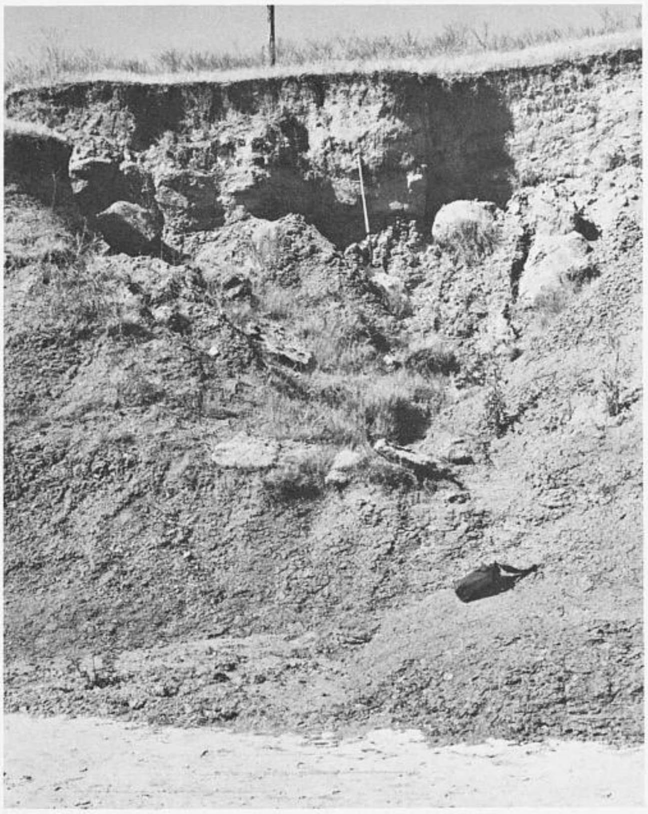

Fig. 2. Austin Chalk-Taylor Marl contact (Loc. 2, Plate I). Three distinct rock types are present: the white area at the bottom is the Austin Chalk (high bearing capacity), the gray area extending vertically to the top of the shovel is the Taylor Marl (low bearing capacity), and the gray and black stratified area above the shovel is alluvium (low to moderate bearing capacity). Note low slope stability of the Taylor compared to the partially cemented alluvial gravels.

Orange stains of limonite are common on weathered exposures of the lower Taylor Marl. They are alteration products of pyrite pigment and pyrite nodules found within the formation. Secondary gypsum is also common (Loc. 2) occurring as one to three inch seams along bedding and joint planes within the Taylor Marl, where weathering has penetrated.

Faults in the Taylor Marl were traced by alignments observed on air photos, by field observation, and by interpretation of surface drainage patterns and electric well logs (Plate I). The lower Taylor Marl is in fault contact with the Austin Chalk (Loc. 1) in grabens (Locs. 1, 3, 4, 5 and Plate I). Float blocks of vein calcite marked by slickensides (Loc. 2) are the principal reminders of fault movement within the lower Taylor Marl outcrop area. Because of thinner soil veneer and typically alternating beds of resistant and less resistant strata in the outcrop belt of Austin Chalk, structural alignments appearing on aerial photographs are more conspicuous there than in areas of outcropping Taylor Marl. However, it is probable that faulting and jointing are as common in the area of lower Taylor Marl outcrop as in the area of Austin Chalk outcrop (Williamson, 1967, p. 23).

Air-Photo Characteristics

Mapping of lower Taylor Marl on aerial photographs is facilitated by characteristic lighter gray to gray-brown soils of the Taylor Marl that are distinguishable from the dark gray to black and white soils of Austin Chalk.

Relation to Urban Geology

The principal factors in shale strength are related to degree of cementation (percentage $CaCO_3$), stratigraphic position relative to a more competent formation, jointing or faulting, climate, and topography of the outcrop area.

Fig. 3. Rill-wash in a clay pit near Ferris, Texas (Loc. 16), illustrating erodability of Taylor Marl on unvegetated slopes.

Jointing increases water infiltration in shale causing leaching of calcium carbonate. This increases the fissility and weakens the shear strength of the shale. Orange limonite stains along joints aid in their identification. Joint spacing averages 2 to 3 feet in outcrops of Taylor Marl in or adjacent to the corridor. In areas where sands and gravel terrace deposits overlay the Taylor Marl, this material may have entered these joints, keeping them permanently open (like french drains). This can have the effect of increasing the depth of weathering, and increasing the potential swell of the clay.

Structures placed on weathered Taylor Marl will tend to seal the surface, thus retarding water gain and loss through evaporation and preventing moisture increase from rainfall except near the edges of the structure. Differential volume changes can be expected between areas exposed to weather and those protected by structures. This effect will be pronounced on the southwest corner of the structure. Due to the sodium montmorillonitic clays typical of the lower Taylor Marl (Beall, 1964, p. 16-19), upon exposure to water and atmosphere, outcrop areas of lower Taylor Marl may exhibit surface rises of eight to ten inches (Font, 1969, p. 42) and swell index pressures from 5000 psf (pounds per square foot) to 20,000 psf at constant volume test values (Dobrovolny, 1963, p. A-63).

Clays should be treated through lime stabilization or other proven methods of clay treatment that control groundwater around the building site. If groundwater cannot be controlled, utilization of deep footings, piling, or vibroflotation methods should be investigated. In all cases, piling and foundation footings should always extend well below the tan to white weathered calcareous shale to unweathered blue-black shale.

Strength and stabilization characteristics of weathered Taylor Marl are related to clay mineralogy (Gillott, 1968, p. 154), therefore detailed soil mapping (Plate II, details A-E), soil profile descriptions, and identification of predominant clay minerals should be reviewed prior to application of remedial measures.

Vegetation can significantly affect moisture migration, erodability, and shrink-swell properties of the Taylor Marl, so the effect of its removal or addition should be carefully considered. New trees should typically be planted a distance equal to the mature height of the species away from the structure.

High montmorillonite content also causes the Taylor Marl to be of low permeability (10^{-8} cm/sec). Major infiltration for septic sewer systems will be through dessication cracks and joints in the shale until they become swollen shut. Large well planned drainage fields (greater than 200 linear feet) will be needed in the impermeable shales. Where population density is high and septic tanks are used, the Taylor soils will probably become contaminated and raw sewage will surface during excessively wet periods (Burkett, 1965, p. 23). Ponding occurs quite frequently in depressions in the Taylor following rains. Because of low permeability, areas where Taylor Marl crops out are excellent potential sanitary landfill sites (Plate IV).

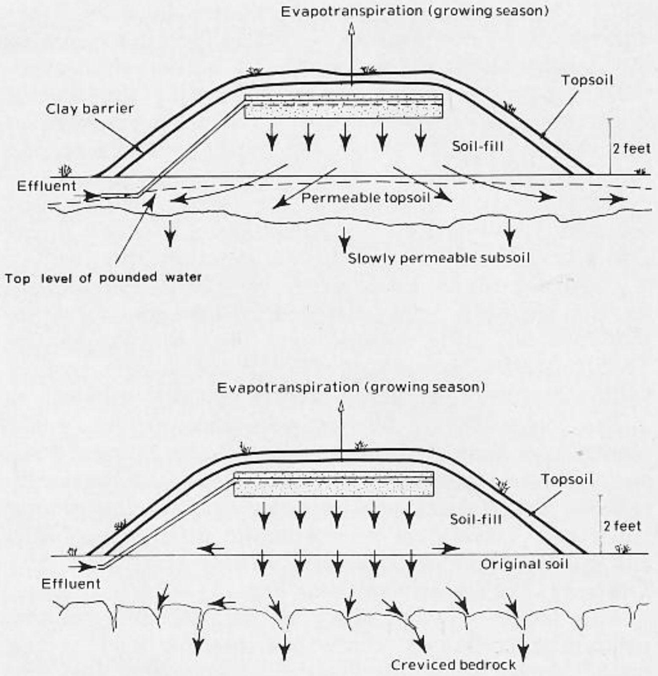

Fig. 4. Diagrammatic sketch showing a mound system for disposal of septic sewage effluent over slowly permeable soils and over creviced bedrock.

In reviewing septic tank performance one must look not only at the absorption of effluent, but also at the capacity of the system to remove fecal indicators and excess nutrients from the effluent. A typical family of four will produce an estimated 300 gallons of effluent per day containing 0.2 pounds of nitrogen and 0.025 pounds of phosphorus. This is 73 pounds of nitrogen and 9 pounds of phosphorus on a yearly basis (Bouma and others, 1972, p. 106). In Wisconsin, in areas of low infiltration, soils over impermeable bedrock such as the Taylor, mound systems are being investigated (Fig. 4). These systems divorce the treatment of wastes from the impermeable soils and bedrock.

Excavation of the lower Taylor Marl can be easily accomplished with light machinery during dry periods. When wet, the clays become plastic, sticky, and unmanageable. The shales, if stripped of their cover vegetation, are highly erodable (Fig. 3).

Following a rain, ponding and slumping of straight valley excavations often occur. If excavations must be left open for extended periods of time, drainage, moisture stabilization procedures, and shoring are recommended.

Excavation of an open cut typically produces a stress relaxation in the ground adjoining the slopes. In a stiff fissured clay (like the Taylor Marl), this process causes the joints to open; rain water invades the joints; and fragments between the joints swell, break up, and reduce the average shearing resistance on the potential surface of sliding, resulting in slope failure. It is not uncommon to decrease the shearing resistance of a stiff fissured clay (Taylor Marl) from one to two tons per square foot to 0.3 ton per square foot or less, adjacent to excavations (Paige, 1950, p. 96).

The Taylor Marl is a poor fill material due to its high montmorillonite content. If adequately stabilized and compacted, it will support low embankments and reasonably heavy loads (Font and Williamson, 1970, p.

14). Proper seating of foundations, pipes, or other underground structures in the Taylor is important due to the high potential shrink-swell. One of the major problems in operation of sanitary sewer systems in cities is infiltration and exfiltration of water into and out of sanitary sewer lines through cracks caused by shrink-swell. System efficiency can be reduced over 60 percent (Dallas Dept. of Water Utilities, personal communication, 1974) during rainy periods.

Slumping and slaking are common in weathered fissile shale. Slope angles greater than 18 degrees should be considered unstable in the Taylor. Among other factors, slope stability in excavations will be related to the strength of the clays, the slope of the cut, the depth of excavation, the depth to a firm stratum, and the length of time of excavation (Peck, Hanson, and Thornburn, 1974, p. 297). Excavation and construction practices on slopes, as well as practices that enhance the water content (add weight and reduce shear strength), are quite hazardous and should be tested through detailed slope analysis.

Due to increased infiltration rates along fault and joint planes, augumented weathering rates have produced thicker soil zones. Several closely spaced borings should be made to test depths to unweathered Taylor prior to construction. Corrosion rates will also be higher along these alignments and careful soil mapping should be performed before major pipeline construction.

The lower Taylor Marl typically supports predominantly grasses with only minor amounts of forbs and woody vegetation. When larger vegetation, such as cottonwood, is encountered, permeability, shrink-swell properties, and soil infiltration characteristics may be different than surrounding areas of Taylor outcrop. Extensive engineering tests and borings are advocated if buildings are planned for these areas to determine local engineering, soils, geological, and hydrological conditions.

AUSTIN CHALK

General Description

In central Texas the Austin Chalk is exposed in a band about one to seven miles wide along the crest of the White Rock escarpment. The Austin Chalk is part of a general homocline which strikes approximately N 10°-12° E and dips about 60 to 90 feet per mile to the east. In Dallas County, four distinct lithologic units are recognized in the Austin Formation (Dallas Petroleum Geologists, 1941, p. 43). In descending order these are the "upper" chalk, "middle" marl, "lower" chalk, and "basal" pebbly marl. Of these units, only the "upper" chalk, "middle" marl, and "lower" chalk are recognized as integral to the interpretation of geological problems within the corridor.

Besides minor inclusions of lower Taylor Marl in fault grabens along the eastern boundary of the corridor, and a four mile strip of Eagle Ford on the southwest extremity, the Austin Chalk is the dominant outcropping formation (Plate I).

East of the corridor, in the subsurface, the Austin is 425 feet thick in the north (Palmer #2, well 1, Plate IV) and 285 feet thick in the south (McDaniel #1, well 3, Plate IV).

The Austin Chalk is composed of alternating massive beds of blue-gray, white-weathering, marly limestone and dark gray, gray-weathering, shaly limestone. Because of percentage variations of chalk to shaly limestone in the different units in the Austin, various distinctive "White Rock topographies" are discernable from air photos. These differences are also visible in the field, in soil types, and in electric well logs in the area and are therefore integral to the interpretation of engineering problems within the area.

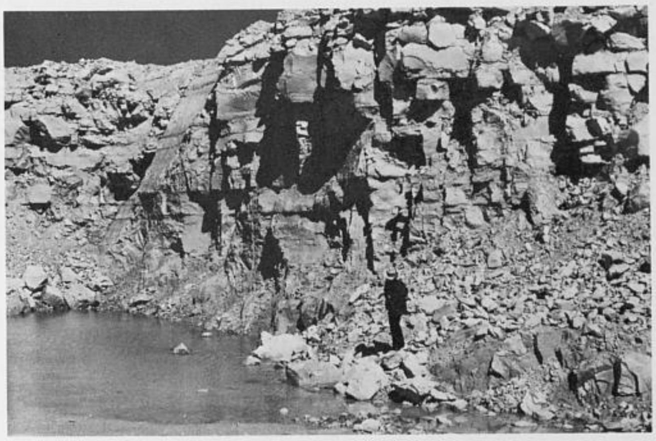

Fig. 5. Massive, dense "upper" Austin Chalk in quarry southeast of Waxahachie (Loc. 6). Note dominant joint patterns and spacing (two to five feet). Marl layers are deeply recessed and thin (five to 24 inches).

In the corridor, the "upper" chalk unit of the Austin Formation (Loc. 6, Plate I) consists of massive chalk beds one to five feet thick that alternate with thin calcareous shale beds that are seldom thicker than a foot (Fig. 5). The massive unweathered chalk is pale bluish-gray in color but weathers to a creamy white color. Calcareous shale beds are pale bluish-gray in color on fresh and weathered surfaces. Differential erosion of this member results in prominent resistant chalk beds forming ledges separated by deeply indented (5 to 12 inches) recesses of calcareous shale. Further weathering of the resistant chalk beds causes them to break down into small conchoidal chips of brittle white chalk. Larger beds may spall into thin sheets or plates producing rounded edges (Locs. 1, 7). While fresh outcrops appear massive, through time, thin widely-spaced clay seams are weathered out dividing the massive beds into smaller two to three foot beds.

Small (⅛-½ inch) pyrite concretions that weather to orange-brown limonite are found throughout the chalk and marl beds.

From an assumed maximum thickness of 180 feet in Dallas County (Dallas Petroleum Geologists, 1941), the "upper" unit is approximately 150 feet thick in Palmer #2 (well 1, Plate IV) in the north and absent east of Hillsboro, Texas, in McDaniel #1 (well 3, Plate IV) in the south indicating a southward truncation (thinning) of the unit (Plate IV).

The "middle" marl unit of the Austin Formation (Locs. 8, 17, Plate I) consists of interbedded chalky marl beds one to two feet thick that form resistant ledges between two-foot to four-foot beds of calcareous shale (Fig. 6). The fresh bluish-gray chalky marl beds weather to tan or buff. The softer marl units are bluish-gray on fresh and weathered surfaces. Outcrops disintegrate rapidly upon exposure to weathering; the

Fig. 6. The "middle" marl unit of the Austin Chalk (Loc. 17) displays one- to two-foot, crumbly chalk beds interbedded with thick two- to five-foot beds of calcareous shale. Rockfalls are common in this unit due to the undermining of less resistant marl beds and expansion of bentonite seams in marls. Joint patterns, while continuous vertically in the chalk beds, cannot be traced through the marl beds. Seepage will occur along chalk-marl interfaces after rains.

chalky marl typically breaks down into sub-conchoidal chips while the laminated marly unit disintegrates into a flaky clay.

Bentonite seams (1 to 2 inches thick) occur within the "middle" marl at several outcrops (Locs. 8, 17) and can be traced laterally for the length of the exposed section. Concretions of weathered pyrite (1 to 3 inches in diameter) form pockets of limonite throughout the more marly beds in this unit. The "middle" marl unit appears to contain more pyrite concretions than either the "lower" or "upper" chalk units.

Apparently because of bentonite seams and thicker clayey chalk (marl units), natural slopes within this unit average two to five degrees less than those in the "upper" and "lower" chalk units. Minor rockfalls are common along exposed cuts in streams. Natural slopes vary between one and three degrees in cultivated areas to forty degrees along streams.

The "middle" marl is about 140 feet thick in Palmer #2 (well 1, Plate IV) in the north and 115 feet thick in McDaniel #1 in the south (well 3, Plate IV).

Fig. 7. Weathered cut in the "lower" Austin Chalk northeast of Hillsboro, Texas (Loc. 12). Here chalk beds average two to three feet in thickness, while marl beds average ten inches to a foot. This outcrop is representative of the upper 50 to 60 feet of the "lower" Austin Chalk. Chalk beds become thicker and marl beds thinner in the lower 150 feet of this unit toward the Austin Chalk-Eagle Ford contact to the west. Note thin Eddy-Stephen series soils developed over this lower chalk.

On air photos, the "middle" marl is differentiated from the "upper" and "lower" chalk units by prominent white and dark mottling and lower overall relief. Most of the outcrop area is presently under cultivation. The contact between the "middle" marl and "upper" and "lower" chalk units appears to be gradational. Due to the gentle dip of the Austin (60 feet per mile) at no outcrop was the transition between the different members clearly seen. The "middle" marl is in apparent fault contact with the "upper" chalk at Locations 9 and 10. Boundaries between the different units have been drawn utilizing air photos, electric well logs, and representative outcrops of each member.

The "lower" chalk unit is lithologically similar to the upper unit as can be seen at Locality 18 (Fig. 7). Its relative distribution within the corridor is shown in Plate I.

Light gray unweathered chalks weather to buff or white and are interbedded with darker gray marl beds of equivalent thicknesses. Chalk beds range from ten inches to four feet in thickness and average two feet in thickness..

Bentonite beds (Loc. 11), aided by jointing, cause slumping of major blocks of chalk (Fig. 8). The upper 40 feet of the "lower" chalk is more thinly bedded (Loc. 12) than the basal 150-160 feet (Loc. 19). The "lower" chalk is differentiated from the "middle" marl by its greater percentage of chalk to calcareous shale.

On air photos, the "lower" chalk is easily discernable from the darker Eagle Ford Shale on the west. More prominent relief, entrenched drainage, and whiter overall color (due to thinner soil veneer, Plate II), make it distinguishable from the "middle" marl to the east.

The lower chalk unit is essentially the same thickness throughout the corridor (Plate IV).

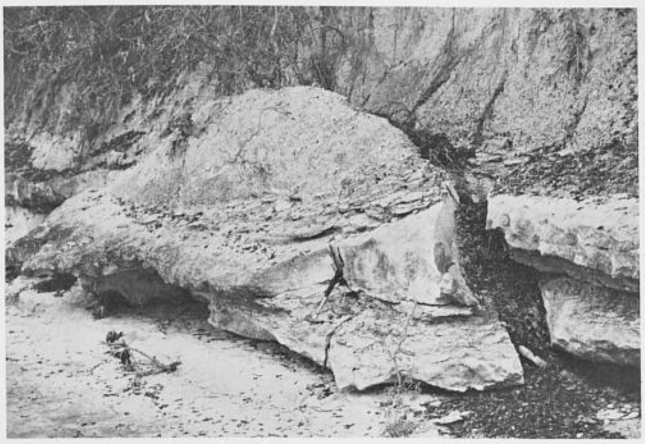

Fig. 8. Rockfalls are common in the "lower" Austin Chalk (Loc. 11), where bentonite seams are present. Here a major block of chalk has failed along joint planes. Knowledge of the local geologic section will aid in anticipating such problems.

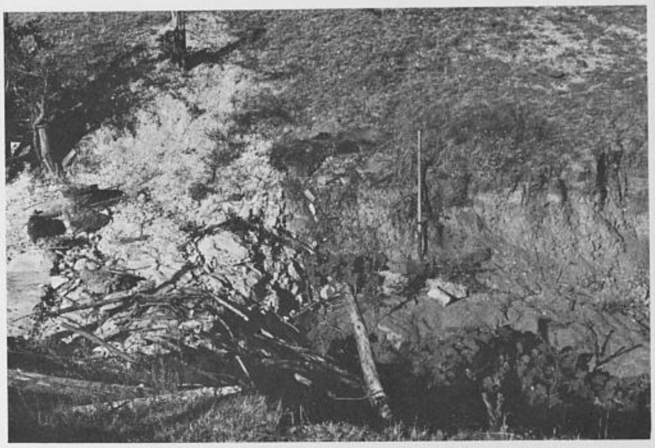

Fig. 9. Abrupt changes in rock type and engineering characteristics occur as a result of this graben in Italy, Texas (Loc. 4). The shovel is in the downthrown block of Taylor Marl; the white area to the left of the shovel is Austin Chalk. Away from stream courses or excavations, such grabens are not apparent, although they underlie the soil and are potentially damaging to construction.

Thicker soil development along more permeable fault and joint zones and analysis of drainage patterns aided in aerial photographic determination of major structural alignments within the Austin Formation. Alignments were field checked and correlated with available electric logs. The majority of faults found in the field corresponded to major alignments. Actual areas of known faulting are shown by solid lines (Plate I). Approximately five percent of all alignments plotted on air photos could be accurately field checked and substantiated as faults. The remainder were usually covered by alluvium and their structural significance could not be determined. The dominant direction of plotted structural alignments (Plate I) was N 10° to 15° E. In several grabens on the eastern edge of the corridor (Locs. 3, 4 and 5) lower Taylor Marl is in fault contact with the "upper" and "middle" Austin units. Other grabens immediately east of the study area near the Austin-Taylor contact strike N 40° to 50° E. The Austin Chalk and Taylor Marl in fault contact can be seen at Localities 1, 4, 5 (Fig. 9). An unconformable contact may be seen at Locality 2 (Plate I).

Joint systems occur throughout the study area, but most obviously in areas of Austin outcrop. Joint patterns, spacing of fractures and strike directions, did not vary noticeably within the varying lithologies of the Austin Formation. Joints were more evident within the lower and upper units than in the "middle" marl (due principally to weathering characteristics of the less resistant "middle" marl unit).

Although variations did exist in 30 measured outcrops, the dominant strike direction of joints was N 45° E. This correlates with measurements by Peabody (1958) in the Waxahachie quadrangle and Dooley (1960) in the Forreston quadrangle. Joints are perpendicular to bedding planes and generally spaced from two to five feet apart.

Major fault and joint trends (Plate I) suggest a probable northward extension of the Balcones fault system through the corridor. The structural map on the Woodbine Sand further suggests downfaulting to the east. Downfaulting to the west occurred in the northeastern part of the corridor (Locs. 9, 10, Plate I).

Air Photo Characteristics

The Austin-Eagle Ford contact is easily discernable by air photos or ground reconnaissance. On the ground, topographic relief of the north-south trending White Rock escarpment, conspicuous outcropping white chalk, and change from Eagle Ford mesquite to Austin Chalk post oak and juniper vegetation clearly mark the boundary on air photos. There is an abrupt change from uniformly mottled appearance of the Austin Formation to the light mottling of the Eagle Ford (Hayward, 1957, p. 27, 31).

The Austin Chalk-Taylor Marl contact is less easily identified on air photos due to heavy soil cover and complication due to faulting. Field reconnaissance is required to establish exact positions of formation boundaries. Approximate lines of contact can be established in air photos by the uniformity of color, low relief and dendritic drainage patterns of the Taylor (Hayward, 1957, p. 24). Soils were also useful in mapping Taylor Marl-filled grabens along the eastern edge of the corridor. Thinner Stephen-Eddy soils (Plate III), representative of the underlying Austin Chalk, aided in drawing the contact between the Austin and Taylor Formations.

Relation to Urban Geology

"Typical" bearing capacities for Austin Chalk (Plate IV) are most common in areas where the "upper" and "lower" members of the Austin crop out (Plate I). Due to the higher clay content (larger marl zones) and thinner chalk beds, lower bearing capacities are predicted for the "middle" marl.

In Austin Chalk, foundation problems will generally occur in areas where structures rest upon the weaker marl units, on the highly plastic soils of the Austin, and over expanding bentonitic clay seams.

Since the "middle" marl unit possesses all three of these less desirable engineering characteristics, it is hypothesized that construction will commonly be more hazardous and costly in areas where it crops out (Plate I).

Fig. 10. "Upper" Austin Chalk in fault contact with Taylor Marl in the spillway of Lake Waxahachie (Loc. 1). Changes in soils, slope stability, bearing capacities, and other engineering properties can occur quite abruptly as a result of faulting. Note Taylor Marl slumping immediately adjacent to the fault contact.

The shear strength of the Austin Chalk is quite high (Plate IV). Predictably lower measurements are possible due to local faulting and jointing which enhance weathering of the chalk. Lower bearing capacities and springs or seeps may be encountered in the lower chalk where old channel cuts are encountered. These areas can cause considerable water problems for extended periods after rains and will probably have to be sealed off or piped around the project.

Grabens along the eastern border of the corridor (Locs. 3, 4, 5) have resulted in the inclusion of "blocks" of Taylor Marl as much as one-fourth mile wide by one mile long, in areas where Austin Chalk normally would be expected to crop out. Engineering properties in these areas are vastly different from those typical of chalk and knowledge of local geology is necessary for proper construction.

Complex faulting within areas mapped as "upper," "middle," and "lower" Austin Chalk may cause some variation between inferred and actual boundaries (Plate I; Fig. 10). Detailed knowledge of local geology will correct this problem for individual construction sites.

Because of high shrink-swell and lower infiltration rates associated with bentonitic clays, knowledge of their position within the section is important for effective engineering design, e.g., bearing capacities, slope stability, and septic drainage systems. Since location and position of bentonitic zones may go unnoticed by standard cone penetrometer tests and small borings, knowledge of the local geologic section is necessary, particularly in areas where the "lower" and "middle" Austin Members crop out. Septic disposal systems are normally ineffective in these areas. While water readily enters joint and fracture systems within the Austin, swelling of bentonites may prevent further infiltration. If properly bedded in washed gravel, the chalk will normally dispose of reasonable quantities of fluids and drainage fields of adequate proportions can be installed on lots of 125-150 feet for private homes (Font and Williamson, 1970, p. 17). However, as a general assumption this is erroneous if bentonite seams are located at shallow depths beneath septic drainage systems. Seepage and flow along laterally continuous clay beds are pronounced after heavy rains. In areas of high-density housing where septic sewage systems are employed, pollution of streams is insured and ponded sewage on surface soils is common. Mounded septic systems (Fig. 4) should be investigated for use in this area.

Rock permeability in limestone is commonly due to open fissures and joints and not to the more uniformly distributed pores (Stagg and Zienkiewicz, 1969, p. 62). Major fault and fracture zones within the Austin (Plate I) can be expected to accept water readily and to conduct it like a pipeline, perhaps to surface as a "spring" at some other location.

The Austin Formation is the most difficult unit to excavate within the corridor. Because of its higher clay to chalk ratio, the "middle" marl is easier to excavate than the "upper" and "lower" chalk units. Blasting will be minimal in the "middle" unit.

"Fault and joint patterns may complicate excavation by serving as effective mechanical wave guides filtering and conducting seismic energy for considerable distances parallel to fracture systems" (Burkett, 1965, p. 25). Ripping of chalk beds is always facilitated when force is applied normal to the dominant strike direction of local joint systems.

By noting soil types (Plate II) depth to bedrock may be predicted within the Austin and major excavations planned accordingly. While shallow or deep excavations in the chalk require little or no shoring, excavations where thicker Houston Black or alluvial soils are encountered are subject to failure by slumping even after minor precipitation.

Seasonal seepage is also common within the Austin Chalk and pumping may be required for extended periods following major precipitation. Flow will be along the more clayey bedding planes in a down slope direction consistent with dominant joint trends.

The chalk members of the Austin Formation make excellent fill materials when properly sealed against moisture infiltration. Improper sealing will result in decomposition of the chalk and possible foundation settlement. Due to its higher clay content, the "middle" marl unit should be avoided for use as stable fill.

Slope angles of 45 degrees can be supported without shoring (Font, 1969) within the "lower" and "upper" chalk units of the Austin Formation. Minor rockfalls can be expected in areas where bentonites and thicker marl beds underlie chalk units as in the "middle" marl or in excavations where slope angles exceed 45 degrees. Near vertical road cuts in the "middle" marl member, while exhibiting negligible rock falls, did show abundant weathering and disintegration. Large talus deposits typically extended out from the base of the slope for several feet. Shrink-swell properties of the clays, undermining of the less resistant marl beds, and jointing combine to augment failure of the chalk beds. In planning major excavations, joint patterns should be observed prior to slope construction and considered in slope design.

Oversteepening or removal of vegetation from the Austin-Eagle Ford contact zone along the White Rock escarpment should be avoided (Fig. 11). Failure to heed this warning will often result in gravity slumping, creep, or massive slide failure of incompetent shale resulting in serious mass wasting of the escarpment face

(Plate I). Due to the thin soil cover in this area and steep slopes it will be extremely difficult to reestablish vegetation and further erosion and slumping is imminent.

Foundation failure attributable to soil properties can be avoided by building in areas where the bedrock is closer to the surface (e.g., areas where thinner Eddy, Stephen, or Brackett soils occur). General areal distribution and characteristics of these soils are interpreted in Plates II and III. Since soil types and associated depth to bedrock can vary rapidly within a small area (Plate II, details A-E), careful testing may enable builders to move construction sites short distances and hence avoid costly excavation and/or foundation construction.

Due to increased infiltration rates along structural alignments (faults), weathering rates have been augmented and thicker soils have developed (Fig. 10). These Austin-Houston Black series soils (Plate III) are highly corrosive and possess high shrink-swell properties.

Eagle Ford Group

General Description

The Eagle Ford Group consists largely of fissile black calcareous to noncalcareous clay, with thin flaggy limestone beds in the lower part. The group is approximately 200 feet thick in Hillsboro #17, thickening eastward to 310 feet in Penelope #1 (well 25).

In the corridor, the Eagle Ford Group may be divided into two units: the South Bosque and the underlying Lake Waco Formations (Adkins and Lozo, 1951, p. 120). The South Bosque Formation underlies the Austin Chalk and is exposed along the western edge of the Austin Chalk escarpment (Plate I, Locs. 14, 19). This formation supports a belt of rolling hills which grade westward into stringers of more resistant silty flagstones of the Lake Waco Formation, evident along the western edge of Hillsboro, Texas (Loc. 13).

Identification of the Austin-South Bosque contact in the field is facilitated by topographic expression, soil color, and change from mesquite of the South Bosque to post oak and cedar elms growing on the "lower" Austin Chalk along the escarpment edge.

Few good exposures of Eagle Ford shales occur within the corridor for the plastic shales are generally concealed under thick black waxy clay soils, recent alluvium, and overwash from the more conspicuous overlying chalk.

Upon wetting, exposed shale will disintegrate into a highly unstable plastic mass consisting of a clay mud enclosing small chips of shale. Mass wasting by slumping and erosion is common especially on uncovered slopes (Loc. 19). Due to the regular slumping, uncovered shale banks adjacent to river systems tend to waste rapidly and maintain steep but unstable slopes. Naturally vegetated slopes within the Eagle Ford Group range from 0 to 15 degrees with north-facing slopes averaging a few degrees steeper than south-facing slopes.

On fresh exposures (Loc. 15), the South Bosque marine shale consists of a dark, steel gray, blocky shale with pyrite-rich seams on many of the bedding surfaces. Weathered exposures are commonly tan to brown in color due principally to the weathering of pyrite pigments to limonite.

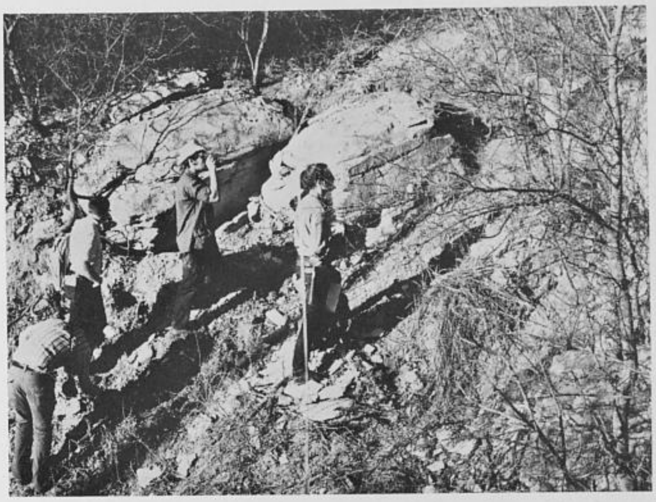

Fig. 11. Austin Chalk-Eagle Ford contact (Loc. 19). Large slump blocks of "lower" Austin Chalk are typical along the Austin Chalk-Eagle Ford escarpment. Stripping of vegetation from the escarpment face will augment mass wasting of the Eagle Ford Shale, and cause renewed slumping. Mesquite trees typically line the Eagle Ford along the face of the escarpment while post and Shumard oak and juniper are common along the Austin Chalk ridge.

The upper part (top 30-50 feet) of the South Bosque shale consists of plastic, soapy, noncalcareous (2 to 8 percent $CaCO_3$) shales rich in bentonite. The lower portion, in gradational contact with the Lake Waco Formation (Loc. 13), consists predominantly of gray gritty calcareous shales (35 to 50 percent $CaCO_3$) interbedded with occasional silty gray limestone flags 5 to 6 inches thick. Transition from low carbonate to high carbonate clays occurs vertically within a few feet (Burkett, 1965, p. 26) (Plate I). Creamy white to tan bentonite seams two to five inches in thickness are common throughout the Eagle Ford Group.

Alignments are visible on air photographs in outcrop areas of Eagle Ford Shale. These consist principally of rectangular surface drainage patterns and prominent linear color changes. These are not generally confirmed as faults by field observations and electric well log data though they are often colinear with fault alignments in Austin Chalk outcrop areas. Alignments on areal photographs tend to suggest a northern extension of the Balcones system.

Air Photo Characteristics

In air photos, the rolling mottled gray hills of the South Bosque Shale are easily distinguishable from the whiter Austin Chalk to the east. Light gray patches along the broad bench just west of Hillsboro indicate the approximate position of outcropping limestone flags of the gradational South Bosque-Lake Waco contact.

Relation to Urban Geology

Engineering problems vary with topographic and stratigraphic position within the Eagle Ford Group. Knowledge of the geologic section is therefore helpful to successful construction practices. At the surface, the bearing capacity of the shale (Plate IV) can be extremely low (1 to 2 tons per square foot), but increases with depth due to increased lateral confining pressure and natural clay stabilization below weathered soil zones. Due to the abrupt transition from low to high calcium carbonate percentages in the Eagle Ford Group, bearing capacities may increase and swelling decrease within a few feet as one moves westward from the Austin escarpment toward the more calcareous fissile Lake Waco Formation (Plate I). Presence of thin limestone beds as well as bentonite seams is difficult to determine from ordinary borings. Knowledge of the geologic section and detailed on-site inspection should precede construction. Stringers of apparently stable limestone may occur over bentonite seams two to five inches thick. Location of these seams is especially critical in design of large foundations where stresses depend on uniformity of subsurface support rather than on soil strength. In most cases, extensive on-site borings should be made to disclose deeper plastic shale layers rich in bentonite.

The Eagle Ford Group is a montmorillonitic compaction shale and is subject to plastic deformation as well as uplift pressures greater than 28,000 lbs./ft.^{2} (Trefethen, 1959, p. 116).

The Eagle Ford Group may fail by flow under large foundations. Samples of this shale are stable when dry, but readily flow and disintegrate upon wetting. In all cases, foundations should be supported by piles, piers, or footings which rest upon unweathered dark blue-black Eagle Ford Shale. To insure maximum support by transferring loads to more massive sections of the formation, footings should be parallel to bedding and distant from hill slopes. Natural hillslopes should be disturbed as little as possible during construction to preserve natural drainage, slope stability, and protective vegetative cover.

Due to the high shrink-swell properties of the Eagle Ford Group and its soils, groundwater control or clay stabilization procedures should be investigated in areas where pier and beam type foundations are not used. Differential volume changes of several inches are possible between exposed and unexposed soil areas. Bentonite clays may swell as much as 1600 percent on prolonged soaking (Trefethen, 1959, p. 116). Foundation excavations and boreholes should be covered or filled immediately before infiltration causes differential swelling and/or settling.

Infiltration rates decrease shortly after wetting due to the expansion of montmorillonite clay within the Eagle Ford Group. Sewage systems, large drainage fields (200 linear feet or greater), will be required. Even with extensive fields, during extended wet periods, sewage may find its way to the surface, polluting streams and land surfaces. Drainage fields should be located topographically lower than foundations to avoid changing the water content of the high shrink-swell clay. Mound systems as advocated in the area of outcropping Taylor Marl should be investigated in this area.

Due to the low permeability (10^{-8} cm/sec) and easy excavation, outcrop areas of Eagle Ford Shale are ideal for sanitary landfill operations (Plate III).

Shallow excavations within the Eagle Ford Group are normally stable except for minor controllable slumping when dry. Wetting of the plastic shale causes severe slumping and ponding in lower areas. Limestone flags within the lower South Bosque Formation may cause minor excavation problems. These flags are usually not more than four to six inches thick and in large excavations are easily rippable. Shoring is needed in deep excavations within the Eagle Ford. Excavation during wet seasons, when slumping and mass wasting are common and the plastic shales become sticky and unmanageable, will be more costly. Due to the loss of cohesion upon wetting, shearing strength and bearing capacity are lessened (Plate IV), often causing heavy machinery to lose traction.

The Eagle Ford Shale is poor fill material due to its high montmorillonite content and high corrosion potential. Fill will typically have three-fourths the bearing capacity of the unweathered shale even when properly compacted. Backfill with materials such as the Austin Chalk should be used around foundations. Such fill should be effectively sealed and covered to prevent piping of moisture under the foundation and decomposition of the pure chalk.

Slope angles of 18 degrees or less and the original vegetation cover should be maintained whenever possible. This is especially imperative along the Austin escarpment where slumping of chalk blocks is common. Natural slope stability within the Eagle Ford Group seems to be related to moisture content, percentage of $CaCO_3$, slope height, and vegetation. For fine textured shale, no minimum angle of repose exists. Minimum effective slope angles may be estimated by observation of undisturbed natural slopes in the same stratigraphic interval in the immediate vicinity (Trefethen, 1959, p. 411).

Removal of vegetation will increase erosion of the exposed clay and increase the swelling potential of the clay by increasing water content. Established root systems that bind the soil and a continuous cloak of vegetation that reduces runoff are the best means of protecting slopes against erosion and failure. Grass cover prevents drying of the clay surface and formation of shrinkage cracks, thus limiting major infiltration. Soil moisture which adds weight to slopes is limited to a depth of about eight feet in grassy areas (Mencl and Zaruba, 1969, p. 148). Confining the toe of the slope to prevent slippage and drainage of gravitational water out of the slope are other remedial methods which can be employed for Eagle Ford (or Taylor Marl) slopes.

Retaining walls should be used only for low embankments supporting clayey soils to prevent loosening of toe areas. Building of large retaining walls strong enough to confine the enormous pressures of swelling is uneconomical (Mencl and Zaruba, 1969, p. 148).

Due to increased infiltration rates along faults and joints, weathering is augmented and deeper soils develop. Closely spaced penetrometer tests and borings are recommended before major foundation construction, particularly along visible structural alignments (Plate I) where faulting or jointing is present. Sand and terrace gravels will fill in shrinkage cracks within the shale, and keep them open for longer periods of time. Depth to unweathered shale in these areas will be increased.

Soil descriptions are important in determining shrink-swell properties, vegetation capacities, landscaping, and minimum depths to contrasting Eagle Ford Shale bedrock (Plate II).

SOILS

GENERAL SOILS INFORMATION

Eagle Ford Shale, Austin Chalk and Taylor Marl alluvial sediments have furnished the bulk of the soil solids in the corridor (Fig. 12). Through weathering processes and time, these materials have contributed to the textural quality and original mineral mixture of the soils. Plate I shows major areas of outcrop of the formations. Plate IV gives their relative mineralogical composition.

The organic matter present in the soil is a product of active plant and animal decay. Throughout the two county area, the Blackland Prairie grasses have had a dominant influence on the soils. Where undisturbed by overgrazing and clean tilling practices, they have stabilized and protected the upper part of the soil while actively aiding in the distribution of mineral matter throughout the deeper zones.

The organic and mineral components of mature soil are in equilibrium with climate and relief. The climate of the two county area is classed as subhumid continental. Rainfall is seasonal, producing both wet and dry periods. Leaching of the soils occurs in areas where heavy clays are present. During a heavy rain, following an extended dry period, rain water is able to move through the desiccation cracks and permeate the lower soil zones. This process is short lived for the cracks soon become swollen shut due to the expansion of the clays. Desiccation cracks also hasten erosion on slopes. During periods of intense rainfall, cracks may easily lead to gullying, resulting in high runoff and erosion of clay soils. During most of the year, rainfall is adequate to cause leaching of the shallower soils. Winters in Texas are not severe enough to be considered significant in soil genesis.

Relief has influenced soil drainage, runoff, horizon thickness, and concentration of chemically active solutions. Slopes of more than one to two percent, typical of the lower and upper units of the Austin Chalk, result in erosion of barren areas. Water is consequently lost and shallow droughty soils develop.

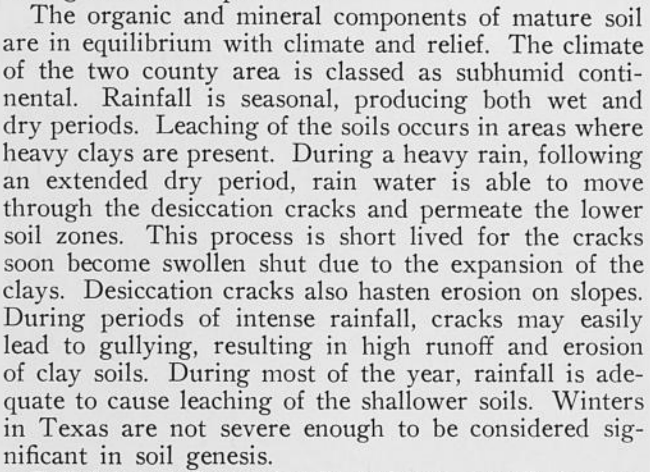

Fig. 12. Relation between geology and topography in the growth corridor. Note that steeper faces are most often supported by resistant chalk overlying easily eroded shales. Quaternary terrace deposits are stream gravels and sands deposited during an earlier era.

Slope orientation is another important variable. West-facing and south-facing slopes are generally less steep, and have more hours of sunlight than those facing north or east. This tends to produce deeper, drier soils and higher soil temperatures on south-facing and west-facing slopes.

Because of their differing individual properties, different parent materials produce distinct profiles related to original texture, slope, and groundwater conditions. Through time, downward migration of soluble salts, fine-grained clay minerals, and other colloids, leads to recognizable, vertically separable, composition and fabric divisions within a soil (Fig. 13). The soil profile will recur at comparable positions of slope, topography, and drainage, within the outcrop area of a particular rock types, thus establishing a mappable pattern.

Soils having similar profiles, color, structure, internal drainage conditions, range in relief, and natural drainage conditions are termed soil series. Figures 14 through 16 show general relationships between soil series and slope and bedrock within the corridor.

Once the characteristics and construction problems are known for a particular soil series, they remain approximately the same wherever that series is mapped (American Soc. for Testing Materials, 1951, p. 55). General soil series properties are related to parent material (Fig. 17). The dotted line denotes the boundary between soil characteristics and the specific soil series. For example, soil series such as the Austin and Altoga in the vertical column on the left side of the chart have been developed from the Austin Chalk and are typically well drained, high carbonate soils. The Houston Black soils share properties of both sides of the dashed line in Figure 17. While Houston Black soils are clayey,

The solum	Horizons of maximum biological activity of eluviation (removal of materials dissolved or suspended in water), or both.	01	Loose leaves and organic debris, undecomposed.
		02	Organic debris partially decomposed.
		A1	A dark-colored horizon with a high content of organic matter mixed with mineral matter.
		A2	A light-colored horizon of maximum eluviation. Prominent in Podzolic soils; faintly developed or absent in Chermozemic soils.
		A3	Transitional to B, but more like A than B. Sometimes absent.
	Horizons of illuviation of accumulation (of suspended material from A) or maximum clay accumulation or of blocky or prismatic structure or both.	B1	Transitional to B, but more like B than A. Sometimes absent.*
		B2t	Maximum accumulation of silicate clay minerals or of iron and organic matter; maximum development of blocky or prismatic structure; or both.
		B3	Transitional to C
	The partially weathered material; absent in some profiles, i.e. where solum is developed to the R horizon.	Cg C	Horizon Cg for intensely gleyed horizon, as in Hydromorphic soils. Gleyed horizon may occur in any major horizon.
		Cca Ccs	Horizons Cca and Ccs are layers of accumulated calcium carbonate and calcium sulphate found in some soils.
	Any stratum underneath the soil, such as hard rock or layers of clay or sand, that are not parent material but will have some significance to the overlying soil.	R or IIC	

*Many soils in this survey area lack B horizons and have, instead, horizons that are transitional from the A1 horizon to the C horizon, which are designated as AC horizons. The plowed surface horizon is designated as an Ap horizon.

Fig. 13. Hypothetical soil profile showing soil zonation and physical characteristics of the various zones. *Adapted from* Soil Handbook for Soil Survey of Metropolitan Area, San Antonio, Texas, USDA, Soil Conservation Service, 1964, p. 134.

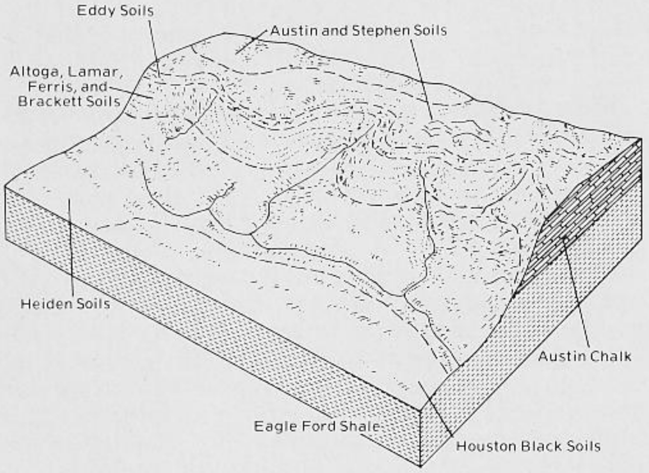

Fig. 14.

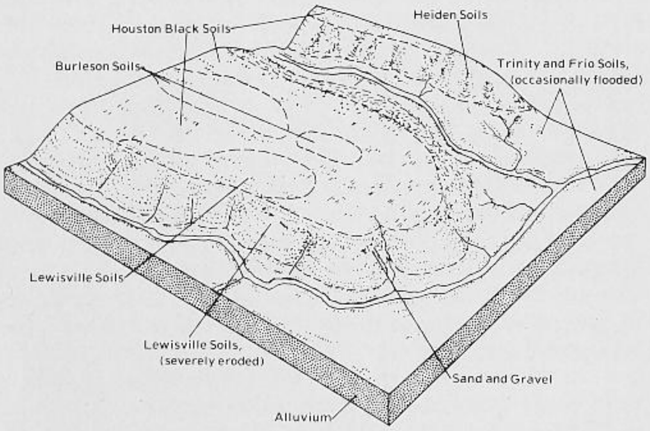

Fig. 15.

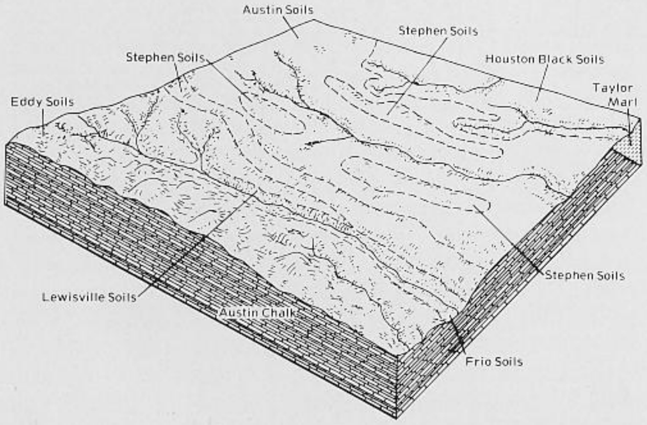

Fig. 16.

Figs. 14-16. Block diagrams showing relationships among geology, topography, and soils in the Interstate Highway 35 growth corridor. *Adapted from* Soil Conservation Service, 1964.

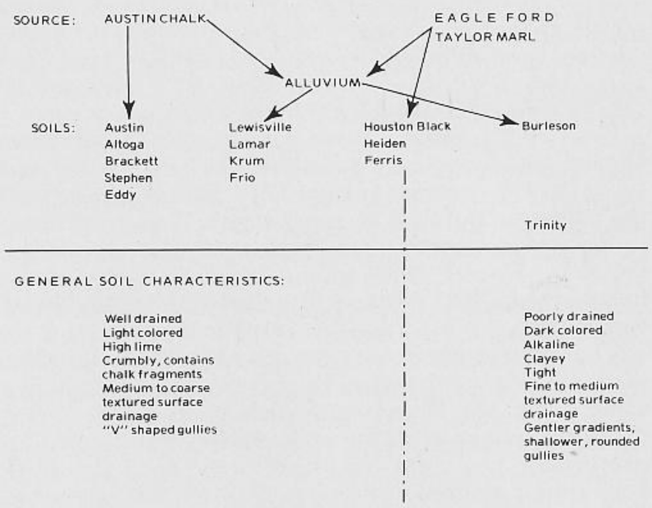

Fig. 17. Soil-bedrock relationships, Interstate Highway 35 growth corridor.

Fig. 18. Aerial photograph of the corridor about five miles south of Waxahachie, Texas (gas pipeline transects area from upper left to lower center). Whiter areas are thinner Eddy-Stephen and Brackett soils. Gray areas are Austin series soils. Black areas are Houston Black soils.

Fig. 19. Low slope stability in vertical walled excavations is indicated in this photograph of the Houston Black clay. Major slumping did not occur until after a rain. The whiter area toward the top of the photograph is an Austin soil and demonstrates the rapid soil changes possible within similar rock types.

tight, and poorly permeable, the Ferris soil is a moderately permeable clay loam.

On a larger scale, recurring drainage and topographic patterns over similar rock types permit mapping of groups of soil series which commonly occur together. These recognizable patterns of component soil series are termed soil associations and are the basic mapping units utilized in land-use recommendations in this study.

SOIL INTERPRETATION FOR SPECIFIC USES

Plate II shows the geographic distribution of soil associations common to the corridor. Mapped units show the geographic ranges of specific soil series which comprise each association. Plate III describes the soil associations so as to allow predictions of problems to be expected as well as to allow recommendations of "most effective" land utilization within each mapped area shown on Plate II.

Due to changes in slope, drainage, and parent material, soil types and engineering properties can change quite rapidly within a small area (Plate II details A-E and Fig. 18). While regional interpretations of land-use capabilities are possible using the mapped associations, scales utilized in Plate II, (1:62,500) as well as in details A-E (1:20,000) of Plate II, are not adequate for specific site engineering. Additional sampling and testing on a much larger scale (1:10,000-1:5,000) are necessary.

Most soils indigenous to the Blackland Prairie are clayey in texture (A-7-6, CH) with two dominant horizons: "A" and "C," and possess the same engineering properties: high corrosion, high shrink-swell moderate to slow permeability, and comparatively good agricultural productivity.

Slopes of eight to 20+ degrees are particularly hazardous to construction practices along the Austin-Eagle Ford escarpment. Detail C, Plate II, illustrates the general relationship of soil types to slope along river systems within the corridor. Along Chambers Creek, north-facing slopes (generally 3 to 20 percent) have thinner soils such as Eddy, Stephen and Brackett, while the more gentle zero to two percent south-facing slopes have deeper soils, such as Burleson, Houston Black, Krum, and Lewisville. Most gravel deposits in the area are found on the north sides of the present stream systems under deeper Lewisville alluvial soils. Gravel deposits occur under 80 percent of the area mapped as Lewisville soil (Soil Conservation Service, 1964, p. 66).

While thinner soils along north-facing slopes may be acceptable construction sites, deeper clayey soils on south-facing slopes along major stream systems will present problems related to high shrink-swell (Fig. 19) and seasonally high water tables (depending on proximity to area streams). Hazards and limitations of soil series common to specific associations are shown in Plate III.

Soil depths to contrasting materials have been illustrated in Plate II. Depth information is useful in prediction of probable foundation conditions, drainage, excavation, and infiltration properties. Plate II shows that major areas of minimum soil depths are found on the west side of the corridor in the northwest corner of the area, in the southwest of the corridor immediately adjacent to the Austin-Eagle Ford escarpment, and on the south side of major stream systems which dissect the area.

Prior to construction, soil mapping and associated borings at scales of 1:10,000 or larger are advised. Location of thinner Stephen, Eddy, and Brackett soils which occur within the deeper Houston Black-Austin associations may alleviate costly foundation construction due to expansion. However, lawn maintenance and utility installation may be more costly where these thinner soils are found.

Control of surface flow and erosion in cultivated areas of thick clayey soils (Plate II) is particularly difficult because of high clay content and desiccation cracks. Crop rotation, strip farming, and use of terraces should be employed in these areas to reduce processes to acceptable levels. Crop rotation in Temple, Texas, reduced average runoff by one third that of a comparable test plot with one continuous crop (corn) and erosion was reduced by 80 percent when oats was used as the cover crop (Colman, 1958, p. 243).

SOILS-GEOLOGY CORRELATIONS DESIGN GROUPS

Regional planners should anticipate land-use restrictions and limitations based on relationships among soils, geology and physiography.

Plates V and VI summarize geologic and soil characteristics for the corridor. Plate VI is based on a synthesis of available geologic and soils information in the corridor. This map acquires the advantage of the detail that is routinely achieved in soil maps while at the same time retains the dimensions of depth from the geologic studies.

While information regarding soils (Plates II, III) and geology (Plates I, IV) can be obtained for specific areas, the basic interpretive map (Plate VI) and design considerations (Plate V) should give an appreciation of the significant control elements of the physical environment, and suggest the detail required in sampling for specific purposes.

DESIGN CONSIDERATIONS: CONSTRUCTION ROCK, GRAVEL DEPOSITS, AND SANITARY LANDFILLS

Integral to successful and economical land-use planning is the location of high grade construction rock, sand and gravel resources, and areas for sanitary waste disposal. A deposit of sand, gravel, or construction material is a valuable asset when within short hauling distances of the center of consumption. These resources are stationary entities; they cannot be relocated by legislation. Problems associated with waste disposal in the corridor are illustrated in Plate IV.

CONSTRUCTION ROCK

The Edwards Limestone is one of the higher purity limestones in Texas, and is also generally well suited for aggregate and other constructional use (Fisher, Rodda, Payne, and Schofield, 1966, p. 2).

Lower Cretaceous limestones crop out along the Johnson-Hood County line and the Hill-Bosque County line. Reserves are approximately fifteen (air) miles from Hillsboro in the south of the corridor to forty-five miles from Waxahachie in the north.

Reserves (in short tons) of the Edwards and associated formations are shown below in Table 1.

TABLE 1

Total Limestone (tonnage)	Ls. (5 air-line miles of railroad)	High Calcium ls. within 5 air miles of railroad	Tonnage of high Ca Ls. 97%
Hill Co.			
0.7	0.66	Not determined	Not determined
Johnson Co.			
1.12	0.39	0.21	0.64

Adapted from Fisher, Rodda, Payne, Schofield, 1966, p. 18.

Characteristics of the Austin Chalk for construction fill material are shown in Plate IV. Outcrop areas of lower and upper chalk (rock type recommended for quarry operations) are shown on Plate I.

GRAVEL

Gravel occurs in localized pockets in close proximity to present streams. Most pits do not exceed a few acres in size. Gravel consists of rounded chalk pebbles in a matrix of yellow clay with lenses of chalk gravel. Chalk pebbles are fairly well rounded. Small amounts of quartz pebbles are often found mixed with chalk pebbles. In many older abandoned pits willows, briers, and grapevines are growing. Springs and seeps are common in these areas.

SANITARY LANDFILLS: WASTE DISPOSAL IN THE GROWTH CORRIDOR

The most satisfactory economic means of disposing of solid municipal wastes (excluding large volumes of industrial wastes) is in sanitary landfills (Flawn, Turk, and Leach, 1970). The primary objective of landfill operations is to isolate the fill from groundwater systems and eliminate pollution. Landfill operation sites must be based on detailed studies of such factors as topography, depth of soil cover, and geologic anomalies (e.g., faults, fracture zones). Preferred areas are broad flat upland areas away from major tributaries in impermeable formations such as the Taylor Marl and the Eagle Ford Group.

Fills should be placed below the soil zone except in special cases where deep impermeable clay soils are developed in ideal topographic positions. Water movement will normally be slow within the saturated Taylor and Eagle Ford clays and contaminants will usually be filtered or fixed closely to the fill site by ion exchange. The primary concern is to prevent surface runoff from traversing the fill and entering the landfill site as runoff. Therefore, daily accumulations of garbage should be compacted to reduce infiltration and chemical activity in the fill.

In the area of Austin Chalk outcrop, special engineering to protect the site is necessary. Impermeable clay layers should be used to line the fill site and to cover it. Subsurface barriers to movement of leachate should be constructed. Where gases and leachates are thus impounded, they can be diverted to collection points for treatment. Use of abandoned sand and gravel pits for landfill sites is poor practice without proper engineering and site monitoring. If these are used, impermeable clay liners are essential to protect streams and groundwater.

Building over old landfill areas may be hazardous due to stability and shrink-swell changes caused by effluent or leachate's reaction with clays. Sites should be examined prior to construction to determine newly acquired physical properties. Long history of production of effluents and leachates (4-5 years) should also be considered before building operations which may cause consolidation resulting in flow or surfacing of these fluids (Flawn, Turk, Leach, 1970).

HYDROLOGY

INTRODUCTION

The basic paradox of urbanization is that it causes an increased demand for municipal, industrial, and recreation water, while at the same time it causes a decrease in locally generated groundwater (Savini and Kammerer, 1961). This is attributed to "roofing over" of recharge areas, moisture holding soils, and small streams. Dominant hydrologic effects which can be expected with increased urbanization of the corridor are illustrated in Table 2.

Need for documentation of magnitudes of present water usage, aquifer capabilities, water quality, and flooding potentials of streams is necessary for future land-use planning as well as for proper utilization of current resources.

TABLE 2. HYDROLOGIC EFFECTS OF LAND AND WATER USE

CHANGE IN LAND OR WATER USE	HYDROLOGIC EFFECT
Removal of trees or vegetation; construction of scattered city-type houses and limited water and sewage facilities.	Decrease in transpiration and increase in storm flow; increased sedimentation of streams.
Drilling of wells; construction of septic tanks and sanitary drains.	Some lowering of water table; some increase in soil moisture leading to possible waterlogging of land and contamination of nearby wells or streams from overloaded sanitary drain systems.
Bulldozing of land for mass housing; some topsoil removed; farm ponds filled in.	Acclerated land erosion, (sediment yield from rural basins was about .77 percent as much as from urbanized basins, Davis and Yorke, 1968, p. 113), stream sedimentation and aggradation; increased flood flows; elimination of smaller streams.
Mass construction of houses; paving of streets; building of culverts.	Decreased infiltration resulting in increased flood flows, (flood peaks can increase from 4 to 6 times that of an undeveloped watershed and the 100 year flood is about 2 to 3 times greater in an urbanized watershed, Anderson and Kapinos, 1968, p. 156), and lowered ground-water levels; occasional flooding at channel constrictions on remaining streams.
Discontinued use and abandonment of some shallow wells; diversion of nearby streams for public water supply; untreated or inadequately treated sewage discharged into streams or disposal wells.	Decrease in runoff between points of diversion and disposal; pollution of streams or wells; death of fish or other aquatic life; inferior quality of water available for supply and recreation at downstream populated areas.

Adapted from Savini and Kammerer, 1961, p. 6.

SURFACE WATER

The corridor, from Hillsboro northward, is included in the drainage basin of the Trinity River. Drainage is principally east-southeast through an extensive network of predominantly intermittent streams. Only Red Oak, Waxahachie, North Prong and South Prong, Chambers and Richland Creeks are perennial (Thompson, 1967, p. 6).

Since the streams flow principally on the Austin Formation, drainage patterns are affected by different rock types of the three members. The more massive "upper" and "lower" chalk units tend to display almost rectangular drainage with sharply incised valleys and conspicuous slightly rounded divides. Drainage on the less resistant "middle" marl tends to be dendritic and lacks obvious structural control. Divides and overall relief are less accented in the outcrop area of middle Austin (Appendix II).

Average annual precipitation in the area is 35 inches. About 15 percent of precipitation (or five inches per year) appears as runoff in the corridor (Leifeste and Hughes, 1967, p. 4). Urbanization of a watershed will increase runoff and produce floods with peak discharges from 100 to 300 percent greater than runoff in equivalent undeveloped watersheds (Epsey, Morgan, and Masch, 1966, p. 89).

Seasonal rainfall and storm intensity, as well as temperature, slope, soils, vegetation, and permeability of the bedrock, affect the amount and distribution of runoff. Rates will vary in the corridor from periods of no flow during late summer and early winter to peak flows during periods of maximum precipitation, February through May. Richland and Chambers Creeks show substantial discharge during the spring months.

To make uneven streamflow available in dependable quantities, storage reservoirs have been constructed. The Waxahachie reservoir, with a capacity of 13,000 acre feet, annually yields 3600 acre feet of water to the town of Waxahachie. This, supplemented with 1500 acre feet supplied yearly by groundwater resources, will serve the total needs of metropolitan Waxahachie until 1980 (Vandertulip, 1961, p. 74-5). Additional smaller reservoirs of a few acres or less have been constructed in the area along minor tributaries and supply rural and livestock water needs.

Present water quality measurements of major streams show the hard, calcium bicarbonate water to be suitable for most municipal, industrial, and agricultural purposes. Analyses (Leifeste and Hughes, 1967) indicate an average of 100 to 250 ppm dissolved solids, 120 to 200 ppm hardness as $CaCO_3$, and 0 to 50 ppm chloride concentration.

GROUNDWATER

About 3700 feet of Cretaceous to Holocene limestone, sandstone, siltstone, and some anhydrite contains aquifers. These formations generally strike north-northeast and dip east-southeast from 50 to 100 feet per mile.

Recharge of aquifers is predominantly through precipitation over areas where aquifers crop out west of the corridor. Even though sandy soils and vegetation in the recharge area aid in retaining rainfall and enhancing infiltration, only 0.5 inch of precipitation per year (out of a yearly average precipitation of 35 inches) is absorbed in undisturbed parts of the outcrop as recharge (Thompson, 1967, p. 30).

After initial infiltration, water movement is downward through the zone of aeration to the zone of saturation. In the zone of saturation, water movement depends principally on aquifer rock type and the existing hydraulic gradient. Movement, while rarely uniform, usually has a nearly horizontal component in the direction of decreasing pressure. This is locally affected by pumping operations. Water in the Woodbine Formation tends to move east-southeast at an estimated

TABLE 3. GROUNDWATER USAGE IN CORRIDOR (1964)

Location or Cause of Discharge:	Acre-feet	Million-gallons-daily
Livestock (Ellis Co.)	660	.59
Rural population (Ellis Co.)	1100	.98
City of Waxahachie (Ellis Co.)	1574	1.40
City of Italy (Ellis Co.)	.74	.07
City of Milford (Ellis Co.)	.65	.06
City of Hillsboro (Hill Co. in 1967)	915	—
Total	4388	

TABLE 4. TOTAL GROUNDWATER WITHDRAWN FROM SELECTED AQUIFERS

ELLIS COUNTY IN 1964

Aquifer	Acre-feet	Percentage of total amount withdrawn
Woodbine	3500	65
Hosston	1840	34
Alluvium	40	.8
Paluxy	8	.2

HILL COUNTY IN 1964

Aquifer	Acre-feet
Hosston (in City of Hillsboro)	915

rate of 10 to 40 feet a year. The corridor lies approximately 14 miles from the aquifer recharge area. It would take water approximately 1800 to 7300 years to make this journey. Water within the Hosston appears to move eastward, as indicated by chemical isopleths plotted by Henningsen (1962). Most natural and artificial discharge within the corridor causes an underflow in major aquifers to the east and north.

The value of aquifers as a source of groundwater is directly related to their permeability and water storage capacity. Coefficients of transmissibility, permeability, and storage are measurements of the hydraulic characteristics of the aquifer. Values of these parameters are averages from several pumping tests conducted near the corridor. Variation from these measurements will occur due to lensing and interbedding of sand and clay, variations in aquifer thickness, variations in sorting, deformation, and cementation of sand; and differences in methods and duration of pumping tests (Peckham and others, 1963, p. 36). Coefficients determined from pumping tests can be used to predict the decline in pumping levels that may be expected from increases in pumpage from existing wells or the decline expected in existing wells from adding adjacent wells. Time distance drawdown curves show predicted water declines for different well spacings for one and ten year periods.

An example of improper spacing of wells occurs in Milford, four miles west of the Neuhoff cattle feed lot. Here, five closely spaced wells in the Woodbine Formation supply 25,000 cattle at a rate of 336 acre feet yearly. Due to the low coefficient of transmissibility and overlapping cones of depression, the local drawdown has averaged 14 feet a year from 1962 to 1965 (Thompson, 1967, p. 41).

Lowering of the water table reflects seasonal variations in pumpage, and to lesser degrees, variations in rainfall and evapotranspiration (Peckham and others, 1963, p. 36). The immediate causes of regional declines in water levels are not clearly known because of an inadequate number of water level measurements. Declines are attributed largely to pumping in Ellis County, or more probably, Dallas County (Thompson, 1967, p. 31).

Present groundwater usage in the corridor is shown in Table 3. It is estimated that 40 acre feet of groundwater was pumped from a few shallow wells in the alluvium of major creeks to irrigate less than 100 acres of cropland. Table 4 also shows the total pumpage in acre feet for each aquifer formation in the corridor.

Chemical quality of water directly determines the water suitability for industry, irrigation, and public supply. While not all groundwater in the corridor meets U. S. Public Health Standards of 1967, wells generally yield water that is suitable for most uses except sustained irrigation.

"Treatment, other than chlorination for public supply does not seem necessary except possibly in areas of high iron concentration" (Peckham and others, 1963, p. 37), however, sodium concentrations above 20 ppm have been associated with high heart attack rates (Dr. H. Wolfe, personal communication, 1975).

CLIMATE

INTRODUCTION

The regional climate of the Interstate Highway 35 corridor is significant to the study of urban geology along this corridor in the following ways:

> (1) Knowledge of solar radiation, temperature extremes, and solar angles permits prediction of fuel requirements for heating and cooling systems, orientation and architectural design of buildings, streets and roads;
>
> (2) Wind directions and wind velocity data allow favorable placement of industry relative to residential areas, prediction of cooling effects, and are necessary for proper engineering design of structures and windbreaks;
>
> (3) Knowledge of precipitation and runoff allows proper design of sewers and drainage systems, stockponds, reservoirs, roofs, surface slopes; and
>
> (4) Humidity data permit prediction of heating and cooling requirements necessary for human comfort.

For this report climate is described as empirically observed quantities which characterize the state of the atmosphere at specific time intervals (months). Observations from Waco, Dallas, and Fort Worth stations were interpreted to yield a regional climatic view of the corridor.

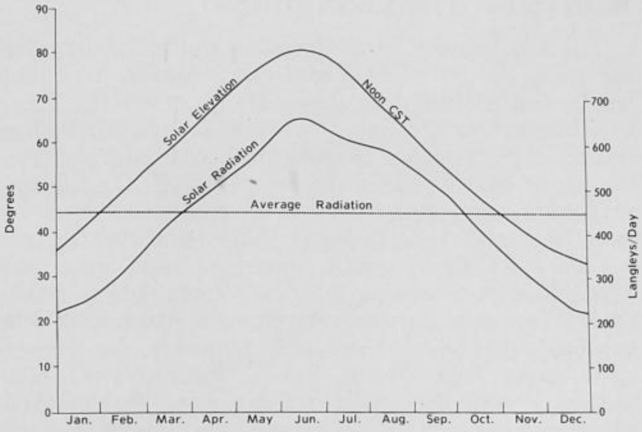

Fig. 20. Variation of solar elevation and intensity of solar radiation by month, Dallas, Texas.

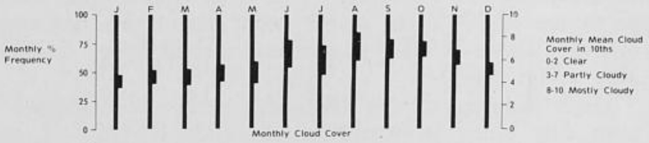

Fig. 22. Monthly cloud cover, Dallas, Texas.

Major climatic factors allow predictions of climatic extremes, show monthly norms, and indicate limitations of potential land use. Microclimatic variations caused by inter-regional differences in topography, soil type, sunshine, shade, and slope orientation, cause local deviations from the plotted norms. For example, length of the frost-free season changes with varying topography throughout the area.

The corridor lies in the extreme north portion of the humid subtropical belt that extends northward from the Gulf of Mexico. The climate has both maritime and continental features. Continental characteristics include rapid changes in temperature, marked temperature extremes, and large daily and annual temperature ranges which prevail during the winter months when surges of polar air move into the area. The maritime climate is most evident in the spring and early summer months when moist warm air moves over the area from the Gulf, resulting in the major precipitation for the year.

Figures 20 through 34 and related text express averages of mean monthly and seasonal variations of climatic elements in the corridor. These are not forecasts of precipitation, temperature, etc., but reflect collective atmospheric conditions which have occurred over periods of years. Climatic data have been generalized to permit regional interpretations of collected data. Conclusions and recommendations for regional planning within the area are shown in Plate V.

MONTHLY SOLAR RADIATION AND SOLAR ELEVATION

Solar radiation, more than any other factor, determines the seasonal and secular variations of climate. While solar energy output is a variable quantity, averages over a 15 year period yield a solar constant

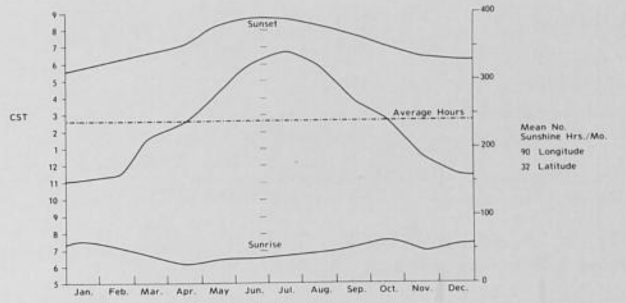

Fig. 21. Sunrise, sunset, and mean number of sunshine hours per month, Dallas, Texas.

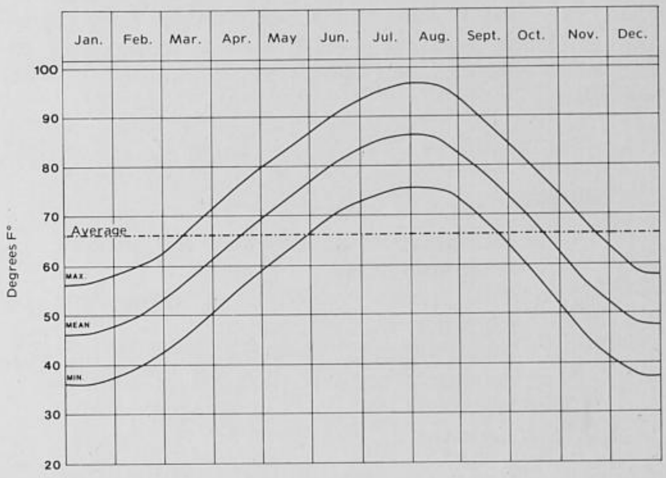

Fig. 23. Average mean, maximum, and minimum temperatures for the Waco-Dallas-Fort Worth area by month.

of around 2.00 langleys (calories per square centimeter per minute). Approximately 140 langleys will evaporate 0.5 cm, of rainfall.

Figure 20 shows the monthly solar elevations above the horizon at noon (periods of maximum insolation) and monthly mean daily solar radiation (in langleys). The area under the upper line shows solar elevations (indicated on the left) for the latitude of 32° 10′. The lower curve represents the mean daily solar radiation, shown in langleys, on the right margin of the table.

Deviations from maximum possible insolation are pronounced during the period from December to March because this period has the greatest frequency of cloud cover. Maximum daily insolation (600 langleys per day) occurs during the period from June to July.

MONTHLY SUNSHINE HOURS, CLOUD COVER, AND SUNRISE AND SUNSET

The duration of sunshine at a specific locality is seasonally dependent. Duration of sunshine is shown in mean hours per month in Figure 21. The possible number of sunshine hours a month in the continental U. S. varies from 370 per month in the south to 375 per month in the north, provided no obstacles are on the horizon. Actual sunshine hours will vary due to cloudiness. This is illustrated by the middle line and

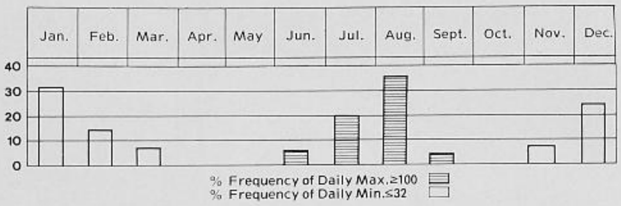

Fig. 24. Percentage frequency of daily maximum temperatures above 100°F. and below 32°F., Dallas, Texas.

the right column of Figure 21. While the period from June to August has an average of 12 hours of sunshine per day, November to February averages only 5. Because very few observations actually record solar radiation, sunshine duration is often used as a substitute to gauge the solar climate (Landsberg, 1958, p. 130). The equation:

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

where;

$Q =$ the radiation actually received on a horizontal surface
$Q_A =$ total radiation received if atmosphere were perfectly transparent
$n =$ actual duration of sunshine
$N =$ maximum possible duration of sunshine
$0.23 =$ constant
$0.48 =$ constant

allows conversion of sunshine hours into radiation intensities.

Mean values of cloudiness per month in percentage of total time are given in Figure 22. Cloudiness, a measure of the amount of sky covered by clouds per unit time, is subject to diurnal, seasonal, and geographic variations. Cloudiness has been included in this table because of its intimate relationship to sunshine and solar radiation. For general approximations the equation $100 - S = C$ may be used.

$S =$ percentage of sunshine
$C =$ percentage of cloudiness

In Figure 22 the left scale shows the percentage of total area covered by clouds in the corridor each month. Partly cloudy percentages are shown by the thicker areas on the columns. Percentage of clear skies is represented below the thicker, partly cloudy bar while percentages of cloudy skies are shown above the thicker area of the bar. By convention, if a station observed equal numbers of completely cloudy skies and completely clear skies over the 24 hour period, the mean value of 50 percent would be recorded, indicating partly cloudy skies. Percentage cloudiness values are convertible to tenths by using the right column.

The cloudiest period is December to March; June to October is the least cloudy period. Normally, the sky is either cloudy or clear and is seldom partly cloudy.

Sunrise and sunset times (CST or Central Standard Time) shown in the left column of Figure 21 were compiled utilizing the 15th day of each month.

The upper line shows the relative amounts of cloudiness each day (between sunrise and sunset).

MONTHLY TEMPERATURES

The temperature of a region is controlled by solar radiation, sky cover, length of day, altitude, prevailing winds, and proximity to major bodies of water. These variables act in a number of combinations to produce characteristic regional temperatures. Air moving from the south usually raises the temperature. During late autumn to late spring, masses of cold continental air from the north tend to lower daily temperatures.

Figure 23 shows mean, minimum, and maximum average temperatures for the Fort Worth, Waco, Dallas area. This table illustrates the changes which should be expected from season to season. However, the temperature curve lags slightly behind the curve of solar heating so that the lowest average mean temperatures occur in January (46°F), and the warmest mean temperatures in late July and August (85°F).

Minimum temperatures of 32°F or below occur about one day out of every three in January to one day out of every four in February (Fig. 24). Maximum temperatures of 100°F or above occur about one day out of every three in August and one out of every five in July (Fig. 24).

High summer temperatures are generally associated with fair skies, westerly winds and dry air. Low winter temperatures are produced by cold fronts or "northers." Although temperatures may drop as much as 20°F in one hour, cold weather usually persists for only one or two days following an intrusion of cold polar air. Important to agriculture is the long frost-free season, 249 days. The first freeze has occurred as early as October 27 and as late as December 27. The last freeze in the spring has occurred as early as February 14 and as late as April 15.

MONTHLY WIND SPEED AND DIRECTION

Wind direction is important in prediction of changing weather conditions throughout the year. Wind speed is important in its effect on vegetation, buildings, erosion, evaporation, location of industry relative to residential areas and general human comfort.

Figure 25 shows mean annual wind speeds from each compass direction for Fort Worth and Waco. Mean annual winds from the north in Fort Worth average 14 knots. At Waco, winds average 11.5 knots.

Figure 26 shows percentage frequency of winds related to compass direction for Fort Worth and Waco. For example, Waco receives winds from the south 19 percent of the time. Throughout the year, it can be seen that south-southwest winds predominate in Waco, while northerly and southerly winds play a dominant role in Fort Worth. Mean annual wind speeds range from one to ten knots about 60 percent of the time in both Fort Worth and Waco. Fort Worth, however, has a greater percentage of moderately high winds (11 to 20 knots). Figures 27 through 34 show seasonal variations of mean wind speed and direction from Fort Worth and Waco.

Mean wind directions during various seasons (Figs. 27-34) show south and southwest winds reach a maximum during warmer seasons. North winds, while not dominating any one season, reach a winter maximum due to intrusions of polar winds. Westerly and easterly winds are the least common. Winds also correlate with

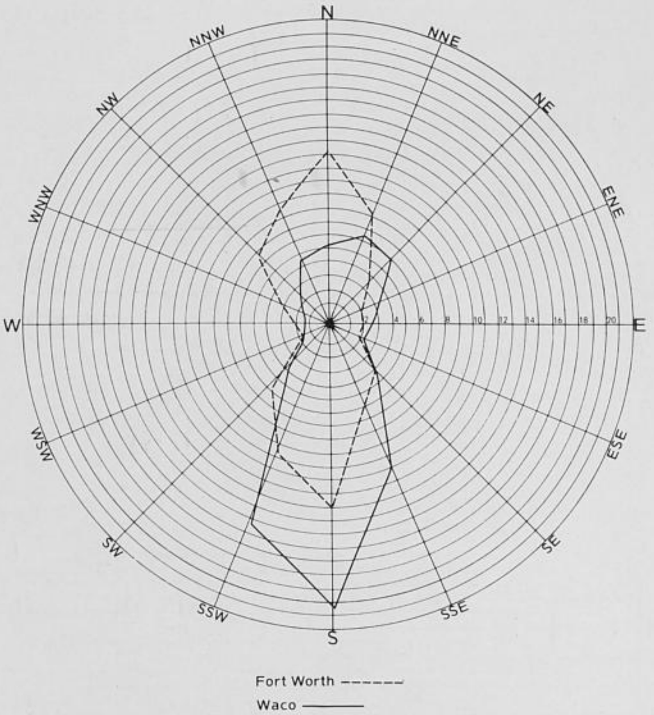

Fig. 25. Annual mean wind speed in knots, Fort Worth and Waco, Texas.

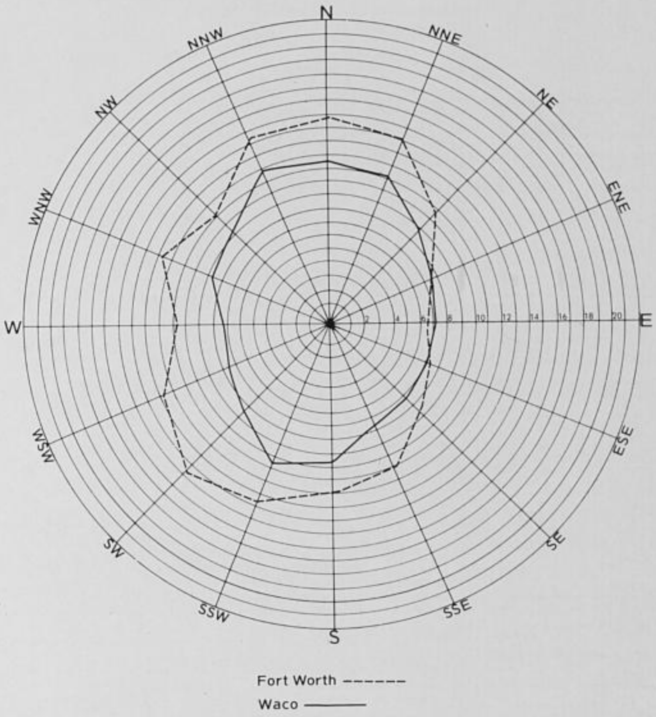

Fig. 26. Annual percentage frequency of surface wind direction, Fort Worth and Waco, Texas.

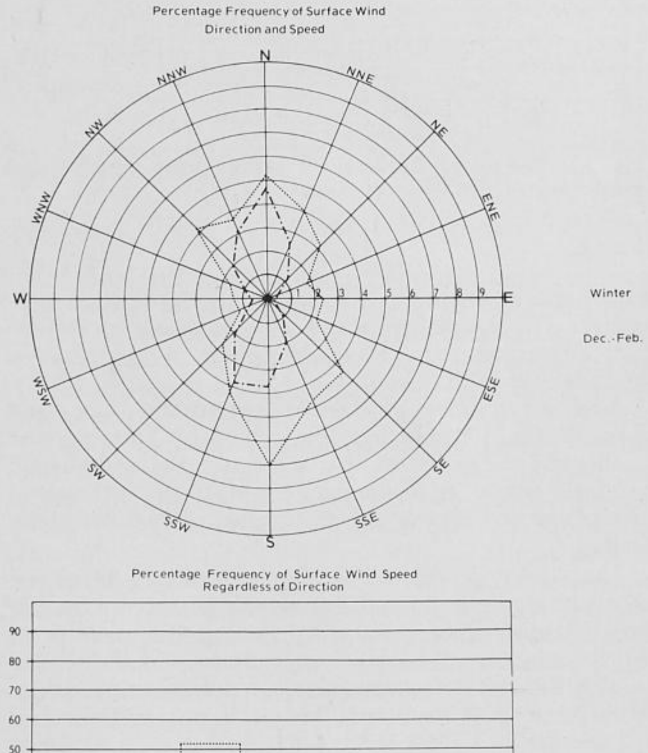

Fig. 27. Percentage frequency of surface wind direction and speed, winter, Fort Worth, Texas.

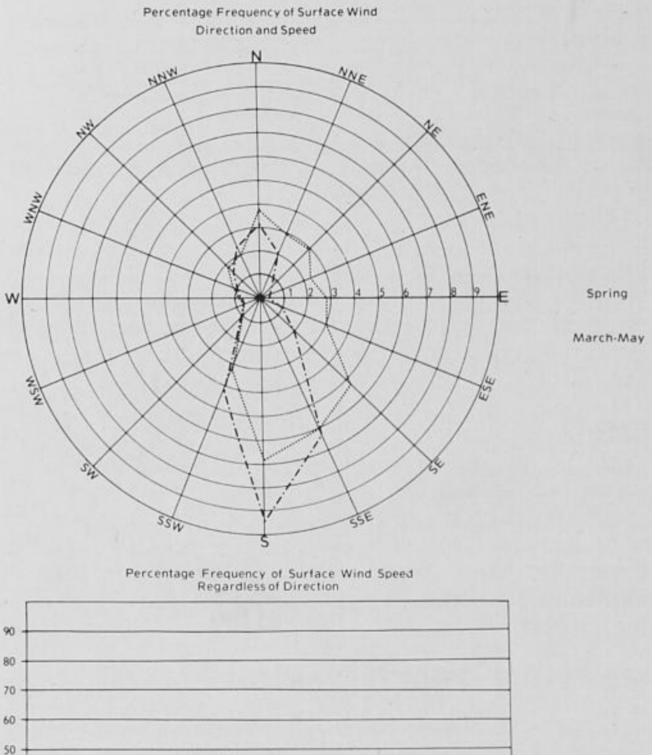

Fig. 28. Percentage frequency of surface wind direction and speed, spring, Fort Worth, Texas.

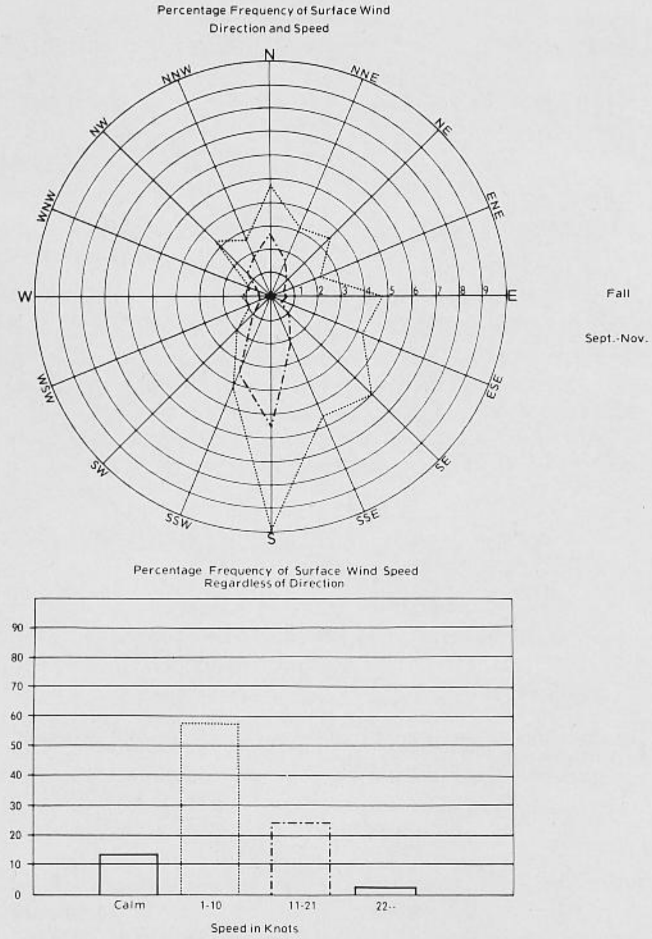

Fig. 29. Percentage frequency of surface wind direction and speed, fall, Fort Worth, Texas.

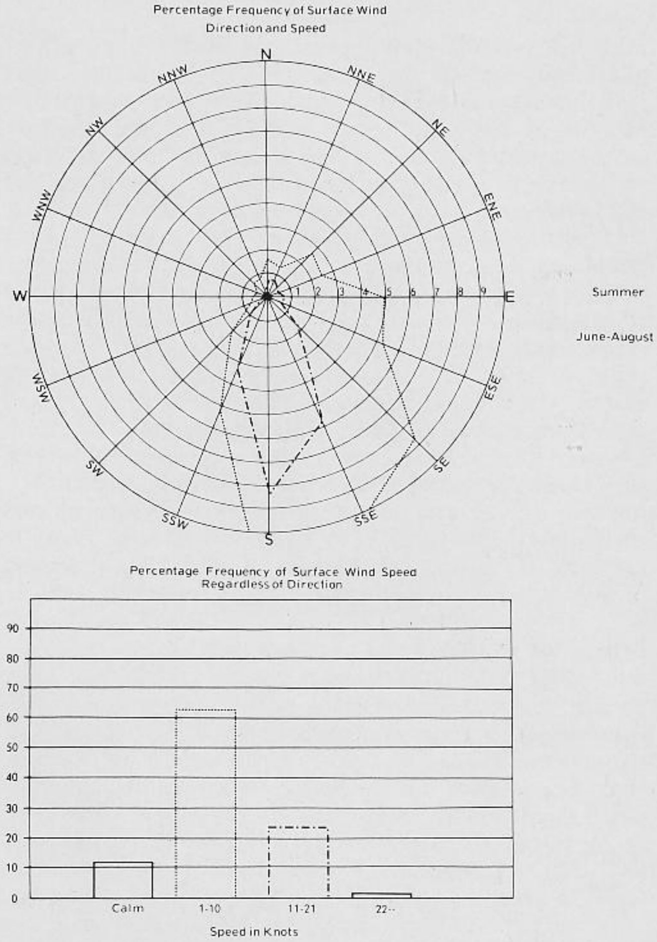

Fig. 30. Percentage frequency of surface wind direction and speed, summer, Fort Worth, Texas.

rainfall. North and northeast winds most often accompany rain in November-February. In May through August varying directions from north to southeast are the rule (U. S. Study Commission-Texas, 1961, p. 12).

During winter, wind speeds of ten knots or less occur more than 60 percent of the time in the corridor. Wind speeds are higher in the spring than in the winter and calms are less frequent. While maximum wind speeds occur in March, lowest wind speeds occur with greatest frequency during the summer months. Generally, wind speeds are lowest about the time of minimum temperature near sunrise and strongest during midday.

MONTHLY PRECIPITATION

Figure 35 shows mean, maximum, and minimum monthly precipitation in millions of gallons per square mile for Dallas, Waco, and Fort Worth. Average mean monthly precipitation in inches, 1931-70, for these three cities is shown in Figure 36. Average runoff is about 15 percent.

The Gulf of Mexico is the primary source of moisture for the corridor. The major topographic high, the northeast-southwest trending Balcones escarpment may have some local influence on local climate by forcing warm and moist air to rise, ultimately producing precipitation or localizing storms. Total annual precipitation diminishes from about 36 inches in Waxahachie to 35 inches in Hillsboro.

High precipitation gradients occur around Dallas and Fort Worth, just north of the corridor. This increase is thought to be due to city and industrial combustion products acting as cloud nuclei, and to an increase of convective and mechanical turbulence related to urbanization.

Mean average rainfall in the area shows a pattern of relatively light rainfall during the winter, increasing to a maximum in the spring during the months of April and May. Generally, precipitation in the winter is slightly more frequent during the morning hours while summer precipitation has an afternoon maximum (U. S. Study Commission, 1961, p. 5).

Because mean values are based on long period precipitation curves, fluctuations in excess of the range from mean maximum to minimum values should be considered possible in any year. Waxahachie has had yearly rainfalls ranging from 54 to 20 inches (Thompson, 1967, p. 5).

Monthly precipitation gives an incomplete description of actual precipitation. Percentage frequency of

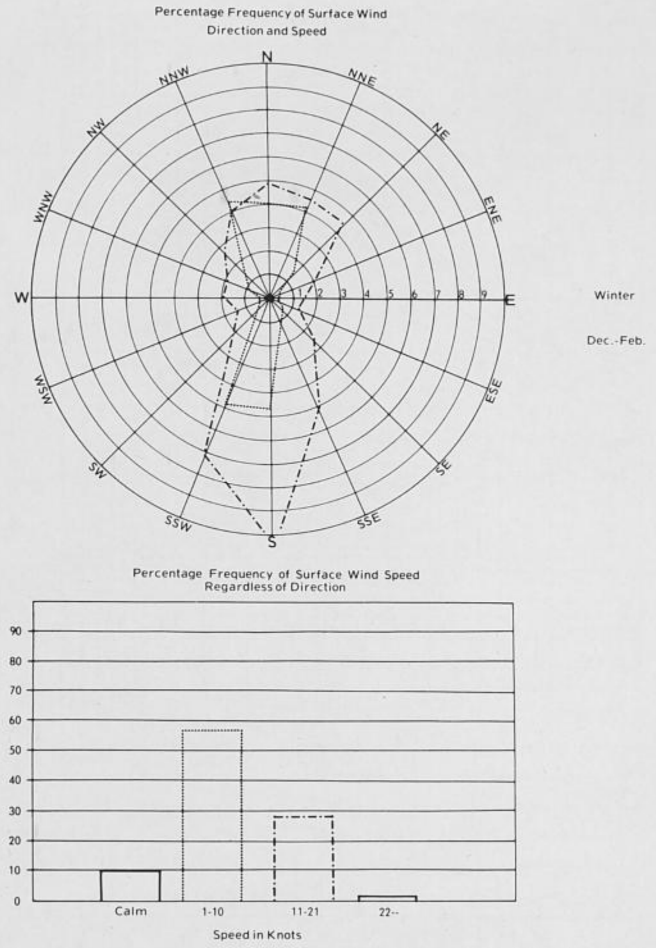

Fig. 31. Percentage frequency of surface wind direction and speed, winter, Waco, Texas.

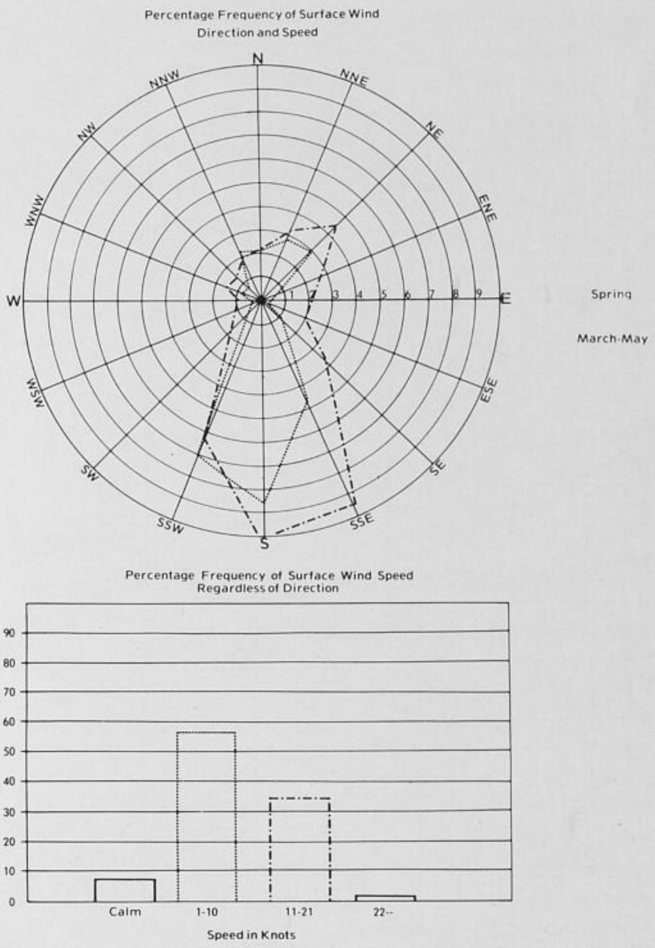

Fig. 32. Percentage frequency of surface wind direction and speed, spring, Waco, Texas.

rainfall related to intensity and duration is of particular importance in this area of storm rainfall. Approximately three-fourths of the total precipitation in the area is caused by thunderstorms and frontal storms. Cyclonic storms do not significantly add to total precipitation.

Figure 37 shows monthly percent frequency of winter and summer storms in the area. Maximum values occur in May and June. Figure 38 shows intensity areas for short duration rainfall and the probability that any given magnitude and rate of rainfall will be exceeded in a certain number of years. This graph can be used to calculate intensities of rain in inches per hour as well as probabilities of its occurrence. For instance, a rainfall of two inches per hour will be exceeded somewhat more often than once each two years in the corridor. This is a factor of considerable importance in design.

DROUGHT

Even during years of normal precipitation there are drought months when additional rainfall is needed for crop production. Here drought is defined as a period of moisture deficiency brought about by a temporary climatic departure toward drier conditions (U. S. Study Commission, 1961, p. 6). The main drought years in the corridor between 1919 and 1960 have been 1924-5, 1930, 1933-4, 1936, 1939, 1943, 1950-6, and 1970-1.

Severe drought exists during periods in which the annual rainfall is less than one-half the long term annual average rainfall and mean temperatures are higher than average (Landsberg, 1958, p. 249). Causes of drought are linked to large scale atmospheric circulations that determine the prevailing winds as well as to smaller storm systems that seemingly initiate the precipitation (U. S. Study Commission, 1961, p. 6).

Figure 39 shows mean monthly humidity measurements by month for Dallas, Texas. Relative humidity reaches a maximum during the early morning hours and a minimum in the early afternoon. Relative humidity is greatest during the months of May through March and lowest during December through February.

Figure 40 illustrates the daily variation in heating and cooling requirements necessary for human comfort for each month of a given year (horizontal scale), and each hour of the day (vertical scale). Shaded portions of this figure indicate those times of the year when shade is needed for human comfort. For the case where the shaded areas move into that portion of the diagram representing night-time, this indicates the need for

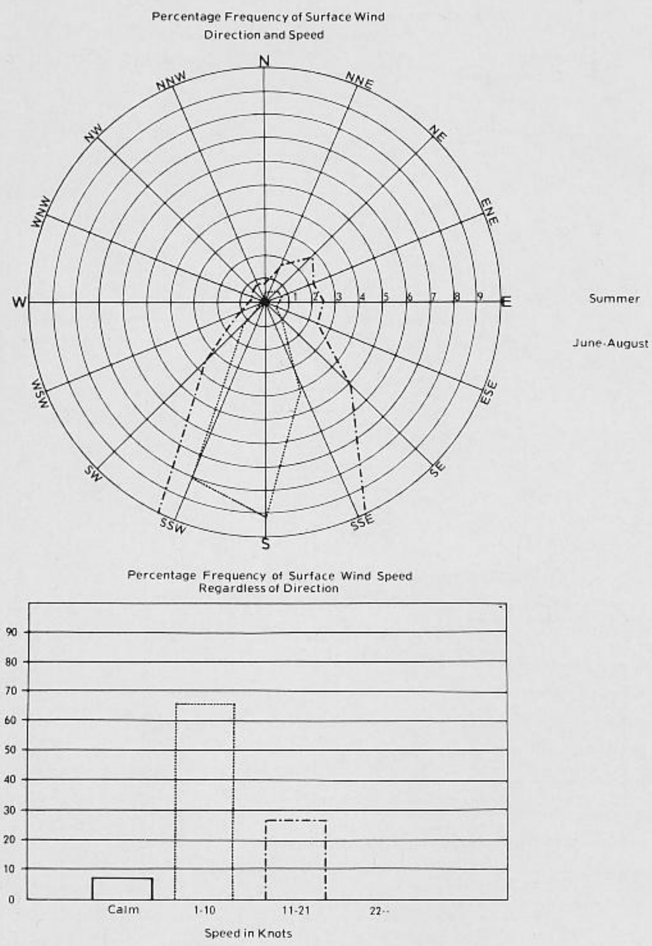

Fig. 33. Percentage frequency of surface wind direction and speed, summer, Waco, Texas.

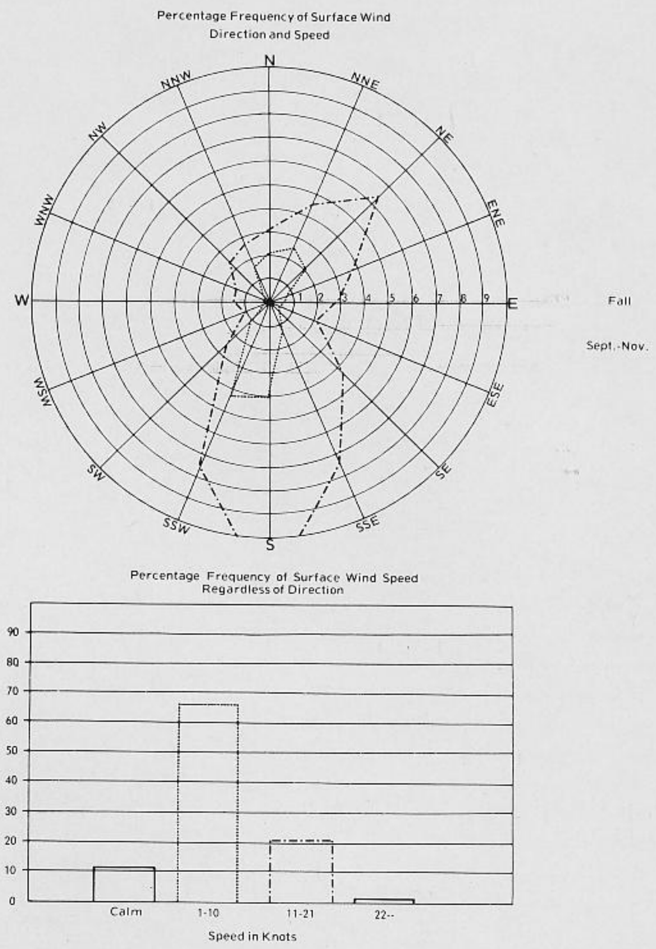

Fig. 34. Percentage frequency of surface wind direction and speed, fall, Waco, Texas.

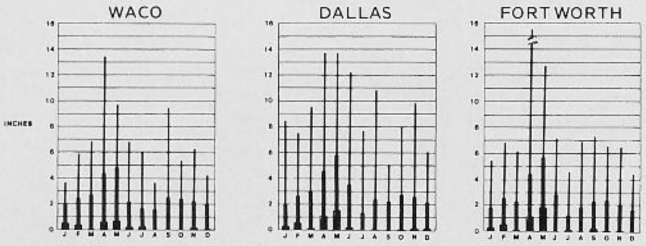

Fig. 35. Monthly precipitation, 1941-1957, in millions of gallons per square mile. Minimum, mean, and maximum precipitation amounts are shown by wide, medium, and narrow bars respectively. Absence of a wide bar indicates that the minimum was zero or a trace. *From* U. S. Study Commission, 1961.

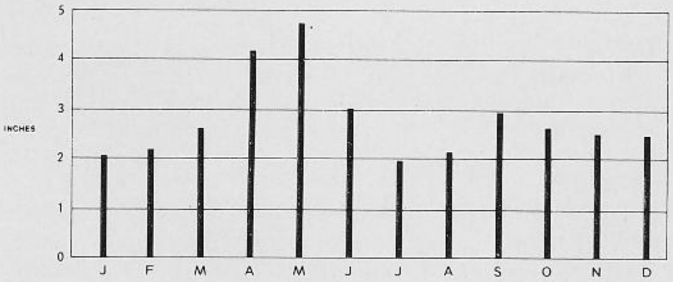

Fig. 36. Average mean monthly precipitation in inches, 1931-1970, Waco, Dallas, and Fort Worth, Texas.

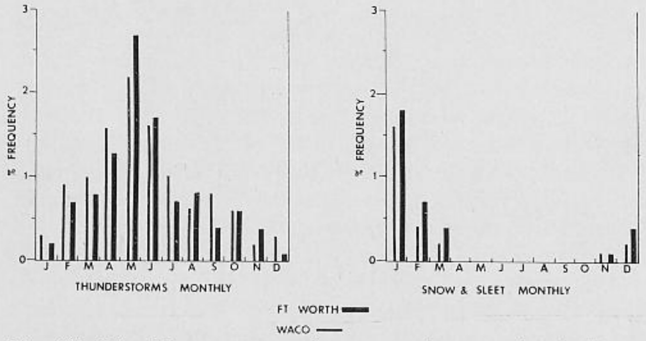

Fig. 37. Monthly percentage frequency of storms in the Interstate Highway 35 growth corridor.

additional cooling input.

"Air movement, as a cooling function in combination with shade, is only useful up to 300 feet per minute, because at higher velocities it becomes irritating to humans" (Reynolds, 1972, p. 48). Cooling requirements above 300 feet per minute (within the 300 feet per minute contour) will have to be translated into refrigerative cooling inputs.

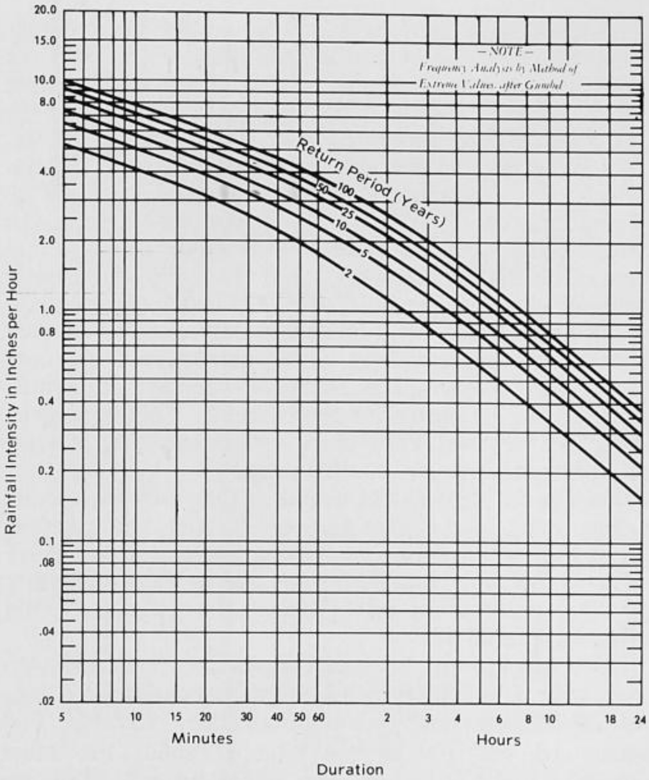

Fig. 38. Short duration rainfall intensity data, Dallas, Texas (1914-1951) plotted to yield storm return period curves. *From* U.S. Study Commission, 1961.

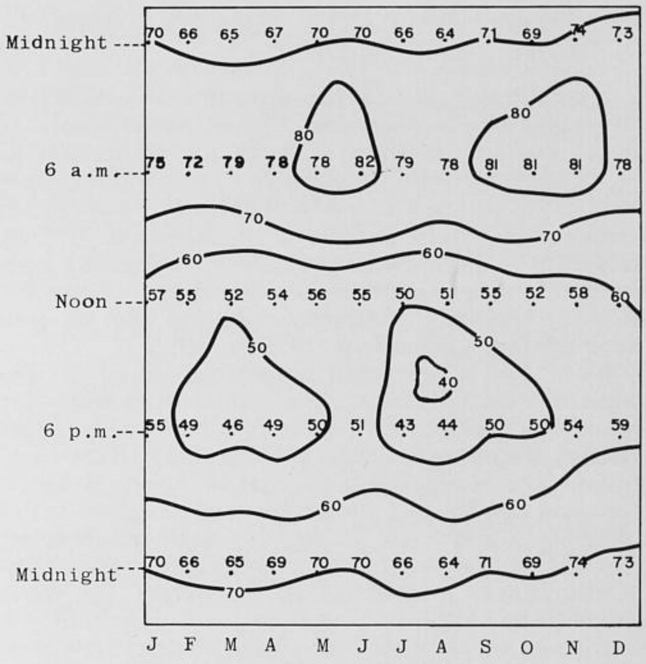

Fig. 39. Mean monthly relative humidity, Dallas, Texas. *From* Reynolds, 1972, p. 18.

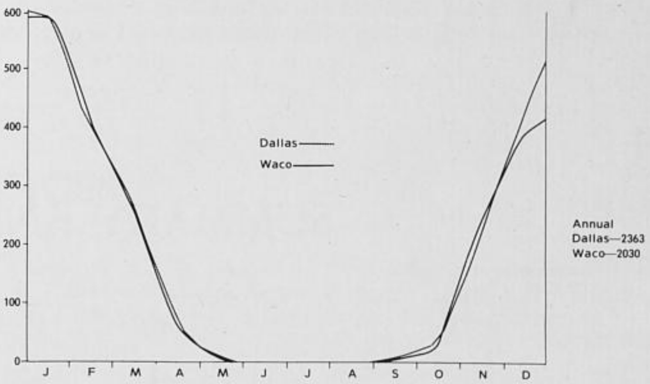

Fig. 41. Total normal heating degree days, based on 65° F., Dallas and Waco, Texas.

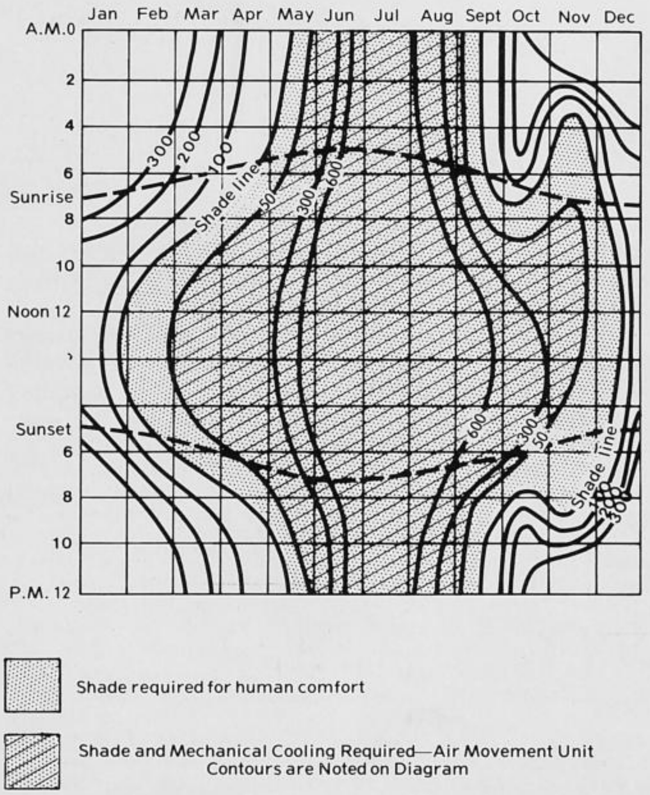

Fig. 40. Variation in heating and cooling requirements for human comfort by month and hour of the day. Contours outside of shade line area show heating requirements in BTU's per square foot per hour. Air movement contours are in feet per minute. *After* Olgyay, 1963, Design with climate.

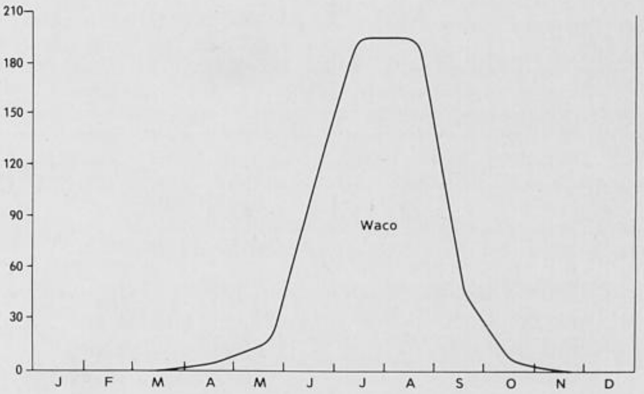

Fig. 42. Total cooling degree days based on 80°F., Waco, Texas.

EVAPORATION RATES, HEATING AND COOLING DEGREE DAYS

Mean annual class A pan evaporation is 80 inches per year for the corridor. Since measurement of actual evaporation from a water or soil surface is complicated by such variables as solar radiation, dew point, wind, precipitation, stream flow and runoff, actual surface evaporation is difficult to determine. Hence, values for evaporation are commonly obtained by measuring the water lost from an exposed pan. Wind and humidity primarily determine water loss from an open water surface (Landsberg, 1958, p. 40).

When soil is saturated, evaporation is rapid. Because of low infiltration rates, evaporation from clay soil is about 72 percent that from a free water surface (Berry, Bollay, and Beers, 1945, p. 743). This evaporation rate is reduced by vegetative cover. Evaporation data can be used for preliminary design of major reservoir projects and is probably fully adequate for the design of lesser projects. Approximately two-thirds of the annual evaporation occurs during the warm period from April to September, and practically the entire net evaporation loss occurs during the period from January to September.

A heating degree day is defined as a day in which the mean daily temperature is one degree below a certain standard value. In this report, the standard is 65°F. A mean daily temperature therefore of 60°F for any given day would yield five heating degree days. Total heating degree days for the month as shown in Figure 41 have been computed by adding the accumulated degree days for that period. This index does not take into account cooling or heating effects by radiation, wind, or evaporation. Cooling degree days based on 80°F have been computed and shown in Figure 42. A cooling degree day may be considered as a day on which the temperature is one degree above 80°F. Temperatures of 65° to 80°F are considered well within human comfort zones. With temperatures in this range, heating or cooling is not normally required if buildings are properly designed. Total degree days plotted are based on cumulative degree days in each month. Waco was chosen as representative of the corridor since temperatures there do not deviate significantly from the norms for the corridor. Cooling degree days can be used as a basis for determining energy requirements for air conditioning.

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 (Environmental Data Service, 1968, p. 36). Monthly energy consumption can therefore be estimated from Figures 41 and 42.

The relationship between degree days and fuel consumption is linear; doubling the number of degree days usually doubles fuel consumption. Generally, the fuel consumed per 100 degree days is about the same whether the 100 degree days occur in only three or four days or are spread over seven or eight days (Environmental Data Service, 1968, p. 36).

SUMMARY AND CONCLUSIONS

Conclusions based on synthesis of geology, soils, hydrology, and climatic information are included in Plate V. Recommendations are based on the physical limitations of this corridor and do not constitute, by any means, the only possible solution. However, in order to ensure that a regional plan is economically justified, it is essential that planned exploitation of an area correspond as closely as possible to its given physical potential (Stewart, 1968, p. 180). Tables and maps presented should allow more precise statements about land suitability within this area.

Recommendations should give the regional planner an appreciation of the control elements of the physical environment, suggest the detail required in sampling for specific purposes, and allow for the safe and economical design of habitats and engineering works.

APPENDIX I

WELL LOGS

Owner	Driller
1. Curtis Hill #1	Faulds Whitehead
2. McClain #1	American Liberty
3. Sardis-Lone Elm Water Corp.	J. L. Meyers' Sons
4. City of Midlothian # 3	J. L. Meyers' Sons
5. J. L. Rush # 1	Johnny Mitchell
6. T. W. Christian #3	Thomas Nowlin Jr.
7. Alvin Nesuda #1	Browning and Smith
8. Wesley Honza #1	M. L. Richards
9. W. E. Smith #1	J. B. Stoddard

10. M. C. Feaster	Hughey and Carpenter
11. Buena Vista Water Well District Well #1	J. L. Meyers' Sons
12. R. S. LeSage #2	Lesco, Inc.
13. City of Milford #2	J. L. Meyers' Sons
14. Brandon Irene Water Supply Corp. #1	J. L. Meyers' Sons
15. A-1 Posey	Phillips Petroleum
16. City of Hillsboro #16	Texas Water Wells, Inc.
17. Certain Teed #1	Layne Texas Co.
18. City of Hillsboro Trinity Test #3	Layne Texas Co.
19. City of Hillsboro #17	H. Meadows
20. City of Abbot #1	J. L. Meyers' Sons
21. McDaniel #1	Glen McCarthy
22. Vosburg #1	A. O. Phillips
23. Nash-Forreston Water District #1	J. L. Meyers' Sons
24. R. S. LeSage #1	Lesco, Inc.
25. Penelope #1	J. L. Meyers' Sons

APPENDIX II

LOCALITIES

This appendix lists localities where type examples of the various formations can be seen in outcrop. Generally these outcrops are outside the main corridor but have been selected because of the superior quality of the exposure.

Locality 16. Dallas County (32° 34′ N; 96° 45′ W). Approximately 20 feet of Taylor Marl exposed in the Acme clay pit 150 feet west of State Highway 75, one mile north of Ferris.

Locality 17. Hill County (32° 02′ N; 97° 58′ W). Approximately 20 feet of "middle" Austin Chalk exposed in White Rock Creek near State Route 22, nine miles east of Hillsboro.

Locality 18. Ellis County (32° 21′ N; 96° 54′ W). Approximately 15 feet of "lower" Austin Chalk (faulted), exposed in South Prong Creek near State Route 66, about 4.5 miles southwest of Waxahachie.

Locality 19. Ellis County (32° 19′ N; 96° 59′ W). Austin Chalk-Eagle Ford contact. Approximately 8 feet of "lower" Austin Chalk and 40 feet of Eagle Ford Shale exposed 9.3 miles southwest of Waxahachie along an unmarked county road; 0.6 mile south and 0.2 mile east of State Route 66.

Locality 20. Dallas County (32° 35′ N; 96° 59′ W). Austin Chalk-Eagle Ford contact. Approximately 20 feet of "lower" Austin Chalk and 35 feet of Eagle Ford Shale exposed along Belt Line Road, 1.9 miles east of Cedar Hill.

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URBAN GEOLOGY INTERSTATE 35 GROWTH CORRIDOR HILLSBORO TO DALLAS COUNTY, TEXAS

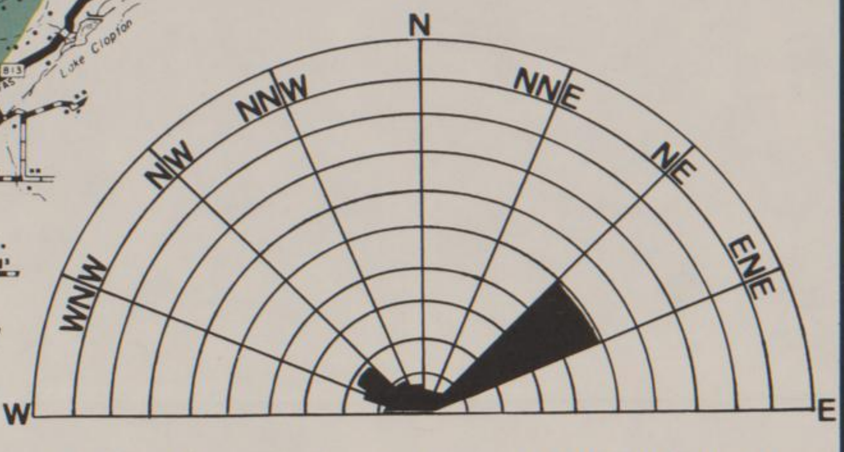
SCALES
0 0.5 1.0 2.0 3.0 4.0 5.0 MILES

P.M. Allen 1975

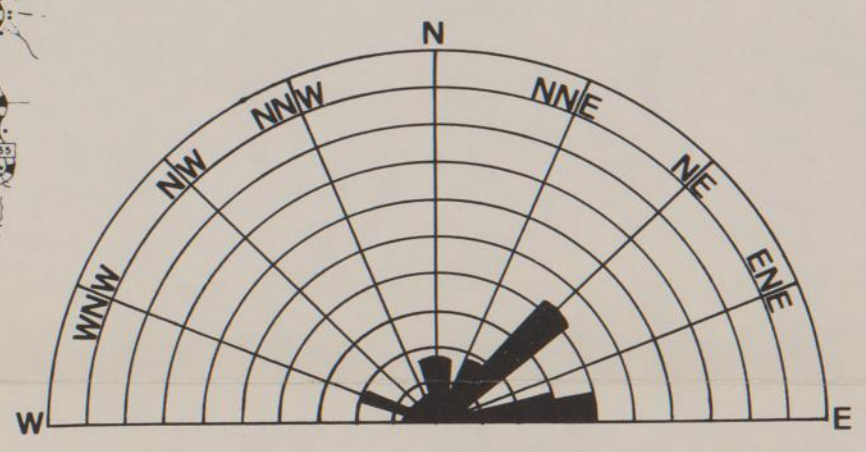
Plate No. I

GEOLOGY

Baylor Geological Studies
Bulletin No. 28



DETAIL A: Percentage frequency of strike direction of 105 vertical joints (Adapted from Reed, 1958, p. 21)



DETAIL B: Percentage frequency of strike direction of 70 vertical joints (Adapted from Dooley, 1960, p. 14)

LEGEND

▨ RECENT ALLUVIUM

▨ QUATERNARY TERRACE DEPOSITS

▨ TAYLOR MARL

▨ (UPPER) AUSTIN CHALK

▨ (MIDDLE) AUSTIN CHALK

▨ (LOWER) AUSTIN CHALK

▨ SOUTH BOSQUE FORMATION

▨ LAKE WACO FORMATION

INFERRED BOUNDARY BETWEEN MAPPED UNITS

KNOWN BOUNDARY

FAULTS
——KNOWN
---------ASSUMED

D-downthrown
U-upthrown

77 LOCATION OF OUTCROP

Base Map adapted from Texas State Highway Dept. county maps.

URBAN GEOLOGY
INTERSTATE 35 GROWTH CORRIDOR
HILLSBORO TO DALLAS COUNTY, TEXAS

P.M. Allen 1975

Plate No. II

SOIL ASSOCIATIONS

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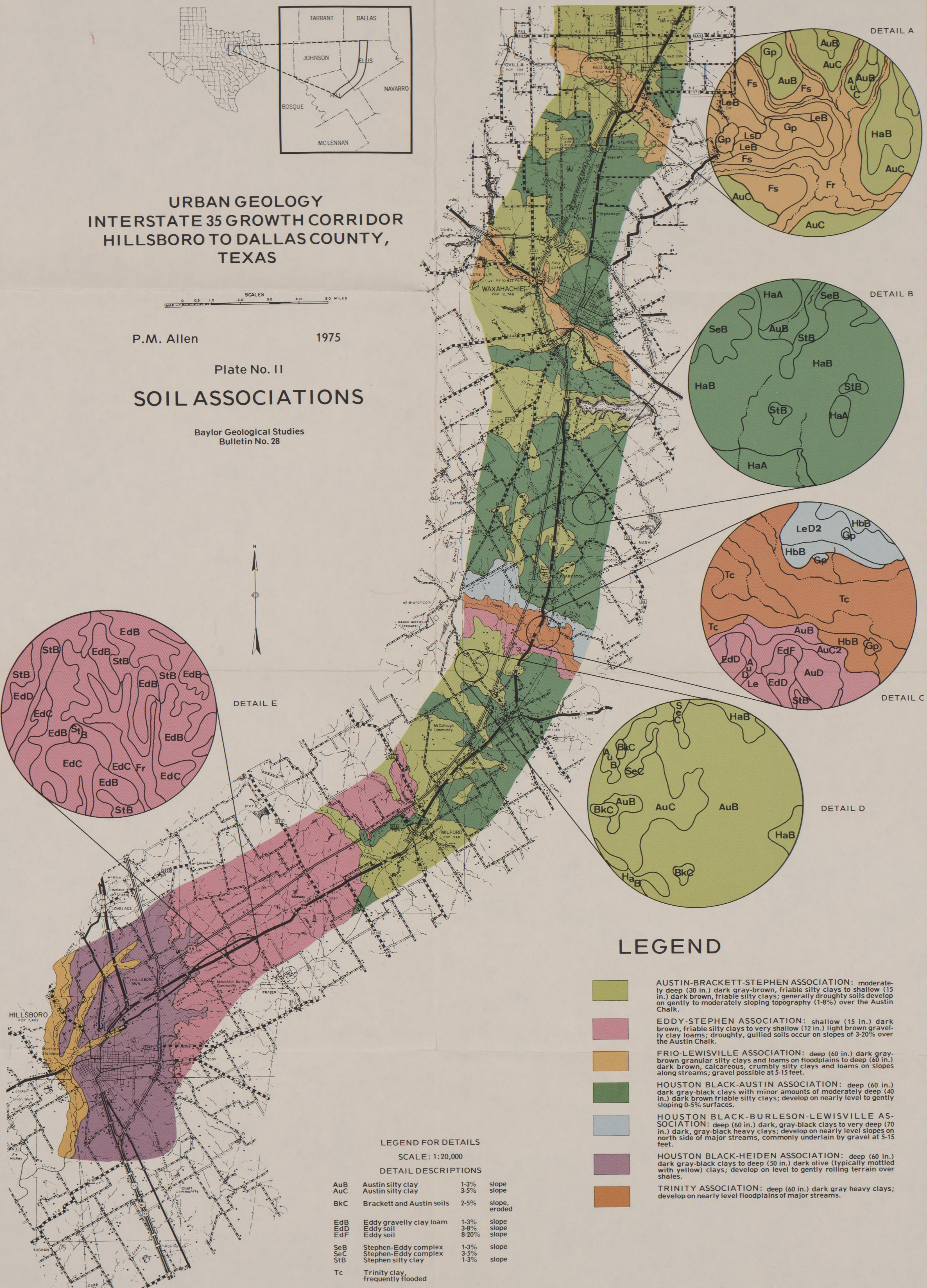

LEGEND

🟩	AUSTIN-BRACKETT-STEPHEN ASSOCIATION: moderately deep (30 in.) dark gray-brown, friable silty clays to shallow (15 in.) dark brown, friable silty clays; generally droughty soils develop on gently to moderately sloping topography (1-8%) over the Austin Chalk.
🟥	EDDY-STEPHEN ASSOCIATION: shallow (15 in.) dark brown, friable silty clays to very shallow (12 in.) light brown gravelly clay loams; droughty, gullied soils occur on slopes of 3-20% over the Austin Chalk.
🟨	FRIO-LEWISVILLE ASSOCIATION: deep (60 in.) dark gray-brown granular silty clays and loams on floodplains to deep (60 in.) dark brown, calcareous, crumbly silty clays and loams on slopes along streams; gravel possible at 5-15 feet.
🟩	HOUSTON BLACK-AUSTIN ASSOCIATION: deep (60 in.) dark gray-black clays with minor amounts of moderately deep (40 in.) dark brown friable silty clays; develop on nearly level to gently sloping 0-5% surfaces.
🟦	HOUSTON BLACK-BURLESON-LEWISVILLE ASSOCIATION: deep (60 in.) dark, gray-black clays to very deep (70 in.) dark, gray-black heavy clays; develop on nearly level slopes on north side of major streams, commonly underlain by gravel at 5-15 feet.
🟪	HOUSTON BLACK-HEIDEN ASSOCIATION: deep (60 in.) dark gray-black clays to deep (50 in.) dark olive (typically mottled with yellow) clays; develop on level to gently rolling terrain over shales.
🟧	TRINITY ASSOCIATION: deep (60 in.) dark gray heavy clays; develop on nearly level floodplains of major streams.

LEGEND FOR DETAILS

SCALE: 1:20,000

DETAIL DESCRIPTIONS

AuB	Austin silty clay	1-3%	slope
AuC	Austin silty clay	3-5%	slope
BkC	Brackett and Austin soils	2-5%	slope, eroded
EdB	Eddy gravelly clay loam	1-3%	slope
EdD	Eddy soil	3-8%	slope
EdF	Eddy soil	8-20%	slope
SeB	Stephen-Eddy complex	1-3%	slope
SeC	Stephen-Eddy complex	3-5%	
StB	Stephen silty clay	1-3%	slope
Tc	Trinity clay, frequently flooded		
Le	Lewisville silty clay		
LeB		1-3%	slope
LeD	Lewisville silty clay	5-8%	slope, eroded
LsD	Lewisville soils	5-8%	slope
Fr	Frio silty clay, frequently flooded		
Fs	Frio silty clay, occasionally flooded		
Gp	Gravel pit		
HaA	Houston Black clay	0-1%	slope
HaB	Houston Black clay	1-3%	slope

Base Map adapted from Texas State Highway Dept. county maps.

Plate No. III

Baylor Geological Studies
Bulletin No. 28

MAPPED SOIL ASSOCIATIONS

	AUSTIN-BRACKETT-STEPHEN ASSOCIATION	EDDY-STEPHEN ASSOCIATION	FRIO-LEWISVILLE ASSOCIATION	HOUSTON BLACK-AUSTIN ASSOCIATION
Description	Granular, crumbly, upland soils are moderately deep to shallow, moderately permeable, gray-brown in color, and develop over the Austin Chalk. Soils of this association occupy gently sloping to undulating terrain throughout the northern two-thirds of the study area. Depth and Type Bedrock: extremes 12" to 80" average 25-30" Shrink-Swell: moderate to high, plasticity indexes have ranged from 15-32. Hydrological Characteristics: USDA Hydrologic Group C, slow infiltration, approximately.2-.63 in/hr.: possibility of "seeps" and "springs" associated with underlying bedrock and topographic position for several days after a rain.	Soils of this association consist of friable silty-clays and gravelly clay loams which are shallow to very shallow, droughty soils. Plowed fields in this association are typically black and white; the light colors correspond to Eddy gravelly, chalky soils and the darker areas to Stephen soils. These soils have developed on somewhat rolling relief over the Austin Chalk. This association occurs along the southern edges of major streams in the study area and along the Austin Chalk Escarpment. Depth and Type Bedrock: extreme 12-30" chalk average 15" chalk Shrink-Swell: low-moderate, plasticity indexes range from about 15-24. Hydrologic Characteristics: USDA Hydrologic Group C, slow infiltration, approximately .2-.63 in/hr.	This association consists of soils on nearly level floodplains and slopes along Waxahachie and Red Oak creeks. Soils range from dark, gray-brown, granular, silty clays and loams in the floodplains to deep crumbly calcareous clays on the slopes. These soils are typically well drained and are often underlain by stratified sand and gravel at depths of 3-10 feet. Depth to and Type Bedrock: extreme 60" to sands, silts gravels, 25' to chalk average 10' to chalk Shrink-Swell: high, plasticity indexes range from about 25-32. Hydrologic Characteristics: USDA Hydrologic Group B, moderate infiltration, permeability .63-2.0 in/hr.; potential flood hazard in areas of Frio soils, springs and seeps are common in this area for up to 30 days following rains.	This association consists of moderately deep (40in.) friable silty clays and deep (60-70in.) deep dark-gray heavy clays. These soils occur on gently rolling terrain primarily over the Austin Chalk. This association extends from Red Oak in the northern one-third of the study area southward to Milford being broken several times by west to east flowing streams. Depth to and Type Bedrock: extreme 40"-10' chalk or calcareous shale average 80" chalk or calcareous shale Shrink-Swell: very high, plasticity indexes from about 25-35 or greater Hydrologic Characteristics: USDA Hydrologic Group C-D, slow to very slow infiltration; permeability .06-.63 in/hr.; drainage problems are possible in large flat areas and ponding will occur after rains in depressions.
Component Soils	Austin soils make up about 50-60% of this association; Brackett and Stephen soils about 30%, and Eddy and Houston Black soils about 10%.	Eddy and Stephen soils together make up 85% of this association with the remaining 15% consisting of Austin, Altoga, Lamar, Houston Black, and Brackett series soils.	Frio and Lewisville soils comprise 85% of the association with 15% Houston Black, Trinity, and Austin series soils.	Houston Black soils comprise roughly 60% of this association, Austin soils about 30%, Stephen, Eddy, and Brackett soils about 10-15%.
Engineering Hazards: Present Usage	This association is one of the main farming areas in Hill and Ellis Counties. The majority is cultivated and produces excellent yields of field crops. Construction in the area is hazardous without proper engineering design due to the extremely high shrink-swell, PVR, and corrosivity of the clays. Utilization of detailed soil maps and U.S. Conservation Dept. services to locate thinner Stephen or Eddy soils is recommended prior to construction. By moving short distances (see Plate II) to these thinner soils, foundation and drainage problems can be alleviated. Design Notes: (a) foundations should rest on stable chalk bedrock. (b) lawns will be hard to establish in thin soil areas and additional topsoil may be needed. (c) underground installation of utilities and site grading will probably encounter chalk bedrock (rippable). (d) corrosive to iron pipe.	Problems associated with construction in this association besides those inherent to the major soil series composing this association, will be related to slope, seepage, and depth to bedrock (see Plate II). Slopes of this association range from 3-8% and are particularly steep along the southern edges of major river systems and near the Austin-Eagle Ford contact in Hill County. Rippable chalk will usually be encountered at 12-16 inches. Soils are well to excessively well drained (droughty) andquite seepy. Design Notes: (a) foundations should rest on stable chalk bedrock. (b) lawn maintenance will be difficult without additional topsoil. (c) underground utility installation and grading will usually encounter rippable bedrock. (d) septic tank problems (depth to bedrock)	Soils are typically seepy due to underlying sands and gravels. Lower areas are occasionally flooded making construction in these area particularly hazardous. Where uncultivated, soils in this association support deciduous trees as Oak and Pecan. Soil depths (see Plate II) average 60 inches. This land is presently used for native pastures and pecan orchards. Design Notes: (a) potentially hazardous area due to flooding. (b) land is highly productive agriculturally for crops, trees. (c) paving over permeable soil areas may affect overall hydrology of river basin. (d) area of potential gravel deposits. (e) soils highly corrosive to unprotected iron pipes. (f) wooded areas along stream potential wildlife habitats, parkland potential.	This association and the Eddy-Stephen association possess the best engineering properties for construction within the study area. Besides engineering characteristics related to these A-7, CH-CL soils, the majority of problems encountered will be related to seepage, slope, and depth to bedrock (see Plate II). These soils are quite seepy and can remain wet for up to 30 days following a major rain. Slopes commonly range between 1-8% with north facing slopes along river systems usually being the steepest. Rippable chalk is found 16-35 inches below the soil surface. Detailed surveys of construction areas can alleviate major foundation problems by locating on thinner Eddy and Stephen soils. Design Notes: (a) clay stabilization needed for foundations, and other structures to control high shrink-swell soils. (b) utilities must be carefully protected from shrink-swell and corrosion. (c) good agricultural productivity. (d) erodable soils, septic tank problems (permeability, depth to bedrock).

	HOUSTON BLACK-BURLESON-LEWISVILLE ASSOCIATION	HOUSTON BLACK-HEIDEN ASSOCIATION	TRINITY ASSOCIATION
Description	This association occurs along the northern edge of Chambers Creek. It is composed of deep clays (60-80in.) and clay loams which have developed from calcareous alluvial sediments. This area is nearly level to gently sloping, and commonly contains gravel pockets at depths of 5-10ft. These pockets, predominately located under Lewisville soils, are old river point bar deposits. Where less fertile Burleson soils predominate, the crops and deciduous trees will be short and scrubby whereas areas of Houston Black and Lewisville soils will support well developed crops and larger transpiration trees. Depth to and Type Bedrock: extreme 60"-20' chalk potential stratified sands and gravels average 10' to chalk Shrink-Swell: very high, plasticity indexes range from about 25-35. Hydrologic Characteristics: USDA Hydrologic Group, B-D, moderate to very slow infiltration; permeability .06 to 2.0 in/hr.;runoff will typically be very high in this area. Location of more permeable Lewisville soils should be noted. Seeps are possible in these areas.	This association consists of deep (60 in.), dark gray black to olive, slowly permeable clays. These soils are situated on broad, nearly level to gently undulating erosional uplands. Soils of this association have formed from calcareous clays and alluvium of the Eagle Ford and Austin Chalk in the southern one-third of the study area. Depth to and Type of Bedrock: extreme 50-100" shale average 70" shale Shrink-Swell: very high, plasticity indexes range from 25-35+. Hydrologic Characteristics: USDA Hydrologic Group, D, very slow infiltration, high runoff; permeability less .06 in/hr.; cracks when dry.	This association consists of deep(60-70in.) heavy clays on the floodplain of Chambers Creek. This soil has developed from calcareous alluvium that has washed down from the Austin Chalk. Depth to and Type Bedrock: extreme 80" to sands, silts gravels 25' or more to chalk average 56" sands,silt gravel 10-15' chalk Shrink-Swell; very high, plasticity indexes range from 23-35+. Hydrologic Characteristics: USDA Hydrologic Group D, very slowly permeable, permeability less .06 in/hr..Cracks up to 30 in. deep when dry; occasionally flooded, ponding in depressions after rains.
Component Soils	Houston Black, Burleson, and Lewisville soils comprise 90% of this association; the remaining 10% is composed of Trinity, Frio, and Austin soils.	Black waxy Houston Black clays comprise 70% of the association, more sloping areas have Heiden soils 20%, and Austin, Trinity, Lamar, Altoga, and Brackett soils 10%.	The Trinity soils comprise 90% of this association, the remaining 10% is composed of Houston Black clays and Lewisville soils.
Engineering Hazards: Present Usage	Heavy plastic clays make construction practices in this area extremely hazardous. The area is presently cultivated and produces good yields of field crops. Design Notes: (a) potential gravel deposits under areas of mapped Lewisville soils. (b) clay stabilization will be needed for structures and utilities to minimize shrink-swell hazard. (c) good agricultural productivity. (d) some well water available from this area for minor irrigation. (e) erodable soils, septic tank problems in Houston Black, Burleson(permeability).	The majority of this area is cultivated and produces good yields of field crops. These soils are capable of producing good yields of grass forage if well managed. Construction practices are hazardous due to high shrink-swell, PVR, and corrosion potentials of the areas soils. Detailed soil maps, U.S. Conservation Dept. services and soil stabilization procedures are recommended in this area. Design Notes: (a) special engineered foundations, structures and/or clay stabilization will be needed for soils (b) soils are highly erodable (c) good agricultural productivity (d) highly corrosive iron pipe (e) septic tank problems (permeability)	Construction in this area is extremely hazardous because of flooding. During and immediately following rains of only average intensity, runoff from adjacent areas is likely to cause ponding. Design Notes: (a) potential flood hazard. (b) wooded areas potential wildlife habitats, parkland. (c) septic tanks should not be used in this soil (flooding, permeability).

Plate No. IV(a)

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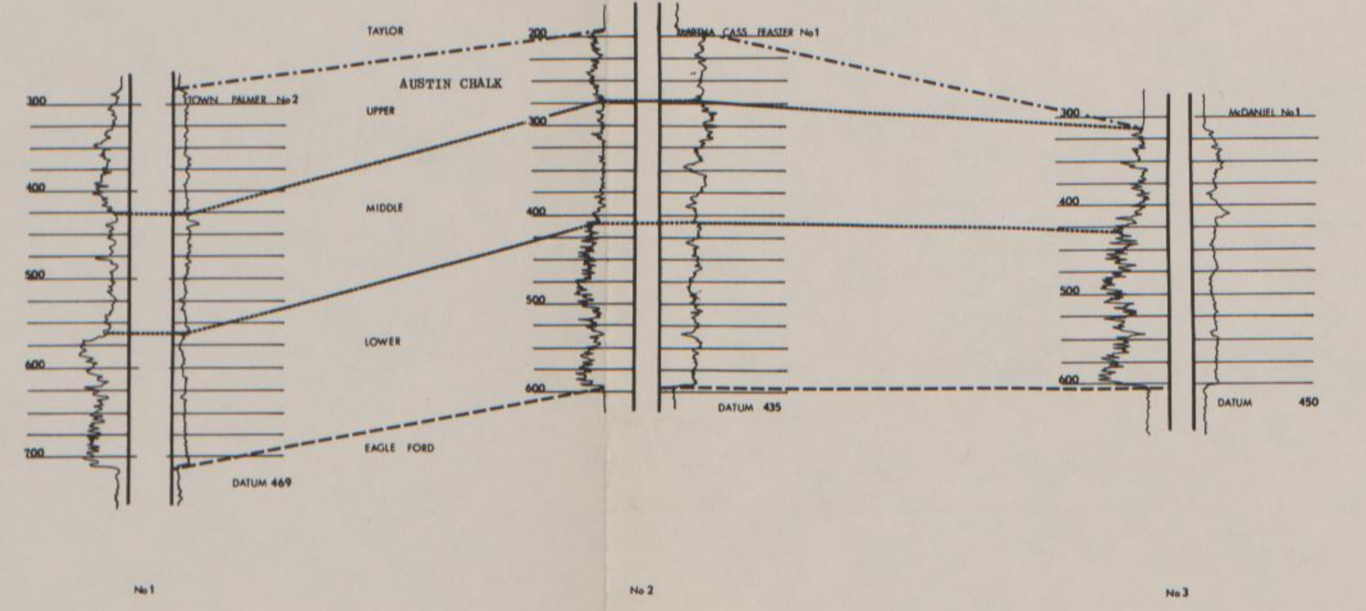
ROCK PROPERTIES OF GROWTH CORRIDOR

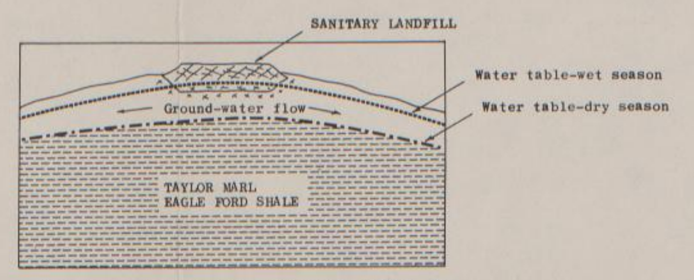
SYSTEM	SERIES	GROUP	GEOLOGIC UNIT	LITHOLOGIC CHARACTERISTICS	THICKNESS	MINERALOGICAL COMPOSITION	SHEAR STRENGTH AND BEARING CAPACITY	SLOPE STABILITY	EXCAVATION PROPERTIES	PROPERTIES AS FILL	POTENTIAL VERTICAL RISE (PVR)	FREE GROUNDWATER	PERMEABILITY	ASSOCIATED SOILS	ECONOMIC ASPECTS
QUATERNARY	RECENT		ALLUVIAL SILTS AND CLAYS	Dark gray-brown silty clay, numerous caliche nodules and chalk fragments rich in humus			Shear strength: low; no real quantitative information available. Bearing capacity: low; .7-1.8 tons per square foot; values subject to frequent lateral change due to differences in moisture content, clay-silt ratio, and nature of underlying deposits.	Poor: plasticity of wet clays, relatively low permeability and high inherent moisture content make highly unstable; maximum 10 degrees.	Easily removed light machinery; slumping straight walled excavations; becomes plastic and sticky when wet, high porosity, low permeability, ponding and drainage problems after rains; low water table(10-15ft.) in many places.	Unstable; easily eroded, slow to moderately permeable depending on degree of compaction; high shrink-swell.	High; 2-7% by volume depending on clay type and moisture content	No potable water occurs in clays; high porosity and inherent moisture content, low permeability; gravel pockets may underly some areas and contain small amounts water.	Severe limitations septic systems .15-1.0in./hour	Burleson, Heiden, Houston Black series.	Depending upon frequency of flooding are excellent farm and range lands.
	PLEISTOCENE		FLUVIATE TERRACE DEPOSITS	Lenses of unconsolidated sand, rounded chalks, limestone, sandy clay, quartzite pebbles, and fossil fragments over Austin Chalk; clay and sandy clay over Taylor Marl and Eagle Ford shales.	45	Not available	Shear strength: low; no real quantitative information available. Bearing capacity: low to intermediate; highly variable; values range from 1.1 to 4.0 tons per square foot; depends upon deposit composition, water content, confining pressure, and whether load static or dynamic.	Natural slope angles up to 10 degrees are maintained due to clay binder and presence of some $CaCO_3$ cemented conglomerates.	Easily excavated light machinery; minor ripping may be required in areas where gravels cemented with $CaCO_3$; slope retention usually adequate unless groundwater encountered; possible at depths of 10-15ft.	Gravels and sands good as above grade fill; depends upon amount clay binder; exceptions when too little or too much clay binder present.	Low: clays incorporated in sand and gravel pore structure	Small to moderate yeilds; satifactory for irrigation in many cases; may be polluted downstream from major urban areas; seasonal usage; only water suitable for sustained irrigation	Moderate permeability; lower terraces pose disposal problems due to high water table; septic systems should be discouraged in these areas due to number stock and irrigation wells tapping this aquifer.	Austin, Eddy, Stephen, Brackett series.	Source of sand, gravel; furnish some water for irrigation and domestic use.
CRETACEOUS	GULF		TAYLOR MARL	Blue-gray, fine grained, laminated calcareous shale with blocky conchoidal fracture; weathers to tan-gray fissil unit with orange limonite stains along joint and bedding planes.	100ft.	60-70% montmorillanite and illite (clays), 30-40% $CaCO_3$ cementing agent and minor amounts of silt, glauconite, hematite, and pyrite	Shearing strength: low; remolded sample tested 3.8 pounds per square inch at zero pounds lateral pressure, 29.2 pounds per square inch at fifteen pounds lateral pressure. Bearing capacity: variable; low to intermediate; increases with increasing depth; at 10-15 feet about 3.5 tons per square foot, at 40-50 feet about 15 tons per square foot.	Natural slope angles up to 20 degrees(slightly higher in north facing slopes 2-3 degrees); no predictable stable angle of repose; practices which increase moisture content, add weight to slope or change slope height augment failure; maximum approx. 18 degrees; also erodes easily and deep rills(8-10ft.) form if vegetation removed.	Easily excavated with light machinery; unweathered blue-gray Taylor will be blocky compared to fissil, friable buff to tan weathered unit; shoring necessary for walls, slopes will usually slump if over 18 degrees; ponding possible after rain; clays will become sticky and hard to manage; near Austin contact stringers of chalk about 2 feet thick may be encountered; are rippable.	Unstable: moderately permeable dry to impermeable when wet; eroded easily; low slope retention; high shrink-swell.	Very high; high percentages of montmorillanitic clays; vertical displacements up to 8in. or more	No potable water found in study area.	Low; sporadic permeability; minor infiltration through dessication cracks will cease shortly after wetting due to swelling of montmorillanitic clays. properties make it excellent area for sanitary landfill operations	Houston Black, Heiden, Burleson, Lamar, and Lewisville series.	Marginal ceramic clays; farm and range-land capabilities
			AUSTIN CHALK	Divisible into three lithologic units: 'Lower' chalk, 'Middle' marl, and 'Upper' chalk; Lower and Upper chalk display gray, white weathering chalk beds(2-5ft.) which alternate with thin beds(1-2ft.) calcareous shale; Middle marl unit displays powdery-gray to buff weathering calcareous shale(2-5ft.) interbedded with chalks(1-2ft.)	510ft.	$CaCO_3$ approximately 70-85% $MgCO_3$ approximately .58-1.37% Al_2O_3 approximately 1.5-2.8% SiO_2 approximately 8-15% with minor amounts of insoluables.	Shearing strength: high; values ranging from 9 pounds per square inch at zero pounds lateral pressure to 110 pounds per square inch at 15 pounds lateral pressure on remolded samples; values will vary with changing lithologies in the Austin. Bearing capacity: high; 14-35 tons per square foot. Knowledge of geologic section and borings needed near Austin-Eagle Ford and Austin-Taylor Marl contacts due to high PVR and low bearing capacities of these units. (Above values for chalk beds; marl beds will probably behave similar to Taylor Marl units and should be avoided).	Natural slopes up to 30-40 degrees maintained with minor spalling in Middle marl unit and minor rock-falls along dominant joint systems especially in Lower and Upper chalk units; undermining of chalk will occur near Austin-Eagle Ford contact especially if vegetation is removed.	Massive, resistant formation; rippable; ripping easiest at right angles to major joint systems(North 45degrees East); higher percentage of blasting will be required in Upper and Lower chalk units; blasting hazardous in Austin for fault and joint systems transmit shock waves for considerable distances parallel to alignments.	Excellent fill material; high slope stability; fairly resistant to erosion; moderate permeability; excessive water percolation will dissolve $CaCO_3$ rich chalk; marl and clay-rich seams should be avoided; Upper and Lower chalk units better source than Middle marl unit.	Nonexistant in chalk to high if building rests on marl bed; soils developed over Austin high shrink-swell; possibly high depending upon depth to shales near Eagle Ford.	Small amounts unpotable water.	Moderate; due to joint and fracture systems which may conduct water like pipeline; seepage problems possible for up to 30 days following major rain.	Burleson, Trinity, Frio, Lewisville series.	Used in manufacture of cement; low grade sub-base material.
			EAGLE FORD SHALE	Dark-gray, tan weathering, plastic non-calcareous shales(2-8%), rich in bentonites, immediately under Austin Chalk; grades rapidly into predominantly gray, tan weathering, gritty textured, calcareous shales with interbedded limestone stringers(6in.) and bentonite seams near western edge of Hillsboro, Texas.	310ft.	70% clay, 4% $CaCO_3$, 4% iron oxides and lesser insoluables: SiO_2--55% Al_2O_3-- 20% H_2O--6% $CaCO_3$--variable; depends upon position in section 3% average upper 40ft. to 15% possible in lower unit west of Hillsboro, Texas. Organics-- 1.55% Fe_2O_3--4%	Shearing strength: low; no real quantitative data available. Bearing capacity: low to intermediate; highly variable, generally increasing with depth; values range 3.5 tons per square foot at 5-12 feet to 18 tons per square foot; surface bearing capacity may be as low as 2 tons per square foot; knowledge of local geologic section important when making tests; values misleading if encounter limestone flags.	Natural slopes range 0-15 degrees; upper 30-50ft. less stable and more easily eroded than lower more calcareous unit; stability depends upon moisture content, overburden, vegetation, and slope height; no single stable angle of repose; maximum 18 degrees.	Easily excavated when dry; when wet disintegrates into highly plastic mass of clay particles enclosing small chips of shale; slumping when slopes exceed 18 degrees; minor ripping may be necessary near western edge Hillsboro, Texas, limestone stringers; ponding after rains; easily eroded, especially upper 30-50ft. of shale unit.	Unstable fill material; high bentonite content; high shrink-swell; impermeable due to high clay content; slumping probable slopes greater 18 degrees.	High; high percentage bentonite	No potable water found in study area; minor amounts found in shallow wells and used for domestic and livestock.	Highly impermeable; swelling of clays retards infiltration properties make it excellent area for sanitary landfill operations	Houston Black, Lewisville, Lamar, Heiden series.	Raw material for cement; use as expanded aggregate.
			WOODBINE FORMATION	Thin-massive bedded sandstone with varying amounts of interbedded shale and sandy shale; sandstone thicker in lower part of formation than in upper; sandstone bodies are discontinuous and irregular.	400ft.	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	A principal aquifer in the study area; supplies most of groundwater used in area; water in upper part of formation has higher mineral content so lower part of formation more important as aquifer.	Not applicable	Not applicable	Not applicable
	COMANCHE	WASHITA (undifferentiated)		Limestone, shale, and sandy to calcareous shale.	500ft.	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not known to yield water in study area.	Not applicable	Not applicable	Not applicable
		UPPER FREDERICKSBURG (undifferentiated)		Limestones, shale, and calcareous silty to sandy shale; some shell agglomerate.	200ft.	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not known to yield water in study area.	Not applicable	Not applicable	Massive dense, high purity reef and reef associated Edwards limestone important source of construction rock in Central Texas. 45 miles west of Waxahachie in the north and 15 miles west of Hillsboro
			PALUXY SAND	Friable packsands; beds of homogeneous fine loosely cemented white quartz sand with varying amounts of clay, shale, lignite, and pyrite nodules.	180ft.	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Yields small to moderate quantities of slightly saline water for domestic and livestock use.	Not applicable	Not applicable	Not applicable
		TRINITY	GLEN ROSE LIMESTONE	Medium to thick bedded, dense crystalline limestone, earthy limestone, gray-black shales, with some interbedded sandy shales, and anhydrite.	720ft.	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not known to yield water in study area.	Not applicable	Not applicable	Not applicable
			TRAVIS PEAK FORMATION	Coarse to fine grained sandstone in upper and lower parts with limestone and some shale dominating the middle; upper sandstone changes to shale down-dip.	480ft.	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Small to moderate quantities of water may be available; not tapped in study area.	Not applicable	Not applicable	Not applicable
			HOSSTON (Basal-Trinity sands)	Massive sandstone containing sparse interbeds of siltstone, varigated red and green shale, sandy shale, marl and limestone.	310ft.	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	A principal aquifer in the study area; yields up to 500gpm for public supply, industrial, and some domestic and livestock use; water quality better than that in other principal aquifers.	Not applicable	Not applicable	Not applicable
		PRE-CRETACEOUS		Black shales, quartzite, and indurated sandstone.		Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not likely source water.	Not applicable	Not applicable	Not applicable



DIFFERENTIATION OF THE AUSTIN CHALK IN WELL LOGS
WITHIN THE STUDY AREA

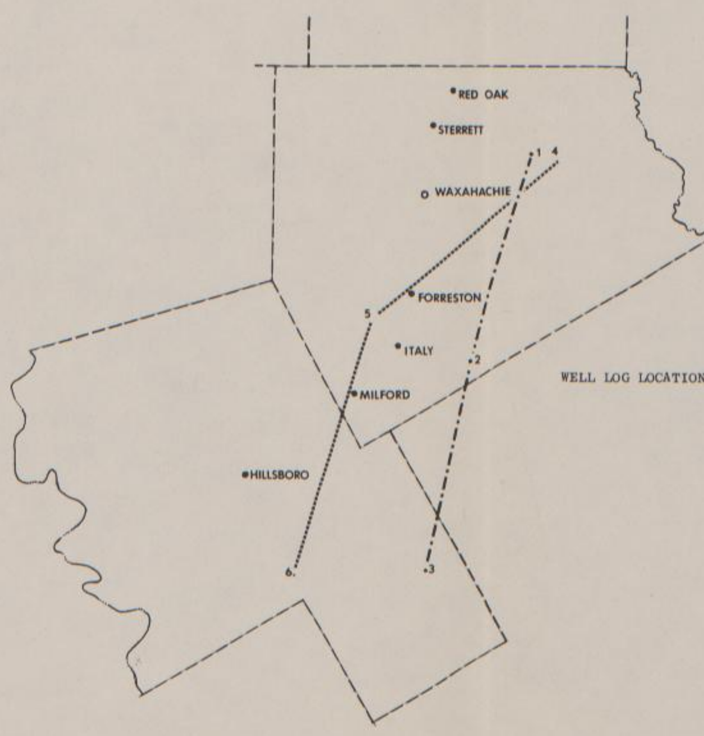
CORRELATION SECTION 1,2,3

Flawn, Turk, and Leach(1970) state that notwithstanding the new ideas and research in progress, the most satisfactory economic means of disposing of solid municipal wastes(excluding large volumes of wastes produced by mines, smelters, and other large industries) is the sanitary landfill.



(Adapted from Flawn, Turk, and Leach, 1970,p. 7)

Low permeability host, moderate climate. 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 low permeability of the host prevents extensive movement of the contaminants. Typical rates of groundwater movement away from the fill would be less than a foot a year(Flawn, Turk, Leach,1970,p. 7).



WELL LOG LOCATIONS

Plate No. IV(b)

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CORRELATION SECTION 4,5,6

DESIGN CONSIDERATIONS OF GROWTH CORRIDOR

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Plate No. V

DESIGN GROUPS DESCRIPTIONS	RECOMMENDED LAND USE	LIMITATIONS FOR CONSTRUCTION PRACTICES
GROUP 1 Thin(12-25in.) Eddy-Stephen soils to moderately thin (20-40in.) Austin-Brackett-Stephen soils; "lower" Austin Chalk bedrock; entrenched drainage, relatively flat devides; greater percentage of high transpiration plants e.g. Post and Shummard Oak, than other design groups; larger trees occur along the edges of present river devides and along the Austin-Eagle Ford escarpment; elevation ranges from 800ft. above sea level near Austin-Eagle Ford escarpment to 700ft. near the contact with Design Group 2.	Residential with planned parkland areas.	Minimal foundation problems if strip off soil cover; near Austin Chalk-Eagle Ford escarpment build back 100-200 feet; excavation difficult, blasting will probably be required for small deep excavations, chalk usually rippable normal to dominant fracture pattern; possible seepage problems after large rains; bentonite seams in marl layers in chalk may cause septic problems.
GROUP 2 Thin(12-15in.) Eddy-Stephen to moderately thin(20-40in.) Austin-Brackett-Stephen, to deep(40-80in.) Houston Black-Austin soils; "middle" Austin Chalk bedrock; rounded devides and low relief; dendritic drainage; predominantly cultivated; large vegetation e.g. oak and pecan, confined to flood plains; elevation ranges from 700ft. above sea level near contact with design group 1 to 600ft. near the contact with Design Group 3.	Commercial; residential about 100-200 feet back from south slopes along west-east flowing rivers	Deep, highly erodable, high shrink-swell soils; bentonite seams in marl beds in bedrock; soil and bedrock conditions require large septic fields; chalk rippable, easiest normal to dominant joint trend, little blasting required; ponding after rains over soils probable.
GROUP 3 Thin(12-15in.) Eddy-Stephen, to moderately thin(20-40in.) Austin-Brackett-Stephen, to deep(40-80in.) Houston Black soils; "upper" Austin Chalk bedrock; level to gently undulating relief; predominantly cultivated; clustered vegetation, larger trees confined to floodplains; elevation ranges from 600ft. above sea level near the contact with Design Group 2 to 520ft. near the contact with the Lower Taylor Marl in Design Group 4.	Industrial.	High shrink-swell clayey soils, foundations should be anchored in stable bedrock; areas of thinner soil cover are available and detailed soil and mapping of geology should preceed any major construction; chalk is often rippable but blasting will probably be required.
GROUP 4 Thick(40-80in.) Houston Black-Heiden soils; Eagle Ford and Taylor Marl shale bedrock; clustered scrub vegetation (mesquite); flat to gently undulating relief; elevations in the Eagle Ford range from 700ft. above sea level near contact with Design Group 1 to 650ft. above sea level near the southwest border of the study area; Taylor elevations ranged from 540ft. to 510ft. above sea level.	Agriculture and parklands; severe limitations for most construction practices. excellent area for sanitary landfill operations	High shrink-swell, erodable, low permeability in soils and bedrock; foundations should be anchored in unweathered bedrock; stablization procedures will be required, large septic fields required; excavation difficult when wet in plastic-sticky soils; slopes unstable in shallow excavations when wet, no single stable natural angle of repose, depends slope height, vegetation etc.
GROUP 5 Thick(40-80in.) Trinity-Frio-Lewisville soils; terrace gravels along major river systems in the area up to 30ft. in thickness; flatlands, used for range and pasture; large percentage high transpiration plants e.g. pecan, oak.	Parkland, pasture, and rangeland.	Flooding hazard, high shrink-swell soils, seeps after rains, areas of economic gravel deposits.

GENERAL CLIMATIC DESIGN CONSIDERATIONS OF THE STUDY AREA

1. residential areas should be built on the western, preferably southwestern, side of the study area due to the prevailing wind directions (Figure 26) ; industry should locate on the east side.

2. parks should be built at right angles, trend east-west to north-south road systems; this will augment local cooling of the prevailing winds and reduce wind velocities up to 80% within the park areas.

3. park areas should be planned in general zoning for they tend to decrease the maximum temperatures, act as sound breaks, and reduce suspended dust upwards of 20%(even within cities) (Landsberg 1958, p. 393).

4. suggested that major streets be aligned in a north-south direction; this will allow prevailing winds passage as well as promote construction in these directions; houses would therefore have maximum east-west exposures and subsequently be shaded by houses built on their southern exposures where maximum insolation occurs.

5. knowledge of temperature extremes(Figure 23) should be compared to humidity values(Figure 39) and general comfort zones(Figure 40) for proper design of habitats.

6. streets, when possible, should have center medians lined with large vegetation; this will tend to keep streets cooler and reduce overall radiation, (heats up to 20 F greater than air temperature), and heating effects on adjacent housing; this would be particularly beneficial on east-west trending streets in the study area.

7. residential areas built on the west and southwest portion of the study area will encounter slightly hilly terrain; here microclimatic conditions should be reviewed prior to zoning; while cognizant of geologic and pedologic parameters, parks should occupy exposed hilltops, major residential areas should be built adjacent to southeast and south slopes near parkland areas, and valleys should be left as parkland.

8. precipitation figures(35-36,38) show storm frequency and rainfall intensities; while obviously of interest in agricultural practices, percentages should also be considered in slope design, erodability of land, type of vegetation, as well as in design of sewers and drainage facilities; major construction should be planned for dry periods for area soils and Taylor and Eagle Ford will be hard to manage when wet.

9. heating and cooling degree days(Figures 41,42) show the thesis area to have minimal energy requirements from the middle of September through October and from the middle of April to the beginning of June; storage facilities for fuel should be planned accordingly.

10. proper control of sunlight is desirable not only from the standpoint of economy, but also for the sake of the general efficiency of people; prior to construction, solar angles(Figure 20) and relief of the area should be considered so building orientation and general design configurations 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 recieve 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 will usually occur on slopes with a south-west orientation.

11. because solar energies average around 1.5 x 10^6BTU per summer day and 7.5 x 10^4 in winter(Figure 20) a cheap source of energy for solar furnaces and possibly air conditioning is concieveably available; Landsberg(1958) states that a test structure in Boston, Mass. with a roof surface of 400 sq. feet operated with a 30% efficiency during winter months; less than one half of the required heat per month had to be artificially supplied in this area of high cloudiness.

CLIMATIC CHANGES PRODUCED BY CITIES AND URBANIZATION

ELEMENT	COMPARISON WITH RURAL ENVIRONS
Temperature	
Annual mean	1.0 to 1.5 F higher
Winter minima	2.0 to 3.0 F higher
Relative humidity	
Annual mean	6% lower
Winter	2% lower
Summer	8% lower
Dust particles	10 times more
Cloudiness	
Clouds	5-10% more
Fog, winter	100% more
Fog, summer	30% more
Radiation	
Total on horizontal surface	15-20% less
Ultraviolet, winter	30% less
Ultraviolet, summer	5% less
Wind speed	
Annual mean	20-30% lower
Extreme gusts	10-20% lower
Calms	5-20% more
Precipitation	
Amounts	5-10% more
Days with less .2 inch	10% more

(Adapted from Detwyler, 1971, p. 132)

HYDROLOGY: PROJECTED WATER AVAILABILITY AND DESIGN CONSIDERATIONS

1. appears that small additional supply of above standard groundwater is presently available in the study area without depleting the aquifers; while pumpage of 3500 acre-feet from the Woodbine is probably slightly more than the average rate of replenishment, pumpage from the Hosston is about 1000 acre-feet less than the assumed average; small additional amounts(1000 acre-feet) of slightly saline water is available from the Paluxy.

2. recommended that farm ponds(one acre or less) be built with their long axis normal to the major north-south prevailing winds; a pond exposing 435 feet normal to the prevailing wind and 100 feet parallel, saved twice as much per unit volume of water as compared to one with the longest shoreline parallel to the prevailing wind(Meinke and Waldrip 1964).

3. high runoff of the area makes additional surface water available for surface or possibly subsurface reservoir construction; water flowing into the present Waxahachie or other major reservoir might conceivably be pumped into the lower Woodbine (after chemical testing), during periods of high stream discharge(Febuary-June) for storage until periods of minimum flow(August-September).

4. another source of water available is from return flows from municipal and industrial use:
    a. projected that the quantity of freshwater available from return flows will double within the next 25 years.
    b. based on synthesis of projected municipal and industrial requirements, water from projected return flows could handle up to one half of these requirements through the year 2020.
    c. quantity of water available from return flow is directly related to quality control procedures
        1. Wells and Gloyna(1966) state that the additional nutrients and oxygen demanding wastes that will be produced by urban run-off and agricultural return flow will make the state's waters unavailable for man's indirect use and personal enjoyment
        2. (idem, 1966) if no additional reductions in concentrations are provided by denitrification and phosphate removal processes, and the present quantities are projected to the year 2020, it would be equivalent to removing from service today approximately two-thirds of the existing wastewater treatment plants.

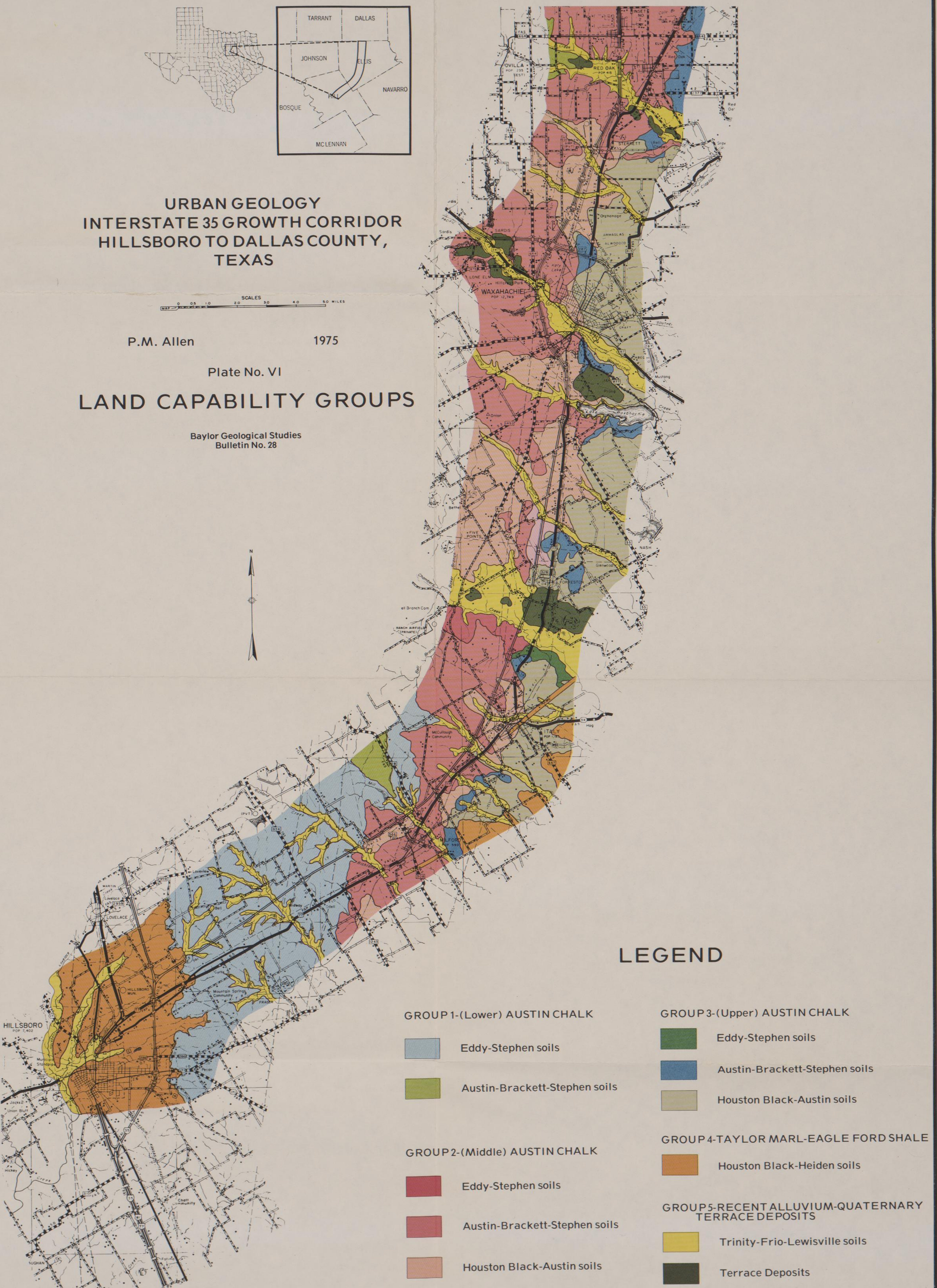
5. based on a comprehensive water survey of the Trinity Basin (U.S. Army Corps of Engineers, 1962, p.11-2) current surface water resources are sufficient to satisfy all water requirements within the study area until the year 2070; this is dependent upon the waste-treatment and water quality control procedures.

6. substantial property damage is possible if the total effect of urbanization is not taken into account in design of stream channel improvements; when 3.53 inches of rain fell in Turtle Creek in Dallas within a 5 hour period, runoff was 92% from this completely urbanized area of 7.89 square miles; from a nearby partly urbanized area of 7.51 square miles runoff was 85% from 4.86 inches of rain (U.S. Geologic Survey Prof. Paper 600-A, 1968, p. 371).

7. in early stages of urbanization within the study area, care must be exercised to avoid seriously polluting area streams before municipal sewers and treatment systems are installed; no septic tank should be located closer than 300 feet from tributaries (Leopold, 1968, p. 16), Linsey and Franzini (1964 p. 570) state that septic tank effluent is foul smelling, contains 50-70% suspended solids and has a very high BOD (.17lb. per capita per day); in all cases soil and geology should be reviewed prior to installation.

8. on the Passaic River in Little Falls, New Jersey between 1948-55 the dissolved solids content of the water increased 10ppm; from 1955-63 the dissolved solids content increased 75ppm or a 40% increase in a period of eight years due to increased urbanization (Detwyler 1971, p. 212).

9. sediment derived from erosion from an acre of ground under construction may exceed 20,000 to 40,000 times the amount eroded from farms and woodlands in an equivalent period of time (Detwyler 1971, p. 212).



URBAN GEOLOGY
INTERSTATE 35 GROWTH CORRIDOR
HILLSBORO TO DALLAS COUNTY, TEXAS

P.M. Allen 1975

Plate No. VI

LAND CAPABILITY GROUPS

Baylor Geological Studies
Bulletin No. 28

LEGEND

GROUP 1-(Lower) AUSTIN CHALK
- ▨ Eddy-Stephen soils
- ▨ Austin-Brackett-Stephen soils

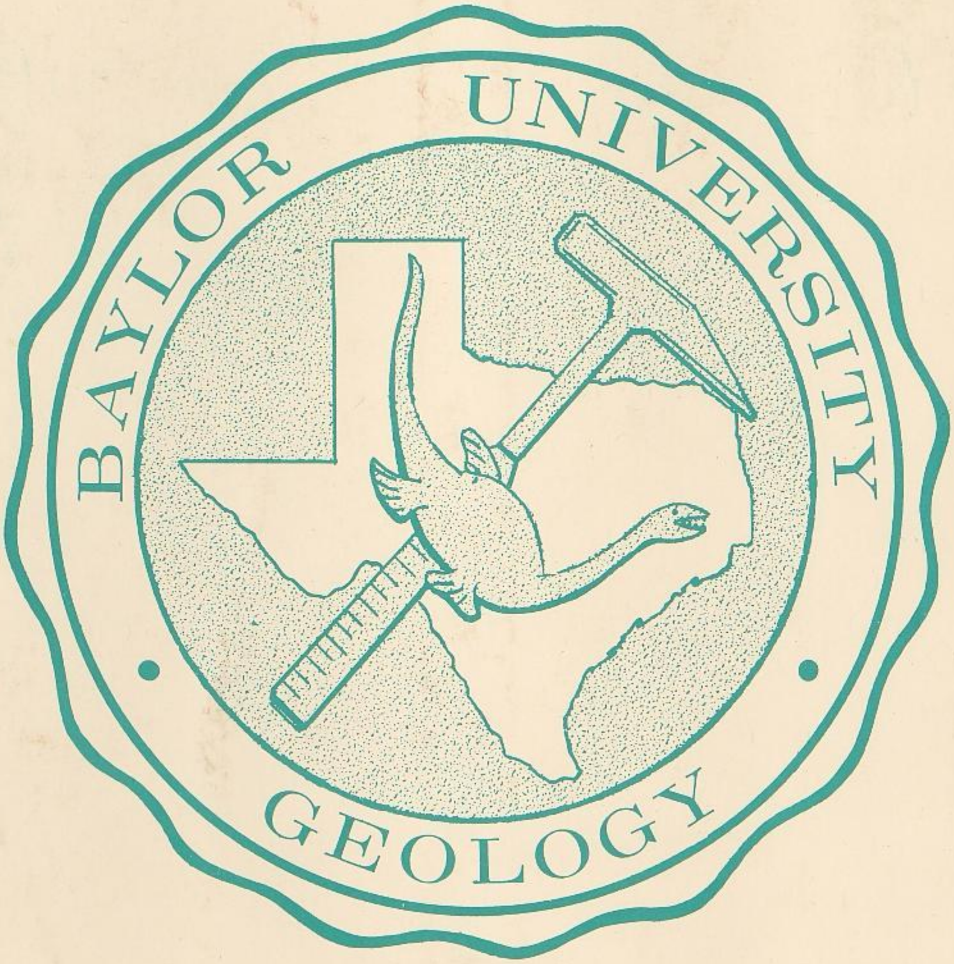
GROUP 2-(Middle) AUSTIN CHALK
- ▨ Eddy-Stephen soils
- ▨ Austin-Brackett-Stephen soils
- ▨ Houston Black-Austin soils

GROUP 3-(Upper) AUSTIN CHALK
- ▨ Eddy-Stephen soils
- ▨ Austin-Brackett-Stephen soils
- ▨ Houston Black-Austin soils

GROUP 4-TAYLOR MARL-EAGLE FORD SHALE
- ▨ Houston Black-Heiden soils

GROUP 5-RECENT ALLUVIUM-QUATERNARY TERRACE DEPOSITS
- ▨ Trinity-Frio-Lewisville soils
- ▨ Terrace Deposits

Base Map adapted from Texas State Highway Dept. county maps.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