ENVIRONMENTAL GEOLOGY OF THE

MANNFORD AREA, OKLAHOMA

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ABSTRACT

This study evaluates the physical environment of the Mannford area, Oklahoma, which has experienced a 214 per cent growth since 1959, in terms of the geologically determined or influenced variables affecting land-use planning. A series of 12 maps has been produced to increase the knowledge and understanding of the environmental geology of the Mannford area.

The Mannford area is situated in east-central Oklahoma, adjacent to Keystone Reservoir, in the Eastern Sandstone Cuesta Plains. The topography is dominated by a series of sandstone-capped benches. Drainage is basically dendritic and intermittent. Sandy terrace deposits of the Cimarron River and of Salt Creek occur as remnants above reservoir level. Silty terrace deposits occur along the intermittent tributaries of Salt Creek.

The climate generally poses little problem in construction. Periods of excessive precipitation in the Spring and Winter ice and snow storms occasionally may interfere with construction schedules.

Bedrock in the study area consists of approximately 220 ft. of alternating sandstones and shales of Upper Pennsylvanian age, which dip westward at approximately 40 ft./mi. The Wann, Barnsdall, and Tallant Formations consist of medium- to very fine-grained sandstones and sandy to silty shales. The Vamoosa, the uppermost formation in the area, is a coarse- to fine-grained sandstone which overlies the Tallant in the western part of the area. Unconsolidated surficial de-

posits, excluding pedologic soils, cover approximately 50 per cent of the study area and include colluvium, flood plain and terrace alluvium, and artificial fill. Two dominant joint sets, averaging N.40°W. and N.50°E, have had a moderate effect on the area's dendritic drainage.

Soils in the area, of the Cross Timbers Pedologic Province and the Darnell-Stephenville and Dougherty-Teller-Yahola Soil Associations, are light-colored and moderately leached. A moderate to good correlation is found between the engineering properties of the soils and their parent materials.

The only significant sources of ground water known to occur in the area are 2 sandstone aquifers in the middle part of the Wann Formation. It is possible, however, that other aquifers occur at greater depth. Intermittent springs and seeps pose local problems to roadbeds, basements, and foundations in the study area where they occur in conjunction with moderately to highly plastic soils.

A series of 12 maps, prepared at a scale of 1:12,000, characterize the study area's environmental geology and its application to specific land uses. These factor maps depict:

Topography--indicates the changes in elevation on a 10-ft. contour interval and shows the works of man.

Drainage--shows the network of intermittent streams which must be considered in the planning of storm drainage networks.

Slope--shows the distribution of slopes of various amounts; economic costs increase substantially when slopes greater than 5 per cent are altered for structures.

Bedrock geology--provides a picture of the location, type, and character of the bedrock in the area as if all unconsolidated deposits had been removed.

Surficial geology--identifies the type, character, and distribution of bedrock, alluvium, colluvium, and artificial fill as if all pedologic soils had been removed.

Soil--shows the distribution and textural character of pedologic soils in the area and serves as a base map for other soil-related factor maps.

Depth to bedrock--shows the distribution and thickness of regolith and where bedrock may interfere with subsurface construction.

Erosion susceptibility--divides the study area into zones of varying erosional susceptibility.

Corrosivity potential--shows zones of varying corrosivity for uncoated steel pipe and identifies particularly corrosive areas where composition or coated steel pipe should be considered.

Recreational suitability--delineates zones of varying recreational suitability.

Plasticity of solum and of subsoil--shows the distribution of plastic soils expected to interfere with construction of roads, basements, and foundations.

Geologic constraint--a suitability map incorporating data from the corrosivity, plasticity, depth to bedrock, and erosion susceptibility maps; divides the study area into areas having minor, moderate, and major geologic constraints for most engineering and planning purposes associated with urban development.

Potential environmental geologic problems include waste disposal and Keystone Reservoir pollution. Soil erosion is a problem. Slope stability and excavation problems occur locally where spring and seep conditions and plastic soils occur. Mannford also is in an area where the possibility of earthquakes does exist. The probability of earthquakes that would be dangerous to life and property, however, is low.

INTRODUCTION

This study summarizes the environmental geology of the Mannford area and discusses in some detail many of the geologically influenced problems associated with its rapid transition from a rural community to a satellite city of Tulsa, Oklahoma. Although the study concerns only the Mannford area, many of the techniques presented can be applied to similar areas.

Geological factors determine to a large degree an area's physical environment and thus often control or substantially affect the growth and development of a community. The physical development of urban areas is determined largely by engineers, architects, and planners who must deal with the environment and the geologic factors affecting it. The physical environment is by necessity altered during community development. Structures of many kinds are built on, with, or through geological materials. Structures, covering areas formerly undeveloped, increase runoff and reduce natural infiltration and recharge of underground water. This increased runoff will require consideration in local drainage networks prior to construction. Supplies of water are depleted by use or contamination. Sand and gravel resources are consumed or covered by construction.

As a city grows, less desirable sites are generally bypassed. Many of these sites are undesirable because foundation conditions are poor. Adequate knowledge of local surficial geologic conditions enables the engineer to overcome or at least minimize the effects of poor foundation conditions.

Long-range planning is a necessity in the development of urban areas. Planners need detailed geologic and hydrologic data in order to plan the efficient use of natural resources and to insure that community development harmonizes with the physical environment.

Objectives and Methods

The primary objective of this study is to provide a comprehensive picture of the physical environment of the Mannford area for planning, engineering, and construction uses. This report is intended for use by laymen, politicians, engineers, planners, architects, geologists, and others. It is hoped that the study, one of the first of its kind in Oklahoma, also will serve as a type example for future environmental studies in Oklahoma. Mannford was selected for an environmental geology study principally for 2 reasons, the rapid population growth as a result of its proximity to Tulsa and the interest of the Mannford city government.

Assessment of the physical environment in the Mannford area required the use of a variety of topographic, climatic, soil, and engineering geology data (Table 1). All available data, both published and unpublished, were collected from the Oklahoma Geological Survey, the United States Soil Conservation Service, the Oklahoma Highway Department, the U.S. Army Corps of Engineers, and the city of Mannford. These data were collected and systematized into a comprehensive picture of the physical environment of the Mannford area. Existing data were supplemented by field mapping of the surficial and bedrock geology as well as a shallow seismic survey of the depth to bedrock.

Table 1.-Physical factors considered in the environmental geology of the Mannford area, Oklahoma.

Elevation	Drainage
Climate	Seismic velocity of bedrock
Slope	Soils
Surficial geology	Plasticity characteristics
Bedrock geology	pH
Structural geology	Grain size
Depth to bedrock	
Resistivity	

Factors modified from Hilpman and Stewart (1968).

A series of 12 maps has been produced for the Mannford area which describe, at a scale of 1:12,000, many of the factors affecting the physical environment of the Mannford area. These maps are generalized and are based, in part, on interpretation and judgment. While useful for planning and other general purposes, the maps, engineering test data, and interpretations should not be relied upon for the evaluation of individual sites. On-site testing at individual sites is recommended to determine if they meet requirements for a specific project.

The methods employed in producing the 12 factor maps are discussed at length in Appendix 3: Procedures and Problems Related to Factor Map Preparation (p. 84). Bedrock and soil engineering data are discussed in the Engineering Geology Data section, and detailed interpretations of environmental conditions are included in the Environmental Geology Interpretations section. A glossary (Appendix 1, p. 76) is included with brief definitions of the geologic terminology utilized in this report. Technical terminology, however, is reduced to a minimum except where clarity would be sacrificed.

Location of Study Area

The Mannford area is a 12 sq. mi. rectangle in northeastern Cimarron Township, Creek County, Oklahoma (Fig. 1). The area is located approximately 17 mi. west of Tulsa on Oklahoma Highway 51 and includes the Salt Creek arm of Keystone Reservoir and the corporate limits of Mannford, Oklahoma.

Economic and Population Growth

The current economic growth of the Mannford area is attributable to the recreational attraction of Keystone Reservoir, completed in 1964, and the anticipated good transportation routes to nearby Tulsa (Morgan, 1970, p. 57). A recent survey of the Mannford Public Schools shows a growth from 328 students in 1959 to 754 in November, 1971 (F. O. Stout, 1971). The population of the Mannford area has increased 214 per cent since 1959, to approximately 1200 persons, and is expected by the United States Census Bureau to approach 20,000 to 30,000 residents by 1995 (Morgan, 1970, p. 30, 58).

Previous Investigations

A report on the geology of Creek County, Oklahoma, which includes a geologic map of the county at a scale of 1:62,500, was published by the Oklahoma Geological Survey in 1959 (M. C. Oakes, 1959). The Creek County Soil Survey by Harvey C. Oakes (1959) provides soil information concerning soil distribution and texture. The soil map also serves as a base map for locating and grouping soils having similar engineering characteristics. Hilpman and Stewart (1968) conducted a pilot study to

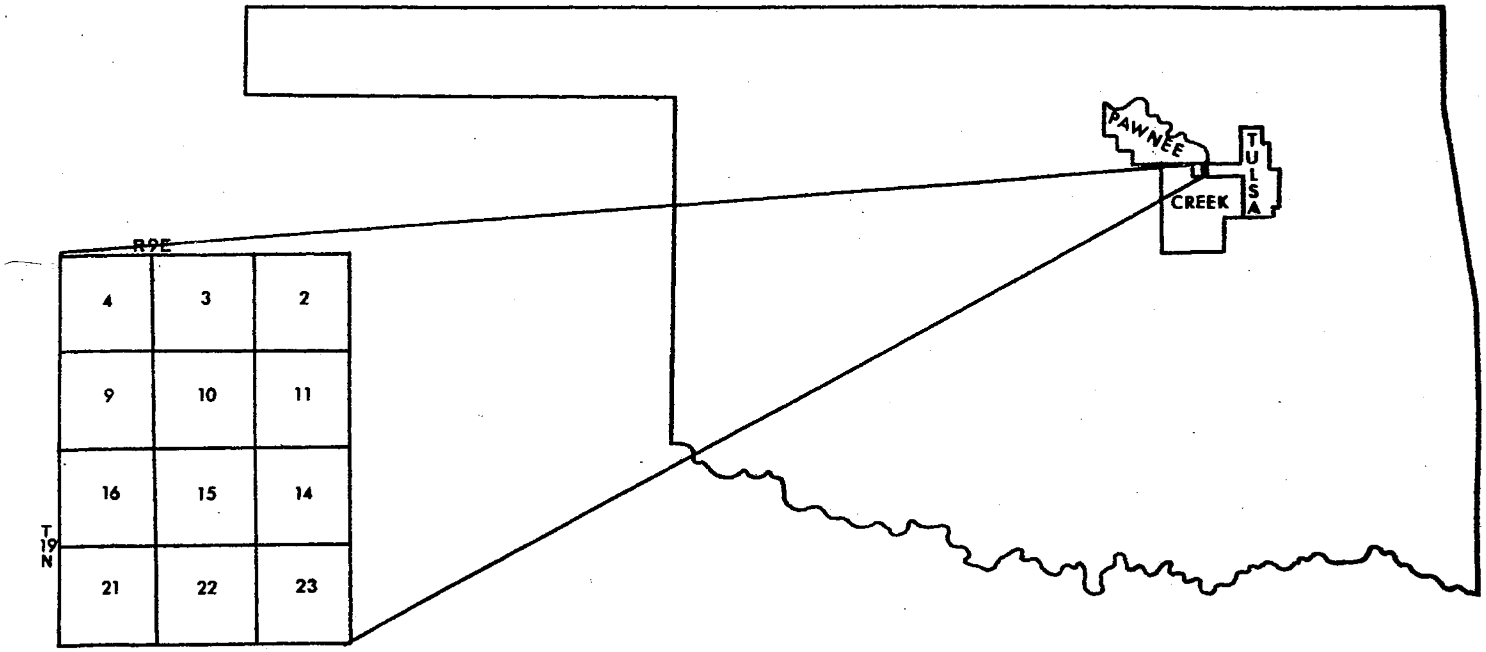


Fig. 1.-Location map of the Mannford area, Oklahoma

determine the extent to which geology could be incorporated into land-use planning. Their paper provided the basic framework and approach for this study.

GEOMORPHOLOGY

The Mannford area lies in the Eastern Sandstone Cuesta Plains of the Great Plains Physiographic Province (Curtis and Ham, 1957). The erosional topography of the area is controlled by alternating sandstones and shales which dip approximately 40 ft/mi. to the west-northwest. The study area is dominated by 4 sandstone-capped benches and 2 bluffs. The benches and bluffs are separated by areas underlain by shales. The city of Mannford is located for the most part on a sandstone bench in the west-central portion of the study area (see Plate 1).

The study area is located approximately 3 mi. southwest of the confluence of the Cimarron and Arkansas Rivers. The Salt Creek arm of Keystone Reservoir, occupying the largest valley in the area, joins the Cimarron arm of the reservoir in the northeastern portion of the study area. The Salt Creek arm of Keystone Reservoir trends north-south and occupies much of the eastern one-third of the study area. Within the study area rather steep bluffs border the reservoir on the southeastern and northwestern sides of the Salt Creek arm of the reservoir. These bluffs are held-up along the east side of the reservoir by the Wann sandstone (ℙw-2) and along the west side by the lower Barnsdall sandstone (ℙb-1) (Table 5 and Plate 4). All other drainages in the area are intermittent tributaries of Salt Creek (see Plate 3). Many exhibit relatively straight segments joining one another at somewhat sharper angles than is characteristic of typical dendritic drainages (Plate 3). A comparison of the drainage orientations (Fig. 2) and of joint orientations (Fig. 6) in the study area indicates a fair correlation especially in the N.40-50°W. and N.40-60°E. intervals. This suggests that the drainage pattern, although basically dendritic, is moderately controlled by the local systematic joint system.

Remnants of stream terraces are recognized in the study area parallel to the reservoir and along some of the tributaries of Salt Creek. The position of the terraces corresponds approximately to the position of the terrace alluvium shown on Plate 5. Along the reservoir are 5 terrace remnants. Remnants of a single terrace surface occurs along each of 4 intermittent tributaries of Salt Creek. Along the upper reaches of each tributary this surface slopes from approximately 800 ft. to approximately 720 ft. near the reservoir. Since exact topographic and time relationships of geomorphic surfaces are not important in an environmental study of this type, no attempt has been made to correlate terraces.

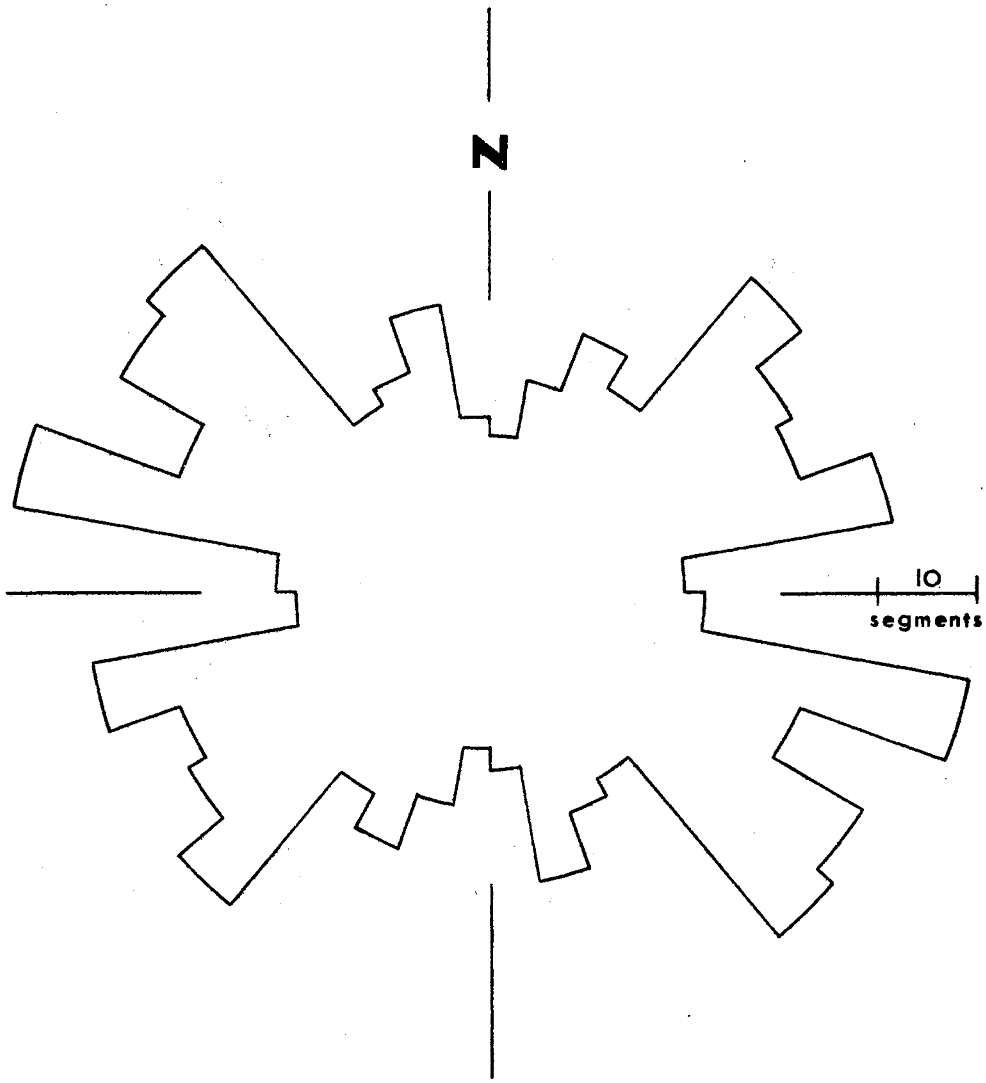


Fig. 2.-Orientations of drainage segments in the Mann-
ford area, Oklahoma

CLIMATE

Among the climatic data applicable to urban planning are: (1) average monthly temperatures (Fig. 3); (2) average monthly precipitation (Fig. 3); (3) precipitation intensities likely to occur on a monthly basis (Tables 2 and 3); (4) the probability of first and last freeze dates (Figs. 4 and 5); (5) the average number of days that minimize temperatures are below freezing (Table 4); and (6) the average depth of frost penetration in the Mannford area. The climatic information presented includes data from Tulsa, 17 mi. east of Mannford, for those years and variables not available for Mannford.

Table 2 and Fig. 3 indicate that some construction delays can be anticipated during April through July when monthly precipitation averages greater than 3 in. and intensities are commonly 0.10-0.99 in./day. Construction delays could be due to heavy rains which interfere directly with surface construction or to seeps which develop hours or days after heavy rainfall. Although rainfall is less from January through April than from May through July, the lower temperature and the lack of vegetation mean that a higher proportion of precipitation is not lost to evapotranspiration and therefore available for runoff and infiltration during the January through April period than during May through July.

Figs. 4 and 5 allow the estimation with some accuracy not only of the occurrence of the first and last freeze dates but also of the probability that they will occur on or before a given date. For example, the per cent chance that the last freeze will occur between any 2 dates is

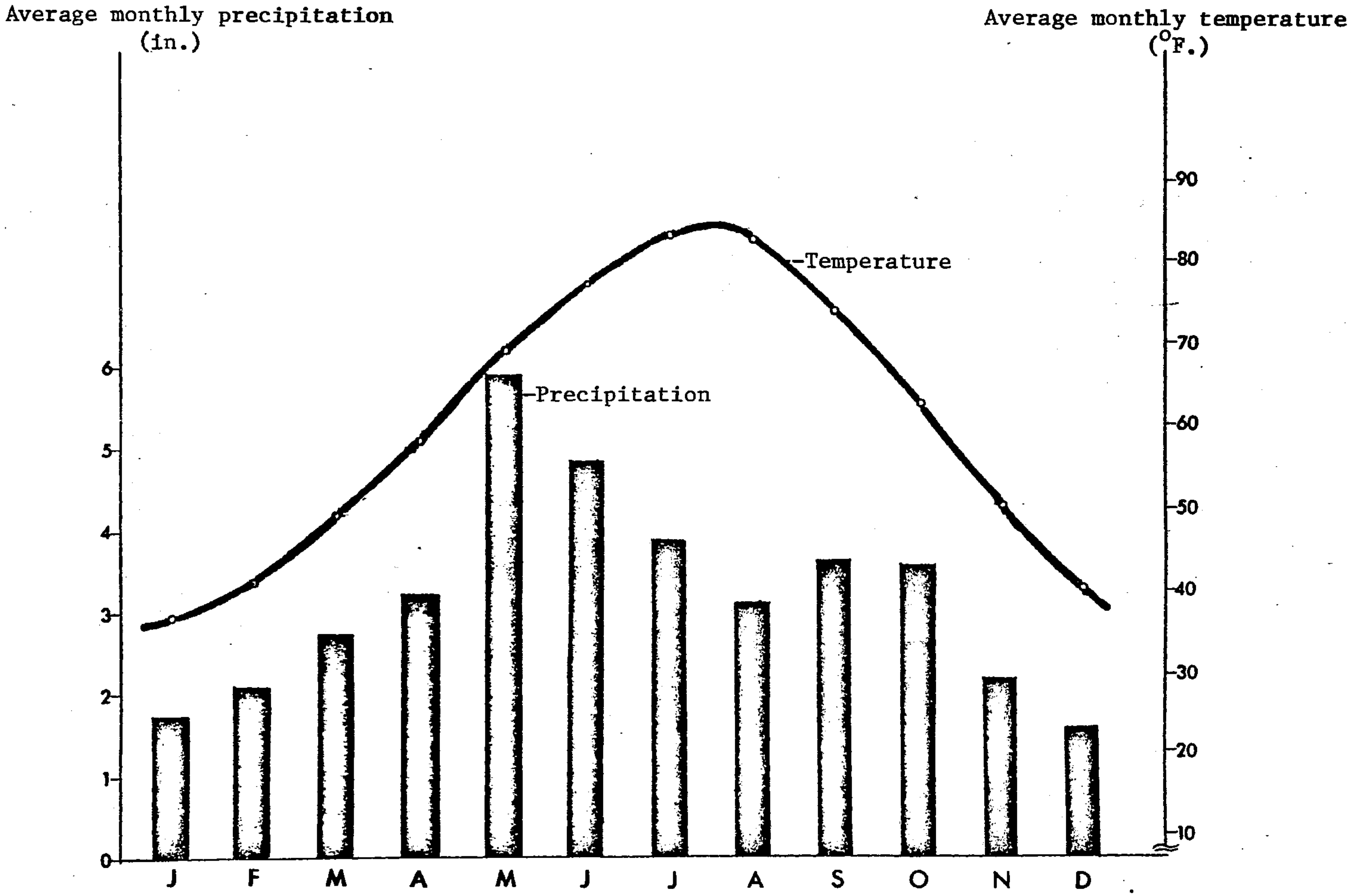


Fig. 3.-Average monthly temperature and precipitation data for Mannford, Oklahoma. Data are averages from 1900-1970. Data modified from Marvin (1930), Reichelderfer (1953-64), White (1965a, 1965b, 1966), and Environmental Data Service (1967-71).

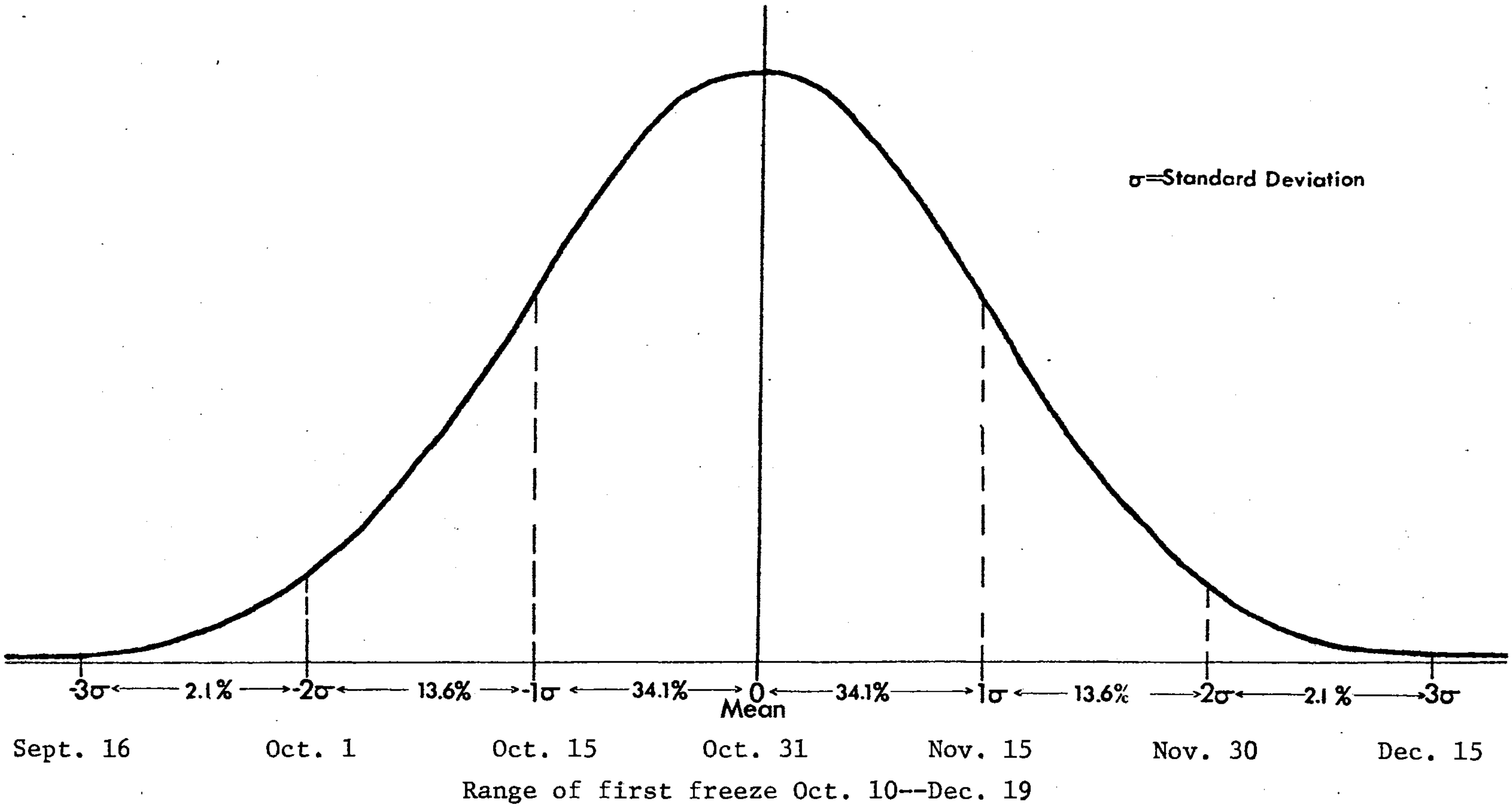
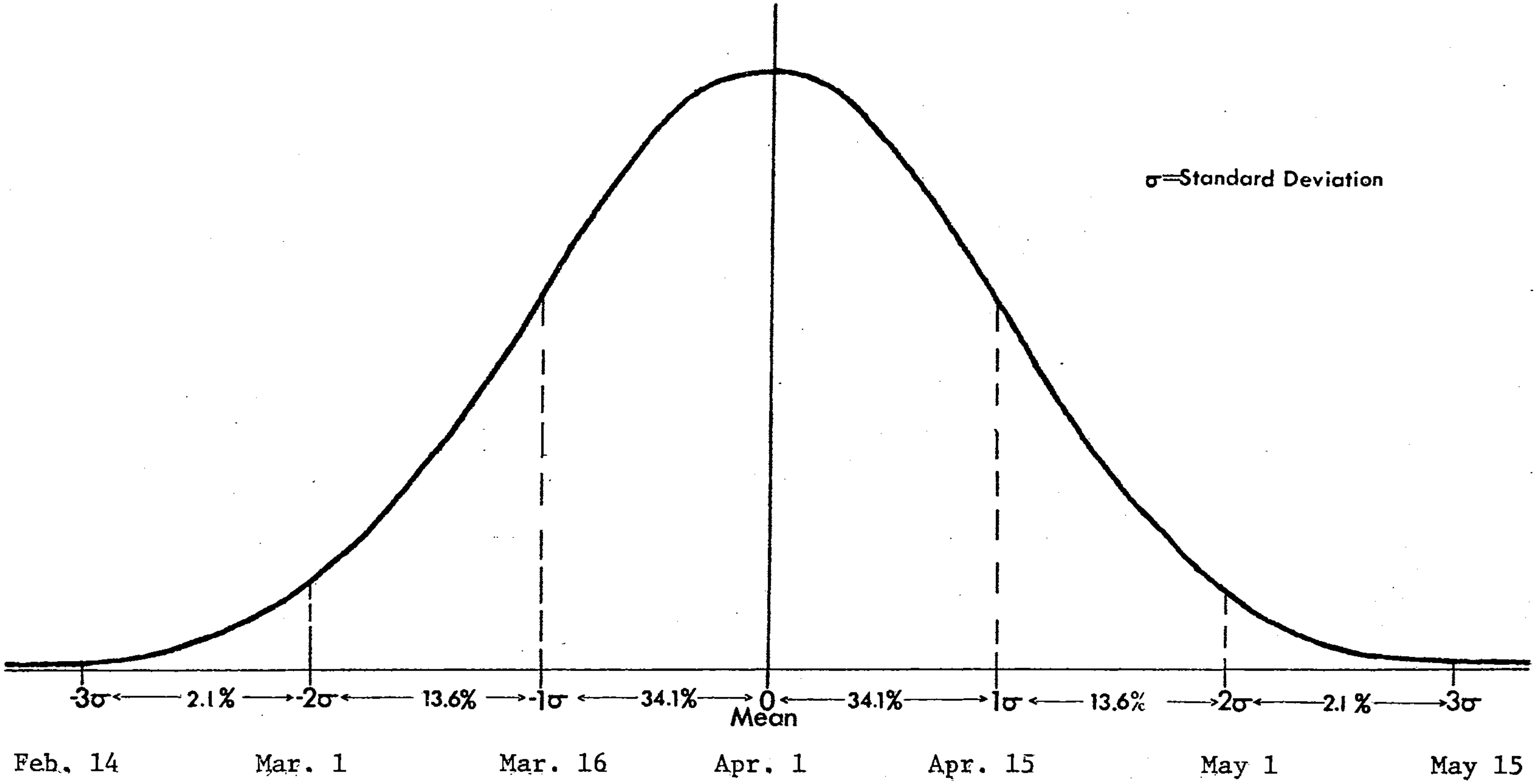


Fig. 4.-Frequency distribution of first freeze for Mannford, Oklahoma. Data are averages from 1900-70. Data modified from Marvin (1930), Lehrer (1960), Reichelderfer (1953-64), White (1965a, 1965b, 1966), and Environmental Data Service (1967-71).



Range of last freeze Mar. 5—May 13

Fig. 5.-Frequency distribution of last freeze for Mannford, Oklahoma. Data are averages from 1900-70. Data modified from Marvin (1930), Lehrer (1960), Reichelderfer (1953-64), White (1965a, 1965b, 1966), and Environmental Data Service (1967-71).

shown by the per cent value below the curve between any 2 dates in Fig. 5. The chances that the last freeze will occur between March 16 and April 1 is 34 per cent. From April 1 to May 15 is approximately 50 per cent of the area under the curve. A contractor starting construction prior to March 16 can expect freezing temperatures to be more frequent since the probability of the last freeze occurring before this date is approximately 16 chances out of 100. Freezing temperatures, of course, would hamper efforts to pour concrete for foundations and would increase labor costs.

Table 2.-Average precipitation intensities for Mannford, Oklahoma.

Intensity of precipitation in in./day	Average number of days in month where intensities reach given value												
	J	F	M	A	M	J	J	A	S	O	N	D	YR.
0.10 - 0.50	3	4	5	6	9	6	3	3	4	3	3	3	52
0.50 - 0.99	1	2	3	3	3	3	1	1	2	2	2	1	24
≥ 1.0	0	0	0	1	2	1	1	1	0	0	0	0	6

Data extracted from White (1965a, 1965b, 1966), Reichelderfer (1953-64), and Environmental Data Service (1967-71).

Table 3.-Chance that precipitation of a given intensity will occur on any given day during each month.

Intensity of precipitation in in./day	Percentage chance in any month											
	J	F	M	A	M	J	J	A	S	O	N	D
0.10 - 0.50	10	14	16	20	29	20	10	10	13	10	10	10
0.50 - 0.99	3	7	10	10	10	10	3	3	7	6	7	3
≥ 1.0	1	1	1	3	6	3	3	3	1	1	1	1

Data modified from White (1965a, 1965b, 1966), Reichelderfer (1953-64), Environmental Data Service (1966-71), and Conrad and Polk (1950, p. 201).

Table 4 shows that freezing temperatures most frequently occur from December through March. A contractor can expect to pour concrete many afternoons from December through March because daily maximum temperatures remain below freezing only 30 to 35 days of this period (Lehrer, 1960, p. 2). Average snowfall in the Mannford area is 9.6 in., occurring generally from January through March (Marvin, 1930, p. 20). Although the prediction of the depth of frost penetration becomes an important consideration in urban areas where winters are more severe than in the Mannford area, the terrain in the study area generally remains essentially unfrozen except for short periods on the order of 10 days or less when frost penetration may be 4 to 6 in. (Marvin, 1930, p. 2).

Table 4.-Average number of days the minimum temperature is below freezing for Mannford, Oklahoma.

Month	Average number of days
J	22
F	14
M	10
A	1
M	0
J	0
J	0
A	0
S	0
O	1
N	10
D	18

Data extracted from Marvin (1930), Lehrer (1960), Reichelderfer (1953-64), White (1965a, 1965b, 1966) and Environmental Data Service (1967-71).

BEDROCK STRATIGRAPHY

The bedrock exposed at the surface in the Mannford area consists of approximately 220 ft. of sandstones and shales, which are part of the Missourian and Virgilian Series of the Pennsylvanian System. The Missourian Series in the study area includes in ascending order the upper part of the Wann, the Barnsdall, and the Tallant Formations with the Virgilian Series represented by the lowermost Vamoosa Formation. An idealized columnar section (Table 5) and the bedrock geologic map (with included cross section) (Plate 4) together show the distribution of bedrock sufficiently for most planning purposes.

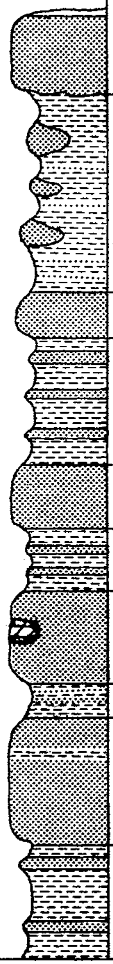
Wann Formation

Approximately the upper one-third of the Wann Formation is exposed in the study area. For mapping purposes, the Wann is subdivided into 3 units, a lower shale, a middle sandstone, and an upper shale.

The lower Wann shale unit (ℙw-1) is a gray to reddish, sandy to silty shale with interbeds of tan to gray, fine- to very fine-grained sandstone. This unit ranges from 25 to 30 ft. in thickness along the eastern border of the study area with the upper portion exposed in the borrow pit south of Oklahoma Highway 51 east of the Salt Creek arm of the reservoir.

The Wann sandstone unit (ℙw-2) is tan to gray in color, medium- to fine-grained, and massive to thin-bedded. Locally, gray to reddish shale interbeds are present near the top of the unit. Thickness varies

Table 5.-Idealized columnar section of the Mannford area, Oklahoma. Symbols on column are the same as on Plate 4.

Graphic Column	Map Symbols	Brief Description	Thickness (in feet)	Formations and Group	System and Series
	IPv-1	Sandstone, buff to reddish brown, coarse- to fine-grained, massive to thin-bedded. Upper portion missing due to erosion.	20-25	Vamoosa Fm.	Virgilian Series; Pennsylvanian System
	IPt-2c, IPt-2b, IPt-2a; IPt-2	Shale, reddish to olive green, sandy to silty; sandstone interbeds. Sandstones, lenticular, buff to reddish tan, fine- to very fine-grained, massive to thick-bedded.	2-20 0-10 50-60 0-20	Tallant Fm.; Ochelata Group	Missourian Series; Pennsylvanian System
	IPt-1	Sandstone, brown to reddish tan, medium- to fine-grained, massive to thin-bedded.	10-20	Tallant Fm.; Ochelata Group	Missourian Series; Pennsylvanian System
	IPb-4	Shale, tan to reddish, sandy to silty; sandstone interbeds.	30-40	Barnsdall Fm.; Ochelata Group	Missourian Series; Pennsylvanian System
	IPb-3	Sandstone, buff to tan, fine- to very fine-grained, massive to generally thin-bedded.	10-25	Barnsdall Fm.; Ochelata Group	Missourian Series; Pennsylvanian System
	IPb-2	Shale, tan to reddish, sandy to silty; sandstone interbeds.	15-20	Barnsdall Fm.; Ochelata Group	Missourian Series; Pennsylvanian System
	IPb-1a, IPb-1	Sandstone, tan to gray, fine- to very fine-grained, massive to generally thin-bedded; Dolomite, lenticular, gray, fine-grained.	0-3 20-25	Barnsdall Fm.; Ochelata Group	Missourian Series; Pennsylvanian System
	IPw-3	Shale, gray to reddish, sandy to silty; sandstone interbeds.	10-15	Wann Fm.; Ochelata Group	Missourian Series; Pennsylvanian System
	IPw-2	Sandstone, tan to gray, medium- to fine-grained, massive to thin-bedded; shale interbeds locally.	25-30	Wann Fm.; Ochelata Group	Missourian Series; Pennsylvanian System
	IPw-1	Shale, gray to reddish, sandy to silty; sandstone interbeds.	25-30	Wann Fm.; Ochelata Group	Missourian Series; Pennsylvanian System

from 25 to 30 ft. with the lower 15 ft. of sandstone being largely medium-grained. IPw-2 forms the bluff along the east edge of the reservoir in the southeastern portion of the study area. The sandstone (IPw-2) occurs above water level along the west side of the reservoir below the Oklahoma Highway 51 bridge in the east-central portion of the study area.

The upper Wann shale unit (IPw-3) is a gray to reddish, sandy to silty unit with interbeds of buff to tan, fine- to very fine-grained sandstone. The shale unit ranges from 10 ft. in thickness just south of Oklahoma Highway 51 east of the reservoir to an estimated 15 ft. in the bluff along the west side of the reservoir.

The sandstones of the Wann are generally coarser grained and thicker bedded than are corresponding units in the Barnsdall. The shales of the Wann weather to a lighter shade of red than do shales of the Barnsdall.

Barnsdall Formation

The Barnsdall Formation in the Mannford area consists of a basal sandstone unit (IPb-1), a dolomite lens (IPb-1a), a poorly exposed shale unit (IPb-2), a sandstone unit of variable thickness and topographic expression (IPb-3), and an upper shale unit containing several sandstone interbeds (IPb-4).

The lower sandstone unit (IPb-1) is tan to gray, fine- to very fine-grained and massive to generally thin-bedded where exposed. IPb-1 is approximately 20 to 25 ft. thick along both sides of the reservoir. Pb-1 forms a ridge bordering the eastern edge of the study area along Oklahoma Highway 51 and caps the bluff along the west side of the reservoir.

A lens of gray, fine-grained dolomite ranging from 0 to 3 ft. thick occurs locally approximately 15 ft. above the base of Pb-1 in the SE 1/4 of Sec. 10 (Plate 1) west of the reservoir. The lens is very poorly exposed.

IPb-2 is a poorly exposed, tan to reddish, sandy to silty shale with interbeds of buff to tan, fine- to very fine-grained sandstone. IPb-2 ranges from approximately 15 ft. in the west to 20 ft. thick in the southeastern portion of the study area. This unit is exposed in the borrow pit east of the Mannford business district just south of Oklahoma Highway 51.

The upper sandstone unit (IPb-3) is buff to tan, fine- to very fine-grained, and thin-bedded to locally massive. Sedimentary structures in the sandstone include initial dip, channels, and small- to medium-scale cross-bedding. These are exposed in the 2 roadcuts along Oklahoma Highway 51 just west of the reservoir. IPb-3 ranges from 10 ft. thick to locally 25 ft. thick in the residential area in the southcentral portion of the study area.

The upper shale unit (IPb-4) is tan to reddish, sandy to silty, and contains several buff to tan, fine- to very fine-grained, to locally silty, sandstone interbeds. This unit is poorly exposed in the study area except in the west-central part northwest of the elementary school where it is exposed along a gulley. IPb-4 varies from 30 to 40 ft. thick with the thicker portion being restricted to the southern part of the study area.

Tallant Formation

The Tallant Formation is subdivided into a lower sandstone unit

(IPt-1) and an upper shale unit (IPt-2).

The lower Tallant unit (IPt-1) is a brown to reddish tan, medium- to fine-grained, massive to thin-bedded sandstone, ranging from approximately 10 ft. thick in the northwest part of the Mannford area to 20 ft. thick in the southwest portion. IPt-1 produces the north-south trending bench in the west-central part of the study area. Locally, IPt-1 exhibits initial dip, channels, and small-scale cross-bedding.

A reddish to olive-green sandy to silty shale unit (IPt-2) occurs above the lower sandstone unit (IPt-1). This unit is highly jointed in the study area and includes several buff to tan, fine- to very fine-grained sandstone interbeds exposed in the roadcut approximately 1 mi. north of the railroad tracks. IPt-2 ranges from 50 to 60 ft. thick in the study area. Within IPt-2, 3 sandstone lenses (IPt-2a, IPt-2b and IPt-2c) occur at various stratigraphic positions.

The lower lens, IPt-2a, is a buff to reddish tan, fine- to very fine-grained, massive to thick-bedded sandstone, which varies from 0 to 20 ft. in thickness. This unit caps the bench in the Mart-Way Racetrack area north of Mannford. IPt-2b also is a buff to reddish tan, fine- to very fine-grained, massive to thick-bedded sandstone ranging from 0 to 10 ft. thick. The Tallant sandstone lens (IPt-2b) exhibits initial dip, channels, and small-scale cross-bedding in the Oklahoma Highway 51 road-cut just north of the Mannford city water tower. IPt-2c is a buff to gray, fine- to very fine-grained, massive to thick-bedded sandstone which varies from 2 ft. in the northwest to locally 20 ft. thick in the west-central part of the study area.

Vamoosa Formation

The Vamoosa in the study area (Pv-1) is a buff to reddish brown, coarse- to fine-grained, massive to thin-bedded sandstone ranging from 20 to 25 ft. thick. Only the lower portion of this sandstone is exposed in the study area. The upper portion is missing due to erosion. The Vamoosa in the study area produces the sandstone-capped ridge in the northwestern portion of the study area.

QUATERNARY STRATIGRAPHY

Unconsolidated materials (exclusive of pedologic soils) are locally more than 10 ft. thick and cover approximately 50 per cent of the study area (see Plates 5 and 7). These materials include flood plain alluvium, terrace alluvium, colluvium, and artificial fill. The textures of all Quaternary deposits are described using the basic soil textural classification of the Soil Conservation Service (see Appendix 2, p. 82).

Flood Plain Alluvium

The only flood plain alluvium presently exposed in the study area occurs along the tributaries of Salt Creek on both sides of the reservoir. The flood plain alluvium in the area is brown to black fine sandy loam to silt loam. Thicknesses range from 3 to 12 ft.

Terrace Alluvium

Most of the alluvial terrace deposits in the Mannford area have been covered by Keystone Reservoir. Terrace deposits above water level are grouped into 2 units on the basis of texture rather than age or topographic position.

The terrace alluvium along the Cimarron River and Salt Creek (Qt-1) is brown to reddish yellow loamy fine sand to silt loam which ranges from 3 ft. thick in the eastern part of the study area to an estimated 15 ft. thick on the island in the northeastern portion of the study area. Qt-1 combines alluvium related to 4 terrace remnants. There are 3 deposits which occur at an elevation of approximately 720 ft. and the fourth occurs at an elevation of approximately 755 ft. The 755-ft. terrace, although not contemporaneous with the 720-ft. terrace, is grouped with it because of texture.

The terrace alluvium along 5 tributaries of Salt Creek (Qt-2) is brown to grayish brown silty clay loam which varies from 1 to 5 ft. thick. The surface of the terrace slopes from approximately 800 to 720 ft.

Colluvium

Colluvium is material that has been moved down slopes by sheet wash and creep. Texture and composition of colluvium will be determined by the upslope material (generally weathered) from which the colluvium is derived. Colluvium in the Mannford area typically contains sandstone fragments transported from upslope in a finer matrix, yellow to reddish color blotches termed mottles, and granule-sized iron and/or manganese oxide nodules. Frequently, colluvial units with large silt and clay fractions are more plastic than the underlying in-situ materials.

The 4 colluvial units mapped in the Mannford area are probably more or less contemporaneous with existing alluvial deposits. One colluvial unit appears to have been derived from only one formation while the others have been derived from more than one formation. A boulder to cobble colluvial unit (Qc-1), composed predominantly of sandstone fragments, occurs on the steep slopes below the bluffs and the benches bordering the east and west sides of the Salt Creek arm of Keystone Reservoir in the central, north-central, and southeast parts of the area. Locally, Qc-1 also occurs on the gentle slopes bordering the west side of the reservoir. The sandstone fragments are generally angular to blocky, and vary from 0.5 to 6.0 ft. in diameter. They are derived from both the lower Barnsdall and Wann sandstones. The colluvial deposit varies from < 1 to 3 ft. thick. Where the blocks are widely scattered, thickness of the colluvial deposit is the thickness of individual sandstone blocks.

The sandy colluvial unit (Qc-2) occupies the slopes below the Tallant Formation in the southern two-thirds of the study area; however, the unit (Qc-2) does occur locally in northern part of the area. Qc-2 is grayish brown to brownish red sandy loam to loam with yellow to reddish mottles common. Black to brown iron and/or manganese oxide nodules and pebble-to granule-sized sandstone fragments also occur. Thickness varies from 0.5 to 5 ft., the latter occurring near the downslope edge of the deposit. The Tallant Formation appears to be the source of the (Qc-2) colluvium.

The silty colluvial unit (Qc-3) occupies the slopes below the Tallant Formation in much of the northern one-third of the study area but differs from Qc-2 in that it is brown to gray loam to silt loam. Yellow to reddish mottling is less pronounced than in the sandy colluvial unit (Qc-2) and iron and/or manganese oxide nodules are few to locally absent. Sandstone fragments incorporated in the deposit tend to be pebble- to granule-sized. This unit appears to be derived from the Tallant and Barnsdall Formations and ranges from 0.5 to 4.5 ft. thick.

The horizontal boundary between the sandy loam (Qc-2) and silt loam (Qc-3) colluvial units is transitional. The reasons for the differences between Qc-2 and Qc-3, especially since they both occur at approximately the same topographic and stratigraphic positions, are not clear. Possible explanations for the differences include: (1) lateral changes in bedrock beneath the deposit with the result that weathered shale contributes more than the sandstone to the character of Qc-3; and (2) mixing of material derived from bedrock with terrace alluvium or eolian material.

A loamy colluvial unit (Qc-4) occurs locally in the northwestern portion of the study area. Qc-4 is a brown to grayish brown sandy loam with yellow to reddish mottling common. The thickness of Qc-4 varies from 0.5 to 3.0 ft. thick. Although Qc-4 appears to be derived from the Vamoosa and Tallant Formations, the contribution of the Tallant sandstones to Qc-4 is difficult to establish. The Vamoosa sandstone is generally coarser grained than the Tallant, but sandstone fragments are few to locally absent in the deposit.

Artificial Fill

Artificial fill was mapped separately because the excavation of in-situ materials alters the engineering properties of the materials and because fill often includes man-made materials such as brick or concrete fragments. The geologic materials used as fill in the Mannford area are quite variable, ranging from clay to boulder-sized sandstone blocks 3 ft. in diameter. Man-made materials probably include bricks, lumber, and virtually any other materials that were available. Some of the fill materials appear to have been obtained from the 2 borrow pits along Oklahoma Highway 51, east of the business district, in the central portion of the study area.

STRUCTURAL GEOLOGY

The Mannford area is located on the Central Oklahoma platform between the Ozark and Nemaha uplifts (Arbenz, 1956). The platform exhibits minor folding and faulting which is thought to be related to deep-seated differential uplift (Ross, 1971). The strike in the Mannford area averages N.20°E. with the dip averaging 40 ft./mi. to the west-northwest.

No faults are recognized in the Mannford area, but joints are common in the sandstone units. Joints are important in an environmental geology study because of their effect upon rock rippability, ground-water movement, and the shear strength of rock.

A plot of the strike frequency of 67 joints, all of which are essentially vertical, indicates 2 joint sets oriented approximately N.40°W. and N.50°E. (Fig. 6). The sets are approximately parallel to those in a large area north and northwest of the Ouachita Mountains (Melton, 1931), including those in central Payne County (Ross, 1971). Chenoweth (Bennison and Chenoweth, 1968) measured 168 joints in Tulsa County, immediately to the east of Creek County, and found 4 joint sets. The northwest-southeast and northeast-southwest sets nearly parallel the 2 trends in the Mannford area. The 2 remaining sets, north-south and east-west, are not recognized in the study area. The northeast-southwest set in the Mannford area sub-parallels en echelon faults in central and eastern Oklahoma.

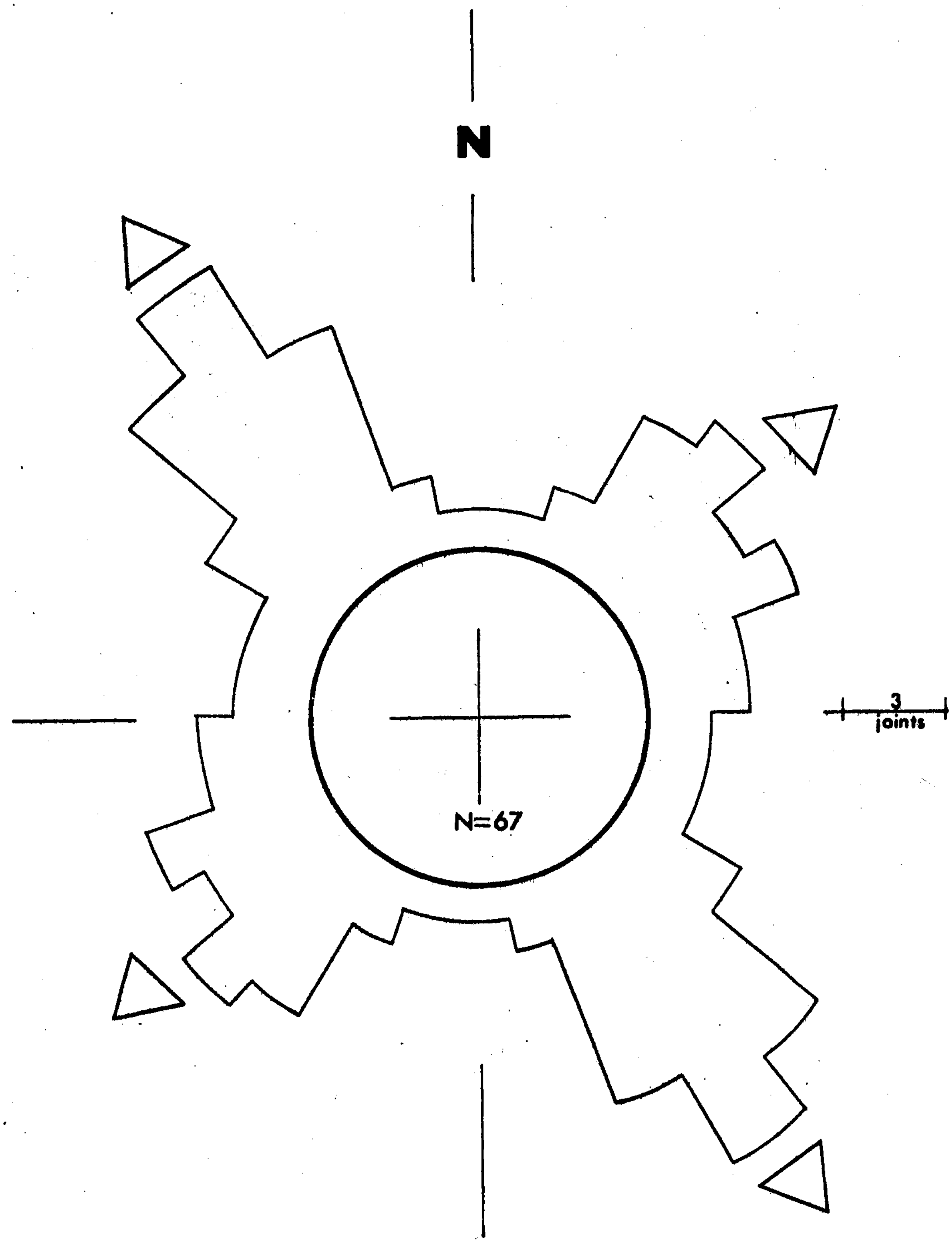


Fig. 6.-Strike frequency of 67 joints in the Mannford area, Oklahoma, showing N.40°W. and N.50°E. directional averages. A 30-degree sliding average was used in preparation of diagram.

SOILS

The United States Soil Conservation Service produces many types of data applicable to urban environmental studies including soil maps, textural data, and engineering test data of pedologic soils. Such data generally show a high correlation with geology since pedologic soils are derived from geologic materials. The soil map for the Mannford area (Plate 6), extracted and enlarged from the Creek County Soil Map (H. C. Oakes, 1959), is utilized in surficial mapping (Plate 5) and as a base map in the preparation of interpretative factor maps (Plates 8-12).

The term soil unfortunately means different things to different people. The layman considers soil to be the loose material found at the earth's surface which is capable of supporting plant life. The engineer defines soil as any unconsolidated deposit composed of an aggregate of mineral grains that can be separated by mechanical means (Terzaghi and Peck, 1948, p. 4). The deposit can be weathered in place (residuum) or unconsolidated material transported from elsewhere. Such deposits can be either at the surface or buried even at great depth. The agronomist defines soil as that portion of the weathered earth's surface which, under physical, chemical, and bacterial processes, produces an unconsolidated material having characteristic horizons and structures and is capable of supporting plant life. Soils are subdivided into the A, B, and C horizons with the A horizon being the zone in which organic matter coats the mineral grains, darkens the soil, and supports the root systems of plants. The B horizon contains illuvial and/or residual concentrations of clay, iron, and aluminum complexes and when grouped with the A horizon is termed the solum. The C horizon, termed the subsoil, is the zone above the unweathered parent material that has been little affected by the soil-forming factors, but frequently contains some of the weathered parent material (Gray and Galloway, 1969). The term soil in this study generally is used in the pedologic sense except in the discussion of soil engineering data (see section on Engineering Geology Data), foundation conditions, and slope stability (see section on Environmental Geology Interpretations).

Soils in the study area are part of the Cross-Timbers Pedologic Province, Red-Yellow Podozolic Group, Darnell-Stephenville and Dougherty-Teller-Yahola Soil Associations Parent materials of these soils include sandstone, shale, shale with interbedded sandstone, alluvium, and colluvium (Table 6). These soils are light-colored, moderately leached, and typically have reddish sandy clay subsoils (Gray and Galloway, 1969).

The Darnell-Stephenville Association in the study area develops from sandstone and shales with interbedded sandstone. The Darnell Series typically is shallow, light-colored, and occupies slopes generally greater than 5 per cent except where sandstone crops out on nearly flat hill tops (less than 2 per cent). The Stephenville Series is similar to the Darnell but exhibits better developed subsoils (Gray and Galloway, 1969).

The Dougherty-Teller-Yahola Association in the study area occupies terrace surfaces of the Cimarron River and Salt Creek. The Dougherty Series exhibits clay subsoils and is developed in the reddish, moderately sandy, alluvial terrace deposits of Salt Creek. The Teller soils occur on the Cimarron River terrace deposits along the northwest and east sides

Table 6.-Soil series and their geologic associations in the Mannford area, Oklahoma.

Soil Series	Brief Description* of Solum	Brief Description* of Subsoil	Parent* Material	Geologic Units From Which Soils are Derived
Bates	Grayish brown sandy loam	Yellow sandy clay loam	Sandstone and sandy shale	Wann, Barnsdall, and Tallant Formations; Colluvium, Qc-1 and Qc-2
Collinsville	Grayish brown sandy-clay loam	Yellowish brown sandy clay loam	Acidic sandstone and sandy shale	Wann, Barnsdall, and Tallant Formations; Colluvium, Qc-2
Darnell	Grayish brown sandy loam and loam	Yellowish red clay loam	Sandstone and interbedded sandstone and shale	All bedrock formations and colluvial units
Dennis	Grayish brown fine sandy loam	Reddish to brownish yellow sandy clay loam	Interbedded sandstone and shale	All bedrock formations; Colluvium, Qc-1, Qc-2, and Qc-3
Dougherty	Pale brown fine sandy loam	Brownish yellow to reddish yellow sandy clay loam	Terrace alluvium	Salt Creek terrace alluvium
Eufaula	Pale brown to pale yellow loamy fine sand	Brownish yellow fine sandy loam	Terrace alluvium	Cimarron River terrace alluvium
Mason	Grayish brown silt loam	Grayish brown silty clay loam	Terrace alluvium	Salt Creek tributary terrace alluvium
Okemah	Dark gray clay loam	Yellowish brown clay	Alkaline clay shale	Barnsdall Formation; Colluvium, locally Qc-2

Table 6 (Continued)

Soil Series	Brief Description* of Solum	Brief Description* of Subsoil	Parent* Material	Geologic Units From Which Soils are Derived
Stephenville	Grayish brown fine sandy loam	Yellowish red sandy clay loam	Acidic sandstone and interbedded sandstone and shale	Barnsdall, Tallant, and Vamoosa Formations; Colluvium, Qc-2 and Qc-4
Stidham	Brownish gray fine sandy loam	Yellowish brown sandy clay loam	Terrace alluvium	Salt Creek terrace alluvium
Teller	Brown silt loam	Red clay loam	Terrace alluvium	Cimarron River terrace alluvium
Verdigris	Grayish brown sandy loam to silt loam	Grayish brown clay loam	Flood-plain alluvium	Salt Creek tributary flood-plain alluvium
Woodson	Dark gray clay loam	Yellowish brown clay	Alkaline clay shale	Barnsdall Formation; Colluvium, locally Qc-2

*Data extracted from H. C. Oakes (1959).

of Keystone Reservoir. The Yahola Series is developed exclusively on the flood-plain alluvium of the Cimarron River and is not exposed in the study area.

GROUND WATER

Known usable ground water in the Mannford area is limited to subsurface bedrock aquifers in the Wann Formation. Local residents indicate that no appreciable amounts of ground water occur in other surface and near-surface deposits. It is possible, however, that other aquifers occur at depths greater than 300 ft. beneath the surface.

The bedrock geology of the area, with alternating sandstones and shales, produces ideal conditions for the development of intermittent springs and seeps. Such springs and seeps generally develop after heavy rains where permeable sandstones overlie relatively impermeable shales. Several springs and seeps were observed by the author after heavy winter and spring rains at the base of the lower Tallant sandstone unit (IPt-1) and at the base of the Vamoosa sandstone (IPv-1). The springs at the base of the Tallant appeared to have the greatest yields. Water, through surface infiltration, moves through the exposed, jointed, and permeable sandstones and collects along underlying shale contacts. A conceptual model is shown in Fig. 7 which illustrates the observed seep conditions and the suspected contribution made by the Keystone Reservoir to one of the aquifers.

Domestic water supplies in the Mannford area are obtained from 2 sandstones near the middle part of the Wann Formation (see Fig. 7). These sandstones are approximately 20 to 25 ft. thick. The upper Wann sandstone aquifer ranges from approximately 90 to 110 ft. below the surface in the eastern part of the area to approximately 195 to 210 ft. beneath

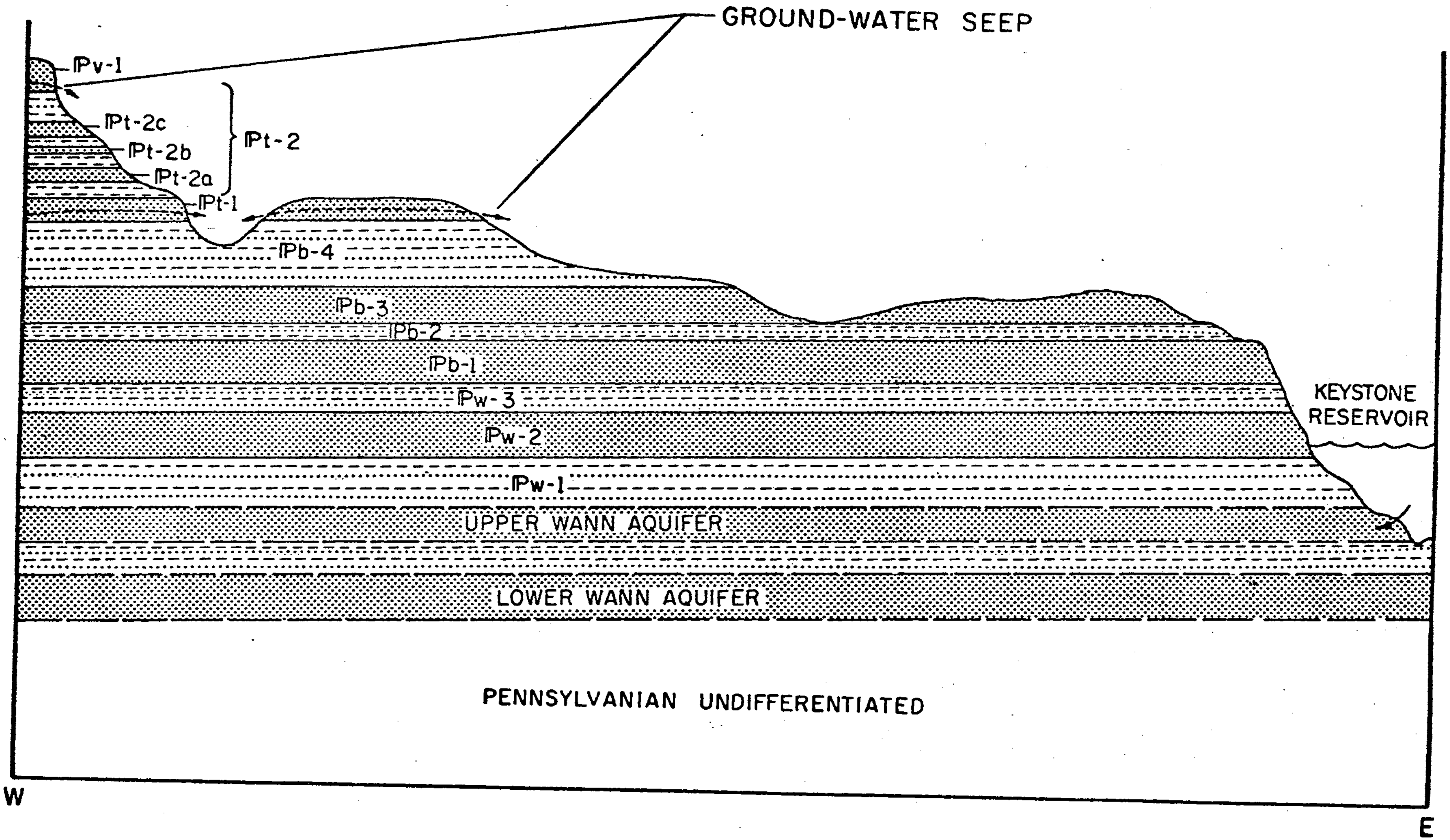


Fig. 7.–Schematic east-west cross section in the Mannford area, Oklahoma, showing expected ground-water conditions. No unconfined water table was observed in the study area.

the surface in the western portion of the study area. The lower Wann sandstone aquifer ranges from approximately 120 to 140 ft. below the surface in the eastern part of the area to approximately 240 to 260 ft. beneath the surface in the western portion of the study area (see cross section Plate 4). Yields of household wells range from <1 to 8 gal./min. with many less than 5 gal./min. (Table 7). The texture, based on the rather low yields of domestic wells in the 2 sandstone aquifers, is estimated to be fine-grained since coarser grained sandstones would have to be tightly cemented to exhibit such low permeabilities.

Table 7.-Data on representative domestic water wells in the Mannford area, Oklahoma, after Keystone Reservoir filling.

Owner	Location (all T.19N.,R.9E.)	Estimated Depth of well (ft.)	Estimated Yield (gal/min.)
Tom Langen	SW¼ NW¼ SW¼ Sec. 10	160	5-7
L. D. Applegate	SE¼ NE¼ NE¼ Sec. 9	170	5-8
Coyote Trail	SE¼ SE¼ SW¼ Sec. 26	175	1-5
Mormon Church	SW¼ NW¼ SE¼ Sec. 22	150	1-5
Ray Carr	SW¼ SE¼ SE¼ Sec. 22	160	3-5
C. Durkey	SW¼ SE¼ SE¼ Sec. 22	160	3-5
Kenneth Cooper	SW¼ SE¼ SE¼ Sec. 22	160	3-5
Ed Craft	SW¼ SE¼ SE¼ Sec. 22	160	3-5
Billy Greenwood	SW¼ SE¼ SE¼ Sec. 21	200	brine
Floyd Williams	NW¼ SW¼ NE¼ Sec. 10	190	3-5
Orville Barton	SE¼ NE¼ NE¼ Sec. 14	300	brine
Jerry Pursell	SW¼ SW¼ SW¼ Sec. 21	100	brine

Knott (1971). Data from oral communication.

Prior to Keystone Reservoir filling, 5 exploration wells were drilled through the Wann Formation in an attempt to provide Mannford with an adequate water supply. Initial yields were fair but drawdown at equilibrium was rather large (Table 8). The decision was made to use surface water rather than ground water for Mannford's municipal water supply. Based on the three-dimensional geologic framework of the area and the fact that all of the static water levels in the exploration wells were above the estimated depth of the 2 Wann sandstone aquifers, artesian conditions appear to exist in these 2 sandstones.

Table 8.-Data from Mannford exploration water wells prior to Keystone Reservoir filling.

Number	Location (all T.19N.,R.9E.)	Depth (ft.)	Yield (gal/min.)	Amount of Drawdown at Equilibrium (ft.)	Static Water Level Elevation (ft.)
1	SW¼ NE¼ NW¼ Sec. 22	377	30	172(?)	679
2	SW¼ NE¼ NW¼ Sec. 22	404	33	59(?)	684
3	SE¼ NE¼ NE¼ Sec. 22	292	35	109(?)	699
4	SW¼ SW¼ SE¼ Sec. 16	360	20	49(?)	703
5	NE¼ NE¼ SE¼ Sec. 21	276	30	72(?)	703

Data extracted from Anonymous (1960).

Persons living outside the corporate limits of Mannford in the study area, west of Keystone Reservoir, are concerned about the apparent increase in dissolved chlorides in many of their domestic wells (Knott, 1971). The author believes the increase in chlorides probably reflects seepage from Keystone Reservoir into one or more westward-dipping sandstone aquifers. The upper Wann aquifer appears to crop out in the Salt Creek Valley east of Mannford below conservation pool level of Keystone Reservoir. The lower Wann aquifer apparently does not crop out in the Salt Creek Valley, but leakage from the reservoir to this sandstone is possible. Water quality analyses indicated chloride concentrations were unsatisfactory for municipal and most industrial uses without extensive water treatment (Table 9). A show of oil was encountered in exploration well No. 2 and was subsequently plugged. This suggests that some chloride concentration may be due to oil field brine.

Table 9.-Water quality analysis for Mannford city exploration well No. 2 prior to Keystone Reservoir filling.

Components	Symbol	Parts Per Million
Calcium	Ca	189
Magnesium	Mg	61
Sodium	Na	650
Chloride	Cl	1249
Sulfate	SO_4^-	176
Carbonate	CO_3	no analysis
Bicarbonate	HCO_3	249
Hypothetical Combinations		
Sodium Chloride	NaCl	1649
Magnesium Chloride	$MgCl_2$	238
Calcium Chloride	$CaCl_2$	94
Calcium Sulfate	$CaSO_4$	245
Calcium Bicarbonate	$Ca(HCO_3)_2$	332
pH 7.10		
Specific Gravity at 72° 1.002		

Data extracted from Anonymous (1960).

The occurrence of seeps in the study area offers the potential for serious problems related to roadbeds, basements, and foundations. Wherever sandstone-over-shale contacts occur at the surface because of natural erosion, road cuts, or open excavations, seeps are possible. Water should not be allowed to collect under structures because the swelling of clays may produce uplift pressures sufficient to crack walls and foundations. It should be remembered that springs and seeps can develop long after construction if the appropriate geologic conditions exist. Fig. 7 illustrates a typical seep in the study area and Plate 4 shows the outcrop pattern of the Tallant (Pt-1) and Vamoosa (Pv-1) sandstones which are most susceptible to seeps. The contractor can use Plate 4 to locate areas where sandstone overlies shale (*i.e.*, areas where springs and seeps are most likely to develop).

Because of the absence of shallow, sophisticated subsurface data for the Mannford area, more data will have to be generated before any comprehensive three-dimensional picture of the local ground-water regime can be made.

ENGINEERING GEOLOGY DATA

All available engineering test data, both published and unpublished, were obtained from the U.S. Army Corps of Engineers, the city of Mannford, the Soil Conservation Service, and the Oklahoma Highway Department. These data were used to characterize the engineering properties of all geologic and pedologic units in the study area insofar as possible. These data are presented and briefly discussed here; interpretations that utilize these data are included in subsequent sections on Factor Maps and Their Uses and on Environmental Geology Interpretations.

Bedrock Engineering Data

The available bedrock engineering data for the Mannford area are summarized in Tables 10 - 12. The bedrock geologic map (Plate 4) can be utilized as a bedrock engineering-feasibility map for planning purposes and for correlating engineering test data and local experience with the various bedrock units. Although the bedrock engineering data presented here generally characterize the bedrock of the Mannford area, they should be supplemented by on-site engineering testing prior to the design and construction of any significant project.

An engineering classification of in-situ bedrock is employed (Table 10) based upon geologic logs of NX (2 1/8-in. diameter) cores using the Rock Quality Designation (RQD). The Rock Quality Designation, based upon the ratio of the amount of NX core lost to the amount recovered at a particular site, indicates the general engineering character of the rock (Deere, 1969, p. 15). In addition, joint-spacing measurements are used in conjunction with seismic velocities to indicate the general engineering character of the rock (Deere, 1969). Brown and Robertshaw (1953) are more specific and indicate that the average seismic velocity of each lithology allows an indirect but strongly correlative estimate of the bedrock's ability to withstand loading. Table 10 shows the bedrock in the Mannford area to be of acceptable quality for most engineering uses.

Table 10.-Engineering characteristics of in-situ bedrock for the Mannford area, Oklahoma.

Geologic Unit	Joint-Spacing	Rock Quality Designation*	Average Seismic Velocity (ft/sec.)**
Vamoosa sandstone	Close+	Excellent	6000
Tallant sandstone	Close	Excellent	6750
Tallant shale	Close	Excellent	4000
Barnsdall sandstone	Close	Excellent	6250
Barnsdall shale	Close	Excellent	5000
Barnsdall dolomite lens	-----	----	14400
Wann sandstone	Close	Excellent	8100
Wann shale	Close	Excellent	4200

*Rock Quality Designation computed from Anonymous (1960).
**Average seismic velocities above water table.
+Close joint-spacing is $\leq$ 1 ft.

Tables 11 and 12 indicate the apparent rippability of each bedrock formation and its suitability for use as subgrade or subbase. These data are particularly valuable in the eastern and western portions of the Mannford area where sandstone layers frequently are less than 2 ft. from the surface. Table 11 shows the Tallant and Vamoosa to be associated with seeps and the Vamoosa and Barnsdall Formations to be susceptible to blackslope failure problems.

Table 11.-Engineering characteristics of the bedrock geologic units in the Mannford area determined by field observation and construction experience.

Geologic Formation	Apparent Material Suitability	Seeps	Apparent Rippability	Landslides or Backslope Failures
Vamoosa	Sandstones, locally for subbase	Numerous, sandstones over shale	Appears Rippable	Slumps noted on 2:1 slopes
Tallant	Sandstones, locally for subbase	Numerous, sandstones over shale	Appears Rippable	None noted
Barnsdall	Sandstones, locally for subbase	None noted	Appears Rippable	Backslope failure noted on slopes greater than 2:1
Wann	Sandstones, locally for subbase	None noted	Appears Rippable	Undetermined

Data extracted from Hayes and McCasland (1967). Information from throughout Creek County including the Mannford area.

Table 12 presents average engineering test data for the bedrock formations in the study area. Sandstones within each formation are considered well suited for subgrade material and the shales poorly suited. Table 12 indicates that all of the formations can be stabilized with cement, but the percentages quoted may be too high for the sandstones. All of the formations are shown to be suitable for subgrade except the Vamoosa which is assigned a poor suitability rating. Hayes (1972) indicates that the Vamoosa was given this rating based on limited testing of the most plastic shale. Since none of the Vamoosa shales occur in the Mannford area, the poor suitability rating indicated in Table 11 is not applicable to the study area. The Vamoosa sandstone in the study area, therefore, should be considered well suited for subgrade material.

Table 12.-Average engineering test data for geologic units in the Mannford area, Oklahoma.

Geologic Formation	AASHO Classification	Suitability for Stabilization		Suitability for Subgrade
Vamoosa	A-7-6(13)	Not asphalt	15% cement	Poor*
Tallant	A-6(110	Not asphalt	13% cement	Fair
Barnsdall	A-7-6(11)	Not asphalt	15% cement	Fair
Wann	A-7-6(11)	Not asphalt	15% cement	Fair

Data extracted from Hayes and McCasland (1967). Information from throughout Creek County including the Mannford area.

*Applicable only to shale units within the Vamoosa which do not occur in the study area.

Soil Engineering Data

All available soil engineering data for the Mannford area are summarized in Tables 13-15. These data were obtained from pedologic soils, common to the Mannford area, throughout Creek County. There are not adequate engineering data available on the unconsolidated geologic materials below the soils in the study area. It should be stressed that on-site testing should be conducted for specific engineering projects.

Table 13 shows the texture, plasticity characteristics, pH, and suitability for road materials of each soil series in the Mannford area. The American Association of State High Officials (AASHO) classification is a system of classifying soils and soil aggregate mixtures for highway design purposes based on the per cent of soil passing certain specific sieve sizes, liquid limit, and plasticity index using an empirical formula (Committee on Classification of Materials for Subgrades and Granular Type Roads, 1945). The sieve analyses indicate the portion of each

Table 13.-Engineering test data for the soil series in the Mannford area, Oklahoma.

Soils Series and Horizons	AASHO Class.	Sieve No. 10	Analysis No. 40	(% Passing) No. 60	No. 200	Liquid Limit	Plastic Index	pH	Stabilization % Asphalt	% Cement	Subgrade Quality
Bates A	A-2-4-(0)	100	99	98	34	NP	NP	6.2	5.0	8	Good
B	A-4(5)	100	99	98	59	26	7	5.4	NO	10	Good
C	A-4(3)	100	99	99	51	28	7	5.5	6.0	10	Good
Collinsville A	A-2-4(0)	100	95	78	32	NP	NP	6.3	4.8	8	Good
Darnell A	A-2-4(0)	100	100	96	25	NP	NP	6.1	4.5	7	Good
Dennis A	A-4(8)	100	99	97	88	31	6	5.9	NO	11	Fair
	A-7-6(12)	100	99	98	84	43	18	6.2	NO	14	Fair
	A-6(7)	100	99	97	60	33	15	6.7	NO	12	Fair
Dougherty A	A-4(2)	100	99	90	43	NP	NP	6.4	5.5	9	Good
B	A-4(2)	100	99	91	45	21	5	5.9	5.6	9	Good
C	A-4(2)	100	99	91	47	25	8	5.1	5.8	10	Good
Eufaula A	A-2-4(0)	100	100	90	12	NP	NP	5.6	3.7	8	Good
C	A-2-4(0)	100	100	93	17	NP	NP	7.5	4.0	8	Good
Mason A	A-4(8)	100	100	99	93	29	8	5.9	NO	11	Fair
B	A-7-6(15)	100	100	100	96	47	23	5.1	NO	15	Poor
C	A-7-6(12)	100	99	98	87	42	20	6.3	NO	14	Poor
Okemah A	A-6(8)	100	93	89	78	39	11	5.6	NO	12	Fair
B	A-7-5(11)	100	84	76	62	54	19	6.0	NO	13	Poor
C	A-7-5(18)	100	97	95	88	60	25	7.1	NO	16	Poor
Pottsville A	A-4(1)	100	100	99	38	NP	NP	5.4	5.2	9	Good
C	A-7-6(11)	100	100	100	94	41	17	4.6	NO	14	Fair

Table 13 (Continued)

Soils Series and Horizons	AASHO Class.	Sieve No. 10	Analysis No. 40	(% Passing) No. 60	No. 200	Liquid Limit	Plastic Index	pH	Stabilization % Asphalt	% Cement	Subgrade Quality
Stephenville A	A-4(1)	100	99	94	41	NP	NP	6.9	5.4	9	Good
B	A-4(6)	100	100	95	64	34	10	5.3	NO	11	Fair
C	A-4(4)	100	100	96	54	27	9	4.9	6.7	10	Fair
Stidham A	A-2-4(0)	100	99	92	23	NP	NP	6.1	4.3	7	Good
B	A-4(0)	100	99	94	36	18	3	6.2	5.1	9	Good
C	A-4(1)	100	100	95	40	24	8	6.3	5.4	9	Good
Talhina A	A-4(4)	100	99	90	53	21	5	7.5	6.1	10	Good
C	A-6(8)	100	99	93	70	34	12	7.6	NO	12	Fair
Teller A	A-4(8)	100	98	95	74	23	5	6.3	NO	11	Fair
B	A-6(10)	100	98	96	83	32	14	6.5	NO	12	Fair
C	A-6(9)	100	98	96	81	31	12	7.6	NO	12	Fair
Verdigris A	A-6(8)	100	100	99	91	35	11	5.9	NO	12	Fair
C	A-4(8)	100	99	98	83	31	10	5.9	NO	11	Fair
Woodson A	A-6(9)	100	98	96	85	37	12	6.4	NO	12	Fair
B	A-7-6(15)	100	99	98	91	51	22	6.4	NO	15	Poor
C	A-7-6(16)	100	98	97	93	51	24	6.4	NO	15	Poor

Data extracted from Hayes and McCasland (1967). Information from throughout Creek County including the Mannford area.

soil passing the No. 200 sieve (i.e., silt and clay on ASTM textural classification) and the portion retained on the No. 200 sieve (sand) (Anonymous, 1969). The liquid limit and plasticity index indicate the shrink and swell characteristics of each soil. When the liquid limit is 30 or greater or the plasticity index is 20 or greater, the soil is likely to swell when wetted and crack extensively when dried.

A brief description of the hydrologic characteristics of each soil series is presented in Table 14. Caution should be exercised in utilizing these data since the subsoil moisture content at the time of testing is not specified. Percolation tests on soils during the Spring, when moisture contents are high, would produce abnormally low permeability values because clay in the soil would already have expanded before the test. Percolation tests taken on a clayey soil during the summer, owing to dessication, would produce abnormally high permeability values because water would move rapidly along dessication cracks. The data, despite the limitations, are applicable to septic field design and installation since low-permeability soils severely limit septic field efficiency.

Table 14.-Estimated minimum permeability of least permeable layer for the soil series in the Mannford area, Oklahoma.

Soil Series	Permeability of least permeable layer (in./hr.)
Bates	0.8 - 2.5
Collinsville	0.05 - 0.20
Darnell	0.20 - 0.80
Dennis	0.05 - 0.20
Dougherty	0.8 - 2.5
Eufaula	5.0 - 10.0
Mason	0.2 - 0.8
Okemah	0.05 - 0.20
Pottsville	0.20 - 0.80

Table 14 (Continued)

Soil Series	Permeability of least permeable layer (in./hr.)
Stephenville	0.8 - 2.5
Stidham	0.8 - 2.5
Talihina	0.8 - 2.5
Teller	0.8 - 2.5
Verdigris	5.6 - 8.0
Woodson	0.05 - 0.20

Data extracted from H. C. Oakes (1959), Long (1968), and Galloway (1959).

Table 15 and Plate 9 (Map of Corrosivity Potential for Uncoated Steel Pipe in the Mannford Area, Oklahoma) summarize the corrosivity potential of the soils in the Mannford area. Identification of highly corrosive soils may alter proposed routes of pipelines susceptible to corrosion or indicate the need for coated or composition pipe. These considerations become especially important where soil drainage is poor, permeability is low, pH is acidic, and resistivity is below 4500 ohms/cm.

Table 15.-Corrosivity characteristics of the B and C horizons for the soil series in the Mannford area, Oklahoma.

Soil Series	Resistance (ohms/cm.)	pH	Uncoated Steel Pipe Life (Yrs.)	Number of Tests
Bates	4500	5.3	20	17
Collinsville	3500	5.6	19	9
Darnell	4100	6.1	22	12
Dennis	3600	6.3	22	11
Dougherty	4100	5.9	21	14
Eufaula	5300	6.0	23	10
Mason	3700	5.9	20	3
Okemah	900	5.5	21	8
Pottsville	----	---	--	--
Stephenville	4700	5.6	21	25
Stidham	5100	5.1	20	5
Talihina	2400	6.6	23	4

Table 15 (Continued)

Soil Series	Resistance (ohms/cm.)	pH	Uncoated Steel Pipe Life (Yrs.)	Number of Tests
Teller	3700	6.4	24	13
Verdigris	2600	5.8	18	8
Woodson	2000	6.5	20	19

Data extracted from Hayes (1971).

FACTOR MAPS AND THEIR USES

A factor map presents one or more types of closely related environmental data at a scale large enough to be useful for planning, engineering, and construction. The selection of individual sites, although guided by factor maps, will require additional on-site geologic and engineering testing to identify local variations in field conditions.

A series of 12 maps based on topography, soils, bedrock geology, surficial geology, and bedrock and soil engineering data in various combinations has been prepared for the Mannford area. A scale of 1:12,000 (1 inch = 1000 ft.) is utilized on each of the 12 factor maps because of the complexity of geologic and soil deposits in the area. Procedures utilized in preparing each factor map and problems encountered are discussed in Appendix 3 (p. 84-96).

Topographic Map

The topographic map of the Mannford area, Oklahoma, (Plate 1) depicts the topography and the works of man. By overlaying other factor maps on Plate 1, the distribution of each variable's intensity patterns can be located geographically and evaluated with respect to topography.

Slope Map

The slope map (Plate 2) shows the distribution of slopes in the Mannford area in terms of per cent. Plate 2 was prepared with a template (see Appendix 3, p. 85) constructed to measure the ratio of change in elevation in feet to the horizontal distance traversed expressed in per cent (Hilpman and Stewart, 1968). Slopes are grouped into 4 categories: 0 to 2 per cent, 2 to 5 per cent, 5 to 15 per cent, and greater than 15 per cent. Approximately 15 per cent of the Mannford area has a 0 to 2 per cent slope, 45 per cent has a 2 to 5 per cent slope, 35 per cent has a 5 to 15 per cent slope, and approximately 5 per cent has a slope greater than a 15 per cent. Most of the existing structures in the Mannford area are located on slopes of less than 5 per cent.

Plate 2, in conjunction with the grade limitation guidelines (Fig. 8), indicates that many slopes in the north, central, and southeastern portions of the study area are within slope specifications for most construction projects likely to be considered in Mannford. Virtually any slope however can be modified for most projects if economic considerations are not involved.

Slope distribution is a major economic consideration because natural slopes frequently require modification to accommodate structures. The cost of excavating soil and rock increases substantially when slopes are greater than 5 per cent because of the larger quantities involved. Sandstone frequently crops out in the study area where slopes are greater than 5 per cent. This further increases costs because of the need to blast or rip. Most sandstones in the study area appear to be rippable (see Table 11), enabling their removal more economically than if blasting is required. Shales in the study area can be excavated with ordinary earthmoving equipment.

Where colluvium occurs on steep slopes, slopes may be unstable (see Plates 5 and 2). The silty colluvial unit (Qc-3) probably is more un-

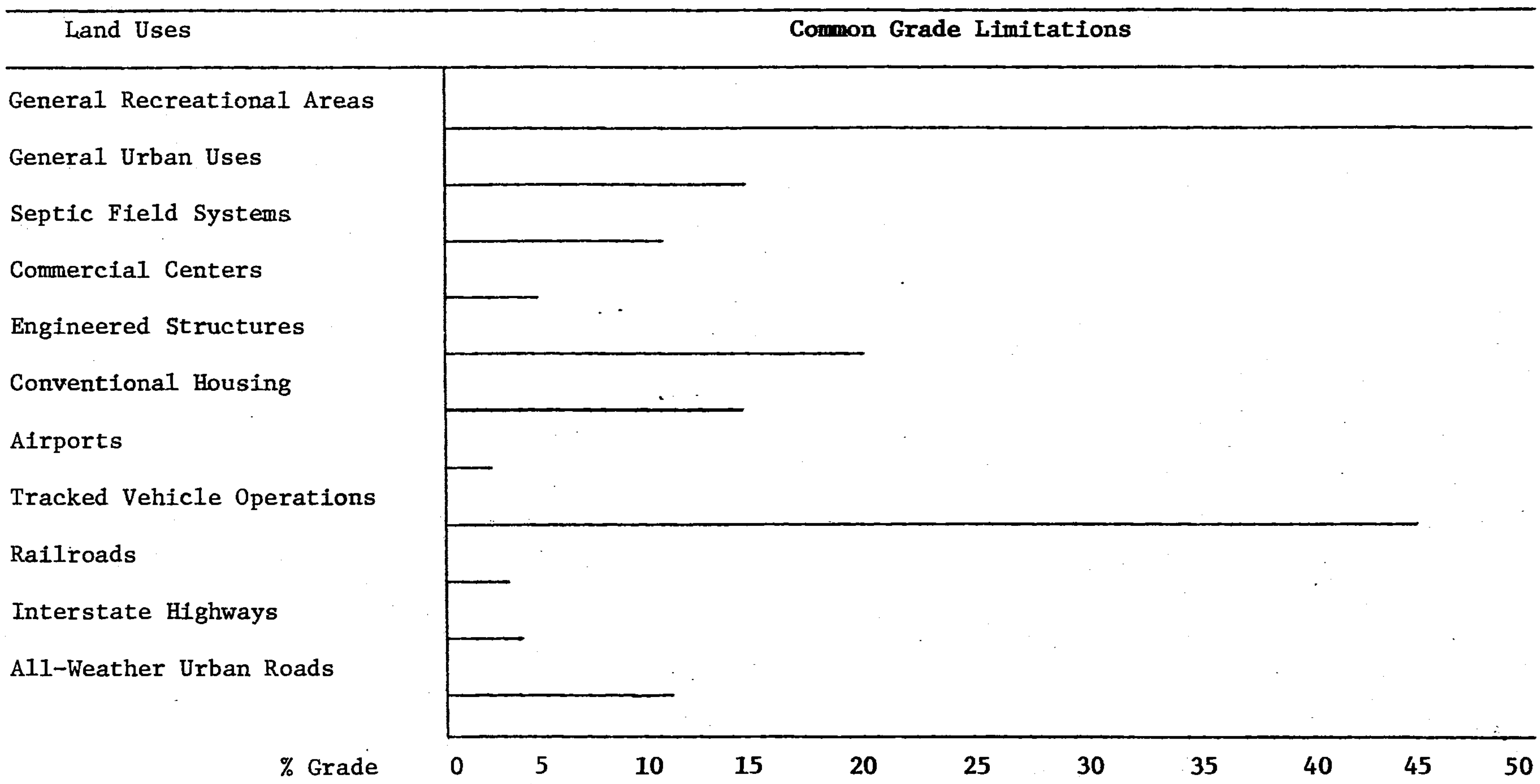


Fig. 8.-Ranges of slopes suitable for various urban installations and activities. Data extracted from Hilpman and Stewart (1968).

stable than the other 3 colluvial units.

Drainage Map

The drainage map (Plate 3) shows the network of intermittent streams in the study area; the only former perennial stream in the area (Salt Creek) has been covered by Keystone Reservoir. The drainages shown are a composite of drainages on published topographic maps at a scale of 1:24,000, aerial photographs, and the Creek County Soil Map (see Appendix 3, p. 86).

An accurate drainage map is important in planning storm drainage networks and transportation routes. Watershed geometry and precipitation data (see section on Climate), supplemented by runoff measurements and local experience, will enable the engineer to make preliminary estimates of the size and location of storm drainage networks and to design bridges, culverts, and fills for road networks. Bridge, culvert, and fill construction disturb the balance between channel geometry and water flow. To restore the balance, local channels may require widening or straightening. Drainages that parallel roadfills may require lining to prevent infiltration into the fill. As more of the Mannford area is developed, of course, substantially greater runoff volumes are to be anticipated as buildings, parking lots, and streets cover more of the land surface.

Bedrock Geologic Map

The bedrock geologic map (Plate 4) shows the distribution of consolidated rock units in the Mannford area as if all unconsolidated materials had been stripped away. Bedrock in the Mannford area consists of an alternating sequence of sandstones and shales with thin sandstone interbeds, which crop out in approximately north-south trending bands. The cross section included on Plate 4 allows projection of bedrock units into the subsurface.

The bedrock geologic map can be utilized as a bedrock engineering-feasibility map for correlating engineering test data and local experience with the various units. A complete description of each bedrock unit is included in the section on Bedrock Stratigraphy.

Surficial Geologic Map

The surficial geologic map (Plate 5) shows the exposed bedrock, colluvium, alluvium, and artificial fill in the Mannford area as if all pedologic soils had been stripped away. Unconsolidated materials, excluding pedologic soils, cover approximately 50 per cent of the area. A description of each unconsolidated surficial unit is included in the section on Quaternary Stratigraphy.

Colluvium occurs in much of the study area but is most common west of the reservoir and downslope from the Tallant Formation. The blocky colluvium (Qc-1) appears to be the only colluvial unit found east of the reservoir in the study area. Flood-plain and terrace alluvium are present along 4 of the intermittent drainages above conservation pool level (720 ft.) in the study area. Other terrace deposits occur locally along the shoreline of the reservoir. Artificial fill is present in the business district, roadfills, and along the railroad. Bedrock lithology is shown where bedrock crops out at the surface.

Soil Map

The soil map of the Mannford area (Plate 6), extracted and enlarged from the Creek County Soil Survey (H. C. Oakes, 1959), shows the distribution of each soil type in the study area. The map served as the base map in the preparation of Plates 8-12. When Plates 8-12 are placed over the soil map, each pedologic soil within a factor map pattern (low, moderate, or high) can be identified and evaluated with respect to its erosion susceptibility (Plate 8), corrosivity potential (Plate 9), recreational suitability (Plate 10), plasticity characteristics (Plate 11), and geologic constraints for general land use (Plate 12).

Depth to Bedrock Map

The depth to bedrock map (Plate 7) shows the distribution and thickness of the regolith in the Mannford area. Approximately 40 per cent of the study area has bedrock exposed or within 2 ft. of the surface. Regolith 2 to 4 ft. thick covers 40 per cent, 15 per cent is covered by 4 to 6 ft., and approximately 5 per cent is covered by more than 6 ft. of unconsolidated materials.

The depth to bedrock map, using a 2-ft. depth interval, has been constructed utilizing refraction seismic data, shallow borings, and visual inspection. Many of the visually determined depths shown on Plate 7 are from bedrock exposed at the surface over distances frequently in excess of 300 ft. Control points occur along the bluffs, on both sides of the reservoir in the south-central and south-eastern portions of the study area, and the sandstone-capped benches bordering the rest of the reservoir. A maximum of 1 point was recorded on the map for each 300 ft. (linear) of exposed bedrock in these instances. Most of the depth-zone lines are dashed to indicate the approximate position of the contacts. A detailed description of the procedure developed and of problems encountered in the refraction seismic survey are discussed in Appendix 3 (p. 89).

The primary application of Plate 7 is to delineate bedrock depth with sufficient accuracy to indicate where consolidated rock will interfere with construction. Fig. 9 shows several minimum excavation depths for various subsurface installations in the Mannford area, Oklahoma. Local construction experience will dictate which depth requirements can be adjusted.

A major obstacle will be encountered in the installation of utility poles, fuel lines, underground cables, and water lines when the depth to sandstone is less than 3 ft. Shale, however, can be excavated by conventional earthmoving equipment. Table 9, Plate 7, and Plate 4 should be used together when subsurface projects are planned, especially in the western and eastern portions of the study area where depth to sandstone is commonly less than 3 ft.

Erosion Susceptibility Map

The erosion susceptibility map (Plate 8) delineates zones of varying erosional susceptibility based on runoff potential. Runoff potential is estimated on the basis of slope, permeability, and soil texture. The soils are grouped on their behavioral similarities. Approximately 45 per cent of the area is classified as highly susceptible to erosion, 50 per cent as moderately susceptible, and 5 per cent of low erosional susceptibility. Those receiving high susceptibility ratings generally are on steep slopes with low permeabilities; conversely, low suscepti-

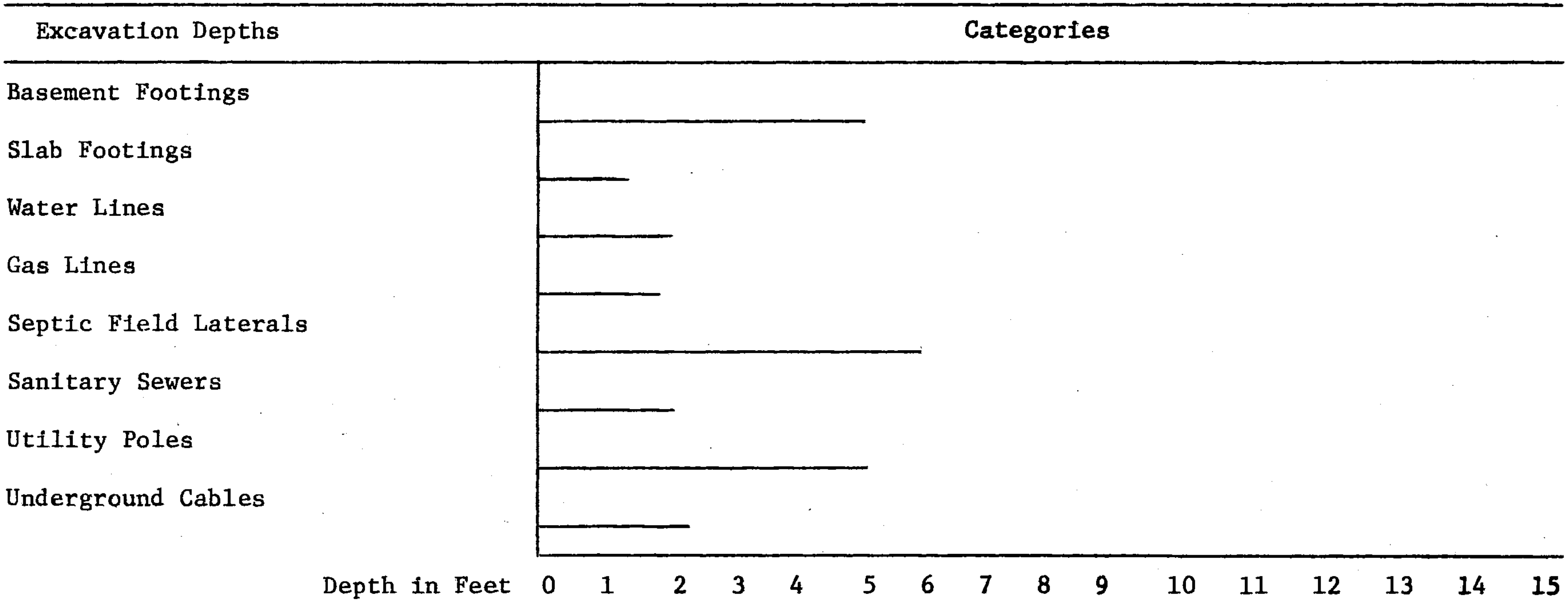


Fig. 9.-Minimum depth requirements for various urban projects in east-central Oklahoma. Data modified from Hilpman and Stewart (1968).

bility group members tend to be on gentle slopes with high permeabilities. Sands generally would be permeable enough to be grouped in the low susceptibility class except that they are susceptible to wind erosion. Silts and clays can be both moderately and highly susceptible to erosion depending upon the percentages of silt and clay and the slopes involved.

Careful land management of vegetation can significantly reduce soil erosion throughout the Mannford area. It should be emphasized that soil erosion is likely to occur on previously undeveloped tracts of land when construction, recreational use, and other non-agricultural activities destroy existing vegetation.

Map of Corrosivity Potential for Uncoated Steel Pipe

The corrosivity potential map (Plate 9) shows zones of varying corrosivity for uncoated steel pipe. Based on the soil's internal drainage, permeability, pH, resistivity, and texture, 3 classes of corrosion potential are recognized. Approximately 95 per cent of the area is classified as being of moderate to high corrosivity potential making corrosivity an important factor in the subsurface installation of pipes, cables, metal fence posts, metal pilings, and tanks of various types. Mannford should consider installing composition pipe where local ordinances permit. Where ordinances require steel pipe, it should be coated and routed to avoid as many highly corrosive soils as possible.

Recreational Suitability Map

The recreational suitability map (Plate 10) delineates zones in the study area on the basis of trafficability, texture, permeability, and depth to bedrock. Approximately 75 per cent of the study area is classified as low recreational suitability, 20 per cent as moderate, and 5 per cent as good. Trafficability is defined in this study as the reaction of a soil to human or vehicular loading. Low trafficability soils when loaded undergo either compaction (clayey soils) or loss of stability (sandy soils). Stability is used here in the sense that sandy soils under loading from vehicles, human, or animal feet have a tendency to move down and laterally thereby destroying the roots of vegetation. Since no distinction is made as to whether the recreational site should be developed or undeveloped, minimal attention is given to topography as a factor. It is obvious, however, that topography is an important factor in the selection of recreational land. The type of use intended will determine the kind of topography that is usable. Plate 2 can be consulted to ascertain slope.

Selection and maintenance of recreational facilities are important to Mannford because of the economic benefits gained from tourists visiting the area and from making the city appealing as a suburb of Tulsa. Mannford is blessed with excellent facilities for water sports but a need exists for parks, golf courses, and other developed recreational facilities. Much of the Mannford area is rather poorly suited for some recreational uses because of low trafficability, shallowness of bedrock, and low permeabilities associated with clayey subsoils. Most of the acreage of moderate recreational suitability is located in the north-central and southwestern portions of the study area.

Map Showing Plasticity of Solum and of Subsoil

Plate 11 shows the areal distribution of soil plasticity for all of the pedologic soils in the Mannford area. Each soil type is grouped into a 2-letter classification on the basis of the plasticity of the solum (A and B horizons) and of the subsoil (C horizon). Categories utilized in establishing the liquid limit and plasticity index ranges for various groupings are shown on the explanation of Plate 11. These include 4 soil groupings that indicate plasticity and a fifth designates formerly oil- and brine-wetted soils. Approximately 95 per cent of the Mannford area exhibits low (classified AA) and moderate (classified AB and BB) plasticity with the remaining 5 per cent approximately equally divided between highly plastic (BC) and formerly oil- and brine-wetted soils (P).

The purpose of the plasticity map is to show the soils of the Mannford area that are likely to undergo changes in volume as a result of changes in moisture (shrink and swell). Highly plastic soils can be identified and generally avoided allowing exploration efforts and resources to be maximally utilized in selecting suitable construction sites and fill materials.

Moderately to highly plastic soils offer serious problems to roadbeds, basements, and foundations. These soils typically have low shear strengths and are susceptible to settlement. Stresses developed by expanding or contracting soils can produce extensive cracking of structures. Soil expansion and contraction in some instances can be minimized by insuring proper drainage under and around the foundation. Proper drainage must be determined by the engineer, but one or more of the following procedures can help to minimize such effects: (1) installing perforated pipe under the foundation; (2) extending gutters beyond the foundation; and (3) placing a concrete, asphalt, or plastic apron around the foundation. These same moderately and highly plastic soils should be avoided if possible as fill materials for the reasons mentioned above.

Geologic Constraint Map for General Land Use

Generally, factor maps present a specific type of physical information. Frequently, however, urban planning is dependent upon several physical factors requiring decisions incorporating a combination of 2 or more factor maps. The map, resulting from the combination of several factor maps, is termed a suitability map (Hilpman and Stewart, 1968). Plate 12 zones the Mannford area into 3 land-use classes on the basis of corrosion potential, plasticity, erosion susceptibility, and depth to bedrock using a weighted averaging technique (see Appendix 3, p. 94). Alluvium, considered to be high in flood potential, is grouped in a separate category under major geologic constraints. The acreage between the reservoir and the U.S. Army Corps of Engineers maximum flood control pool (754 ft.), shown by the dashed line on Plate 12, is susceptible to flooding. The area is zoned as if it were not susceptible to flooding since some construction, excluding housing, may be allowed by the U.S. Army Corps of Engineers. It should be stressed, however, that flooding may occur in this area during periods of high precipitation in the Arkansas and Cimarron River drainages.

The purpose of this highly interpretative map is to indicate those areas where minor to moderate constraints are expected to occur in the construction of streets, roadways, foundations, and subsurface utilities. Minor to moderate constraints mean that an area has low flood potential, low to moderate corrosion potential, low to moderate plasticity, low to moderate erosion potential, and depth to bedrock generally greater than 3 ft. Approximately 10 per cent of the study area is of minor, 80 per cent is moderate, and 10 per cent is of major geologic constraints. Most of the present development in the Mannford area has occurred in areas of minor to moderate geologic constraints. A mile-wide strip running from north to south through the west-central portion of the study area appears to be the area best suited for further community development. Minor to moderate geologic constraint indicates that most limitations of construction sites can be overcome readily. For example, corrosivity can be minimized by using composition pipe where local ordinances will permit and by providing adequate drainage in areas where moderately plastic soils are present. Erosion on construction sites can be minimized by seeding of slopes as soon as possible.

Because of the interpretative nature of Plate 12, the information should be used with care. An area mapped as being of minor geologic constraint may be adequate for 1 set of project requirements but only moderately suitable for another depending upon the relative priority of the variables being considered in a particular project.

ENVIRONMENTAL GEOLOGY INTERPRETATIONS

The interpretations made in this section are based upon the data summarized in the sections on Structural Geology, Soils, Ground Water, Engineering Geology Data, and upon the 12 factor maps of the Mannford area.

Liquid Waste Disposal

Frequently associated with the industrial growth of an area is the problem of disposing of liquid wastes. Previous oil production may result in number of abandoned and unplugged wells, making a decision to dispose of liquid wastes in the subsurface a great risk. Unplugged wells produce an open formation condition in the shallow subsurface geologic units which may result in ground water and surface-water pollution by waste fluids during or after injection.

Before the Mannford area is considered for subsurface disposal of fluids, a thorough investigation should be conducted using all available well information possibly supplemented with information from exploratory wells. Consideration also must be given to locating as many of the abandoned wells as possible and to plugging them. A hydrologic evaluation of the ground-water system also should be conducted (see Ground Water section) to determine the type, depth, quality, and flow regime of the ground-water system in the area at least as deep as fresh water is found an possibly even deeper. Obviously, such exploration would be extremely expensive and the Mannford City Council might, under such circumstances, elect to restrict any development of industry which might produce toxic liquids that might require subsurface disposal.

Because of (1) the cost of locating and plugging all abandoned oil wells in the area; (2) the lack of sufficient data concerning the ground-water system; and (3) the costs involved in evaluating the subsurface ground-water system, disposal of wastes by injection should be generally avoided in the study area.

Solid Waste Disposal

The only practical method of solid waste disposal is to bury it in relatively impermeable material such as shale since many leachates may be toxic. Many communities locate sanitary landfills in alluvial deposits of high permeability along stream drainages. As a result, streams and lakes have been polluted by direct surface runoff from landfills and by percolation of leachate into ground water which in turn enters local drainages where the water table intersects the streams.

Sanitary landfills should be located in low-permeability materials that are not in close proximity to subsurface aquifers, springs, seeps, or local stream drainages. Sanitary landfills in the Mannford area should be situated on the west side of the reservoir, since the bedrock dips to the west, to avoid down-dip movement and discharge of leachates into Keystone Reservoir. Covering the top and walls of landfills with clay or some other impermeable materials such as plastic films will reduce the amount of leachate migration.

A Tulsa firm currently disposes of Mannford's solid waste in the Chandler Park area of Tulsa. In the future, Mannford will dispose of its own solid waste. A new disposal site is being investigated west of the reservoir in the Terlton area near Oklahoma Highway 48 approximately 4 mi. northwest of Mannford (M. C. Kimberly, 1972). This site, located in Pawnee County, is in the Vamoosa Formation.

Keystone Reservoir Pollution

The pollution sources for Keystone Reservoir in the Mannford area are both natural and man-made. The Salt Fork of the Arkansas River, northwest of the study area, and Salt Creek of the Cimarron River drainage, within the study area, contribute natural chlorides to Keystone Reservoir. Local residents indicate that Salt Creek, prior to the construction of Keystone Reservoir, was considered to be high in dissolved chlorides. Salt Fork of the Arkansas probably contributes more natural chlorides than Salt Creek to the natural pollution of Keystone Reservoir within the study area.

A major pollution source for Keystone Reservoir in the Mannford area is sediment eroded from slopes and transported into the reservoir. The soils zoned as being of high erosion susceptibility pose the largest potential sediment contribution (Plate 8). Erosion generally can be controlled by seeding exposed slopes and by maintenance of existing vegetation along the intermittent drainages.

Pollution from oil seeping into Keystone Reservoir does not appear to be a serious problem in the study area. Only 1 abandoned well, outside the study area, has required plugging since the reservoir was completed. Leakage of brine or petroleum, however, is possible from the unknown number of unplugged oil wells suspected to be present below the reservoir's conservation pool level as secondary recovery operations are conducted in oil fields in the area. Detection of oil seeps is relatively simple but finding and plugging wells within the reservoir is very difficult.

Foundation Conditions

Plate 5 (surficial geology), Plate 7 (depth to bedrock), Plate 11 (plasticity of solum and of subsoil), and Plate 12 (geologic constraint for general land use) are useful in appraising local foundation conditions. Examination of each of the maps will identify the type of foundation problem expected to occur at any site being considered.

Soils with liquid limits greater than 30 or plasticity indices greater than 20 are the most susceptible to shrinkage and swelling with changes in moisture. The following procedures should help to minimize such effects: (1) the installation of perforated drainage pipe under foundations; (2) the construction of concrete, asphalt, or plastic aprons around foundations; and (3) roof drains extended well beyond foundations.

Silty and clayey surficial deposits including the Teller, Mason, Okemah, and Woodson Soil Series and the silty colluvial deposit (Qc-3) offer serious problems to roadbeds, basements, and foundations. These moderately to highly plastic soils typically have low shear strengths and are susceptible to settlement.

Sandy surficial deposits in the Mannford area including the Eufaula, Stephenville, Darnell, and Dougherty Soil Series and the sandy colluvial unit (Qc-2) visually appear to be in a rather loose in-situ condition. Buildings constructed on such deposits, if not compacted prior to construction, may undergo settlement as a result of the rearrangement of sand grains because of static loading produced by the structure or because of vibrations.

One of the more important factors affecting foundation construction is depth to bedrock. Sandstone commonly occurs within 3 ft. of the surface in the study area. Shales occurring within 3 ft. of the surface are not a problem since they can be excavated by conventional earthmoving equipment. Table 11 indicates that the sandstones in the Mannford area are rippable with a D-9 Caterpillar tractor. Generally, ripping of sandstone is possible as long as bedding planes and joints are 3 ft. or less apart. Where sandstone is massive and not well jointed, blasting may be necessary. Local construction experience will dictate which techniques are most satisfactory when such problems arise.

Bedrock is so shallow in much of the study area that most heavy structures may be founded directly upon bedrock. The Rock Quality Designation (see Table 10) suggests that buildings without basements, which require high bearing capacities, may be founded directly upon sandstones which are at least 3 ft. thick and relatively free of joints. Buildings with basements, which require high bearing capacities, may be founded directly upon shales depending upon the shear strength, density of joints, thickness, and other engineering properties of the unit. Sandstones probably should be avoided where basements are planned for economic reasons. On-site investigations and local experience will determine the feasibility of such practices at each site.

Erosion Control

Some of the soils in the area contribute substantial amounts of sediment to Keystone Reservoir (M. C. Kimberly, 1971). Surface gulleying and silting of storm sewers are also problems resulting from soil erosion. Plate 8 should be used to identify areas of high erosion susceptibility where erosion is a serious problem. Seeding of exposed slopes and intermittent drainages should substantially reduce the amount of erosion and minimize the headward erosion of gulleys.

Erosion also is a potential problem in recreational areas (Plate 10). Erosion may become serious where sandy and silty soils are subjected to human or vehicular traffic and where slopes are greater than 5 per cent.

Slope Stability

Although local officials indicate that slope stability problems in the study area are local and minor, the Vamoosa and Barnsdall Formations are susceptible to slumping and backslope failure when slopes are on the order of 2:1 or greater (see Table 11). Unconsolidated materials or shales may be susceptible to slumping where steep natural slopes occur. Any excavations for roads, foundations, basements, and ditches also are susceptible to slumping. Where sandstone blocks, bounded by bedding planes and joints, occur on very steep slopes such as roadcuts, there is a danger of rockfall.

Excavation

Some excavation problems probably will be encountered in the study area as a result of springs, seeps, (see section on Ground Water) and shallowness of bedrock (Plate 7). Table 11 indicates, however, that sandstones can be ripped with a D-9 Catepillar tractor where bedding thickness is less than 3 ft. and joints occur. Locally, where massive, unjointed sandstone is encountered, other measures based upon local experience will be required to excavate bedrock.

Springs and seeps are possible virtually anywhere a sandstone overlies a shale in the study area. Springs and seeps have been observed by the author, during the late winter, flowing from the base of the lower Tallant (IPt-1) and the base of the Vamoosa sandstone (IPv-1). Contact springs may develop in the area following rainy periods in both old and new excavations. If a contact spring occurs in an excavation for a foundation, water may soften the material under the foundation and reduce its shear strength, or produce settlement of the structure during and after construction. The leakage of water into structures also is possible. If seeps are encountered in excavations and temporary ditches, particularly in shales, shoring and sump pumps should prevent failure of the walls. Temporary ditches in unconsolidated materials should be shored even if water is not a problem.

Mineral Resources

Oil exploration in the past in the Mannford area was rather extensive. During the period from 1922 to 1959, there were 471 producing oil wells within a 6 mi. radius of Mannford (M. C. Oakes, 1959, p. 69). Oil exploration today in the Mannford area is virtually nil. Several wells, however, still are producing in the area.

A more current problem associated with oil production is the installation and maintenance of pipelines. Plate 9 shows the moderately to highly corrosive zones expected to cause pipeline corrosion problems. Since several pipelines do cross Keystone Reservoir outside the study area, corrosive failure may occur because of the dissolved chlorides in the water. Density differences between saline and relatively fresh water may produce stratification of the water with the saline water concentrated along the bottom of the reservoir. Corrosion might be reduced if it were possible to suspend pipelines above the more saline layer.

Sources of sand, gravel, and curshed limestone are not available within the study area. The Lost City Member of the Hogshooter Limestone, approximately 15 mi. east of Mannford, offers the primary source of crushed limestone for concrete in the study area. Another possibility is a limestone unit of the Dewey Formation. The unit is approximately 5 ft. thick and crops out about 5 mi. east of the study area. Since the alluvium of the Cimarron and Salt Creek drainages are covered by the reservoir, local contractors generally obtain sand and gravel from the Arkansas Valley alluvium, near Sand Springs, 15 mi. to the east of Mannford. Several large dredging operations are located along the Arkansas River, near Oklahoma Highway 51, within easy access of Mannford.

Seismicity

The Mannford area, although not generally considered prone to earthquakes, does occur in an area of low probability for earth tremors (Algermissen, 1966). Algermissen shows the study area to have a higher probability for earth tremors than does approximately 80 per cent of the United States. Although no major earthquakes are known to have occurred in the area in historical times, a few earth tremors have been felt in east-central Oklahoma. Although the probability of earthquakes that would be dangerous to life and property is low, the possibility does merit consideration in the design of large buildings and other large structures.

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APPENDIX 1: GLOSSARY

AASHO Classification--American Association of State Highway Officials Classification; a classification based upon highway performance; based upon plasticity and texture; indicates the suitability of soils for highway construction.

A Horizon--The uppermost zone in the soil profile from which soluble salts and colloids have been leached and in which organic matter has accumulated.

Alluvium--Unconsolidated material deposited by a stream.

Aquifer--A body of earth material which has distinct boundaries and includes units of materials that together permit an appreciable volume of water to move from one boundary toward another under ordinary field conditions.

Bedding--Separate individual layers (beds or laminations) in sedimentary rocks.

Bedrock--Consolidated rock exposed at the surface or underlying the regolith.

Bench, sandstone-capped--A comparatively level, narrow and raised landform capped by sandstone.

B Horizon--The lower part of the solum which is enriched by decomposition or precipitation of material from the overlying A horizon.

C Horizon--The unconsolidated or weathered material from which a soil has been derived.

Clay--Sediment composed principally of particles less than 0.0039 mm. in diameter (range used by the geologist); less than 0.005 mm. in diameter (range used by the engineer).

Colluvium--Unconsolidated material that has been moved down slopes under the influence of sheet wash and creep.

Conglomerate--Consolidated sedimentary rock composed largely of rounded rock fragments greater than 2 mm. in diameter.

Creep--The imperceptibly slow downslope movement of rock and soil materials.

Cross-bedding--An arrangement of stratification of rock inclined to overall bedding planes.

Dendritic drainage--The drainage pattern characterized by irregular branching (branch-like) with tributaries joining the main streams at all angles.

Dip--The angle and direction of inclination of a sloping bed of rock always measured perpnedicular to strike. Dip is commonly expressed in degrees of inclination below the horizontal (or in ft./mi.) and generalized compass direction of dip.

Dolomite--Consolidated sedimentary rock having a composition of $CaMg(CO_3)_2$; will produce gas when diluted hydrochloric acid is applied to powder.

En Echelon--Parallel features such as faults that are offset like the edges of shingles on a roof when viewed from the side.

Environmental Geology--The branch of geology dealing with the relationships between man and his geological habitat.

Escarpment--A sharp and steep slope extending a substantial distance.

Factor Map--A map presenting one or more types of geologically related information of environmental significance.

Flood-Plain--A strip of relatively smooth land bordering a stream underlain by alluvium and subject to flooding by the stream.

Formation--A formally named geologic unit that can be recognized in the field and that is thick enough to be mapped at a scale of 1:25,000.

Geologic Map--Map showing geographic distribution of geologic units at the surface or in the subsurface.

Geomorphology--That branch of geology which deals with the form, general configuration, and evolution of land forms.

Grade--The measure of inclination defined as the ratio of change in elevation in feet to the horizontal distance traversed expressed in per cent.

Hydrology--The science of water.

Illuviation--Deposition in the B horizon of colloids, soluble salts, and mineral particles which have been leached from the A horizon.

Initial Dip--The angle of slope of bedding surfaces at the time of deposition; the contacts between layers usually being approximately parallel with the surface of deposition.

In-situ--A term indicating that a material is in its natural position or place.

Interbedded--Two or more types of geologic materials occurring in alternating beds.

Intermittent Stream--A stream which flows only part of the year, as after a rain.

Joints--A fracture in rock across which no appreciable movement has occurred.

Landform--Erosional or depositional feature that makes up part of the surface of the earth.

Leachate--Water that has filtered through a deposit of a natural or man-made nature picking up material in solution.

Lenticular--Lens-shaped.

Liquid Limit--The moisture content of a clayey material at the point where it passes from a plastic to a liquid as determined with a liquid limit instrument.

Mappable Unit--A deposit, including formations, that can be recognized in the field and is large enough to be shown on a map.

Massive--Term applied to geologic beds greater than 3 ft. in thickness and consisting of only one type of rock.

Mottling--Blotchy variations in color caused by poor drainage in unconsolidated deposits and weathered materials.

Nodule--Small more or less rounded body generally somewhat harder than the enclosing sediment or rock matrix.

Outcrop--An exposure of rock.

Parent Material--The weathered bedrock or unconsolidated material from which soil is derived by soil-forming processes.

Pennsylvanian Period--The geologic time period during which the rocks found in the study area were deposited; approximately 270 to 325 million years ago.

pH--Refers to acidity or alkalinity; scale ranges from extremely acidic (pH=1) to extremely alkaline (pH=14); neutral (pH=7).

Permeability--The property of rock or unconsolidated material which allows it to transmit fluids.

Plasticity Index--Numerical difference between liquid limit and plastic limit of a specific soil.

Plastic Limit--Moisture content at which a soil changes from the solid state to the plastic state; moisture content at which a soil will just begin to crumble when rolled into a thread 1/8 in. in diameter.

Porosity--Pore space in a rock or sediment expressed in per cent.

Quaternary Period--The most recent geologic period; approximately the last 1 million years.

Refraction Seismic Technique--Geophysical exploration technique based upon measuring the rate of transmission of compressional waves through earth materials.

Regolith--The mantle of weathered rock, unconsolidated material, and pedologic soils that commonly overlies bedrock.

Residuum--An unconsolidated deposit which is weathered in place.

Rippability--Susceptibility of a rock to be broken by a ripping device pulled or pushed by a D-9 Caterpillar tractor or its equivalent.

Rock Units--A bed of rock, a group of beds of rock, or any rock body that exhibits properties that allow it to be distinguished from other nearby rock bodies.

Sand--Sediment ranging in size from 0.062 to 2.0 mm. in diameter (range used by the geologist); 0.074 to 2.0 mm. in diameter (range used by the engineer); sand is sediment which passes the No. 10 sieve but is too large to pass through the No. 200 sieve.

Sandstone--Consolidated sedimentary rock consisting of sand grains cemented together by materials such as calcite, silica, iron oxide, and clay.

Seep--An area where water comes to the surface from underground saturating surface materials.

Seismic Velocity--The rate of propagation of seismic waves in earth materials usually measured in ft./sec.

Seismicity--A property of the earth pertaining to its ability to produce earth vibration (earthquakes).

Series, Soil--The basic soil mapping unit; each series has characteristic structures, textures, chemistry, and mineralogy.

Shale--A consolidated sedimentary rock consisting predominatly of clay-sized particles; lithification is by compaction and cementation.

Sheet Wash--Movement of water down a slope in which the water is not concentrated in streams.

Shrink and Swell--A process of expansion and contraction which occurs in soils, shales, and clays containing those clay materials which expand when wet and contract when dry.

Silt--A unconsolidated clastic sediment ranging in size from 0.0039 to 0.062 mm. in diameter (range used by the geologist); 0.005 to 0.074 mm. in diameter (range used by the engineer).

Soil--1. Soil science (pedology): material at the earth's surface which has been modified and acted upon by physical, chemical, and biological agents and that has developed horizons with characteristic structures, textures, chemistry, and mineralogy; 2. Geology and popular; unconsolidated material at the earth's surface that will support plant life; 3. Engineering: unconsolidated material of any type no matter where it occurs.

Solum--The upper portion of a soil profile in which the processes of soil formation are active; the solum in a mature soil includes the A and B horizons.

Spring--An area where water comes to the surface (in greater volume than a seep) from underground, saturating surface materials.

Stratigraphy--That branch of geology which deals with the formation, composition, sequence, and correlation of consolidated and unconsolidated rock.

Strike--The direction or bearing of a horizontal line in the plane of an inclined stratum, joint, or fault.

Subsoil--Term applied to the C horizon (parent material) of a pedologic soil.

Surficial--Geologic materials or units, consolidated or unconsolidated, that crop out at the surface.

Terrace--Elevated remnant of an old flood-plain left behind by a downcutting river.

Thick-bedded--Strata in which bedding ranges from 4 in. to 3 ft. in thickness.

Thin-bedded--Strata in which bedding ranges from approximately 1 to 4 in. in thickness.

Water Table--The level below which consolidated and unconsolidated rock are saturated with water.

Weathering--The physical and chemical breakdown of consolidated and unconsolidated rock materials at the earth's surface.

Definitions of some of the above terms were taken or adapted from:

Anonymous, 1960, Dictionary of geological terminology: Garden City, New York, Am. Geol. Inst., 545 p.

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APPENDIX 2: BASIC SOIL TEXTURAL CLASSIFICATION

The textural classification used in this study was developed by the Soil Conservation Service of the U.S. Department of Agriculture (Anonymous, 1937, p. 201). Under this system of classification, soils are grouped into categories based on their relative percentages of sand, silt, and clay (see Fig. 11). The classification utilizes a triangular grid which has as its 3 axes the percentages of sand, silt, and clay.

The broad textural grouping of any soil can be determined when the percentages of 2 or more of the size fractions (sand, silt, and clay) are known. For example, the textural classification of a soil containing 40 per cent sand, 30 per cent silt, and 30 per cent clay would be determined as follows. Locate 40 per cent sand on the sand axis along the bottom. Then move upward and to the left along this dashed line until the 40 per cent sand line intersects the 30 per cent silt line. The point where the 2 lines intersect is also on the 30 per cent clay line along the left side of the graph. The intersection of the 40 per cent sand line, 30 per cent silt line, and the 30 per cent clay line occurs within the clay loam texture zone.

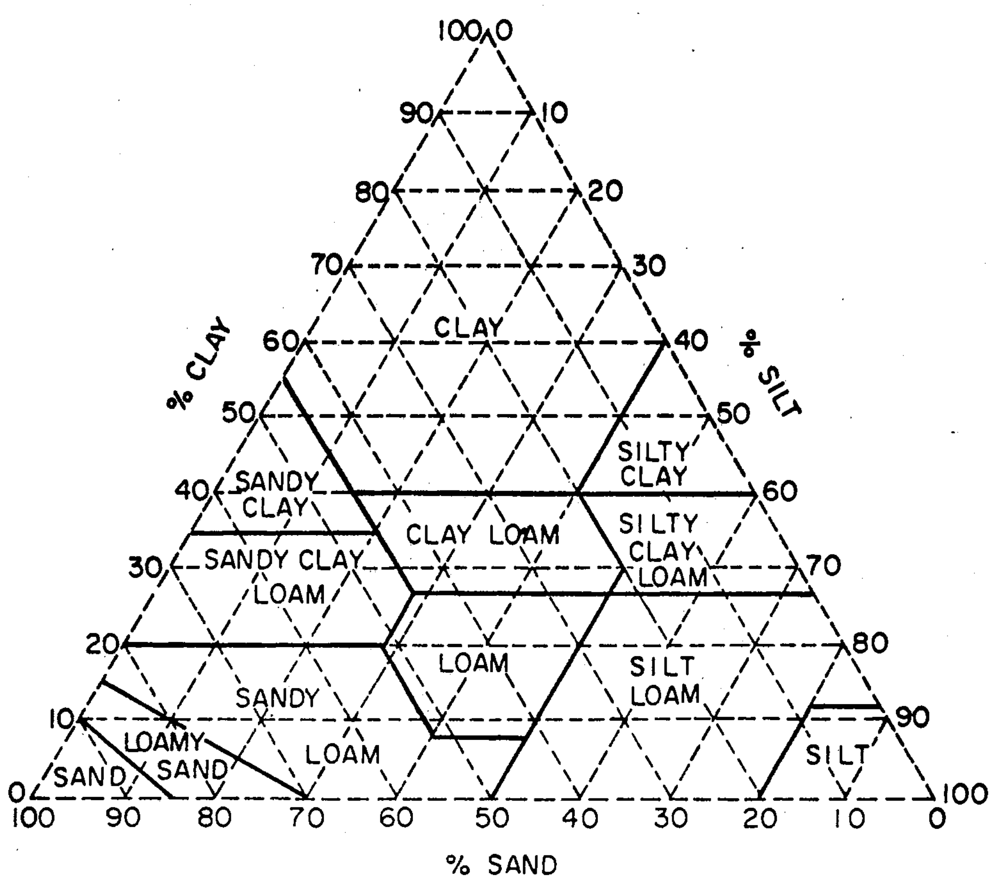


Fig. 11.-Basic soil textural classification. Extracted from Anonymous (1937, p. 201).

APPENDIX 3: PROCEDURES AND PROBLEMS RELATED TO FACTOR MAP PREPARATION

The purpose of this section is to discuss the techniques, methodology, and problems involved in the preparation of each factor map.

Topographic Map

The topographic map (Plate 1) is a composite of parts of the 7½-min. Keystone Dam and Mannford SE Quandrangles published by the U.S. Geological Survey. The composite map was enlarged from a scale of 1:24,000 to 1:12,000.

Slope Map

Slopes in the Mannford area were mapped using a special template, existing 7½-min. topographic maps, aerial photographs, and field observation. The template can be used to measure slope variation on any 7½-min. topographic map with a 10-ft. contour interval by comparing contour line spacings on the topographic map with defined slope ranges on the instrument (see Fig. 10). The template is placed at right angles to any pair of contour lines. Contour line spacing for each slope category on the instrument is then checked with the spacing between the selected pair of contour lines on the topographic map. When the spacing between the selected pair of contour lines corresponds to the spacing between 2 lines on the template, the per cent slope is read from the instrument. The template is then moved along the selected pair of con-

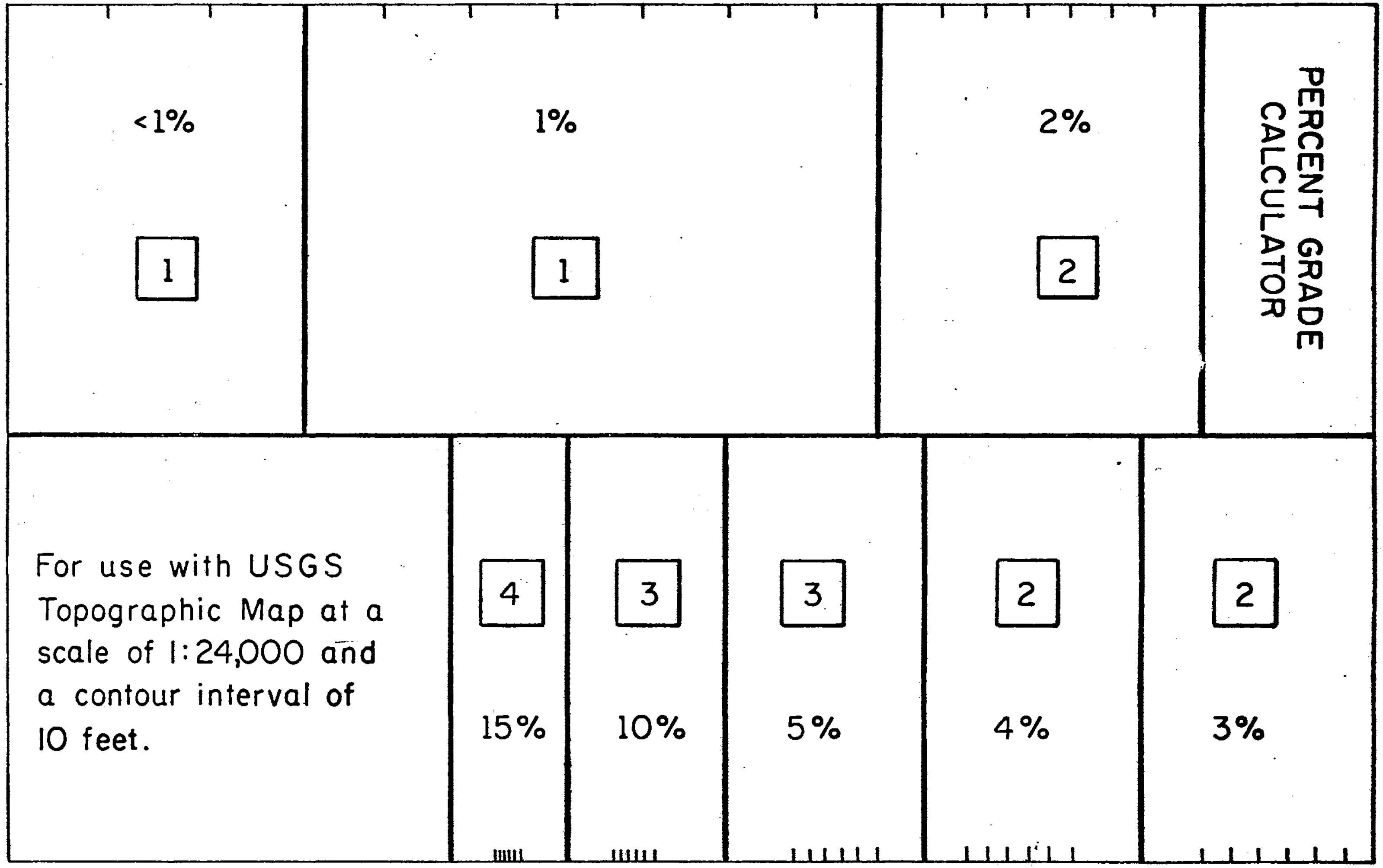


Fig. 10.-Per cent grade calculator. Extracted from Hilpman and Stewart (1968).

tour lines until the spacing increased or decreased sufficiently to change slope categories. A boundary line is drawn on the topographic map at right angles to the pair of contour lines at the location where the slope changes categories. The process is repeated for each pair of contour lines over the entire studyarea utilizing the 4 categories defined on the instrument (Fig. 10) and in the Slope Map subsection of the section on Factor Maps and Their Uses.

Normally areas on the slope map (Plate 2) show an incremental change in slope from less than 2 per cent increasing upward to slopes of greater than 15 per cent. In some areas, however, where slope changes rapidly by more than 2 categories, topography and map scale prevent a delineation of the middle slope category. For example, a slope may change rapidly from greater than 15 per cent to less than 5 per cent, but topography and available map space prevent delineation of the 5 to 15 per cent category.

The smaller the contour interval and the larger the horizontal scale of a topographic map the more accurately slope can be determined without field work. Since the contour interval is 10 ft. and the horizontal scale is 1:24,000 on the topographic maps used in this study, the exact geometry of each slope cannot be determined from the topographic map alone. Some interpretation, based upon field observation and aerial photographs, was necessary in order to visualize details of topography which are not sharply delineated on the topographic map. In some areas, field checking was done.

Drainage Map

Published sources including the Creek County Soil Map and U.S.G.S.

topographic maps, supplemented by aerial photographs and field observation, were used to compile a composite drainage map (Plate 3). The drainage map differs in some details from published maps. The author resolved the differences between the topographic map, soil map, and aerial photographs by relying on aerial photographs and field observation.

Bedrock Geologic Map

Field mapping of bedrock geology (Plate 4) in the study area was completed during the summer of 1971. The Oklahoma Geological Survey has published a geologic map of Creek County (M. C. Oakes, 1959) at a scale of 1 in. = 1 mi. which aided in mapping the study area on a larger scale. The author made a reconnaissance of the area by car and on foot along the section lines, roads, gullies, and drainages. The second step was to measure the most complete stratigraphic sections available. The author used the formational boundaries defined by Oakes. Many of the 13 stratigraphic sections measured in the area are less than 20 ft. thick and covered intervals are common. The measured sections were useful primarily in acquainting the author with the bedrock stratigraphy in the area and are not included in this report because of their discontinuous nature.

The author used field mapping on aerial photographs and comparison with the mapping done by M. C. Oakes (1959) in order to produce the bedrock geologic map (Plate 4). Where adequate control was lacking, the position of contacts was estimated taking into account the geometrical relationship between dip and topography. The bedrock corresponds in general to the geologic map by M. C. Oakes with the following refinements: (1) the Wann Formation is divided into a lower shale, a thick sandstone, and an upper shale; (2) a dolomite lens is mapped locally in the lower Barnsdall sandstone (IPb-1) in the east-central portion of the study area; and (3) sandstone lenses within the Tallant Formation appear to be more continuous and locally thicker than is shown by M. C. Oakes.

Surficial Geologic Map

The unconsolidated surficial deposits in the study area were mapped in the field using natural exposures, auger borings, and aerial photographs. Colluvium was the most difficult unconsolidated deposit to map. Augering proved to be rather unsatisfactory because mixing during the augering made the differentiation of colluvium from other units difficult. Mottling, structure, and any shale pebbles present generally were destroyed by the auger. Colluvium is most easily identified in natural gullies, or man-made ditches. Where they do not exist, it is best to dig a hole. Since colluvium differs considerably from alluvial deposits in texture, color, composition, and topographic position, colluvial boundaries on the surficial geologic map are solid lines where bounded by sandstone in place or by alluvial deposits. Elsewhere, dashed lines are used.

Alluvial deposits presented only minimal problems in field mapping. Flood plain and terrace alluvium were mapped on the basis of information obtained from auger borings, gulley inspection, aerial photographs, the Mannford soil map, and especially on the basis of geomorphology.

Soil Map

The Mannford soil map (Plate 6) was extracted from a portion of the Creek County Soil Map (H. C. Oakes, 1959). The soil map was then enlarged from a scale of 1:20,000 to 1:12,000.

Depth to Bedrock Map

Depth to bedrock (Plate 7) in the Mannford area was determined using visual measurements, seismic refraction, and auger borings. The seismic refraction study was conducted with the Electro-Tech Model ER-75-12 12 channel seismic refraction recorder. The method, theory, and mathematical analysis of the data are not described here in detail. Those interested in such details are referred to Dobrin (1960). The seismic refraction study involved a 2-layer case to determine the interface between low velocity regolith overlying high velocity bedrock.

The only difficulty encountered with the seismic refraction study was the establishment of a satisfactory geophone spacing configuration. Several fixed geophone spacings were tested including 2 and 3 ft. intervals. Both spacing intervals resulted in a scattering of points on the time-distance graphs and an insufficient number of points to define the individual velocity slopes. Further experimentation indicated that a variable geophone spacing was required. The most satisfactory geophone spacing proved to be 2 ft. spacings from 2 to 12 ft. and 3 ft. spacings from 12 to 30 ft. from the energy source. Instantaneous dynamite caps, placed 1 ft. in the ground, were used as the pulse generator. This spacing provided the necessary number of points (5 to 6) for each slope. The first and the second velocity slopes represented the regolith and bedrock respectively.

The accuracy of the seismic computations for depth to bedrock was determined by auger borings taken adjacent to the first 15 shot holes. Computed depth to bedrock was within 10 per cent (approximately 6 in.) of the measured depth.

Erosion Susceptibility Map

The grouping of individual soil types into 3 erosion susceptibility classes (Plate 8) is based on an evaluation of runoff potential using slope, permeability, and soil texture. For example, a soil which is primarily silt, found on slopes greater than 5 per cent, and of low to moderate permeability would be considered to be of high runoff potential placing it in the high erosion susceptibility class. Using the characteristics described above, soil types and their characteristics were compiled in tabular form to facilitate evaluation and grouping.

Generally, soils were easily grouped into one of the erosion susceptibility classes, but in some cases, interpretations were required to assign soil erosion susceptibility ratings. For example, the Okemah-Woodson soil which has a low permeability and clay loam texture could be considered highly susceptible to erosion. Because the soil is present on 0 to 2 per cent slopes and the clay has sufficient cohesion to retard erosion, the Okemah-Woodson clay loam was placed in the moderate erosion susceptibility class. A second example is the Eufaula Soil Series on the island in the northeast portion of the study area. The Eufaula has a low runoff potential because of high permeability, slopes less than 5 per cent, and a loamy sand texture. These characteristics normally are considered to be of minimum erosional susceptibility and would place the Eufaula in the low erosion susceptibility class if wind erosion was not considered. The Eufaula, however, is very susceptible to wind erosion where vegetation has been destroyed and it was placed in the moderate erosion susceptibility class under a separate wind erosion category.

Map of Corrosivity Potential for Uncoated Steel Pipe

Corrosivity data (Table 15) and the soil surveys of Creek County (H. C. Oakes, 1959), Pawnee County (Galloway, 1959), and Hughes County (Long, 1968) provided the data necessary to group each soil into 3 classes of corrosivity potential. The variables considered were internal drainage, permeability, pH, resistivity, and texture. The corrosivity map is only applicable to uncoated steel pipe and should not be applied to such materials as concrete (Hayes, 1971). Using the characteristics described above, soil types and their characteristics were compiled in tabular form to facilitate evaluation and grouping into corrosivity potential classes. For example, a soil with poor internal drainage, low permeability, acidic pH, a resistivity of 1000 ohms/cm., and a clay loam texture would be considered as high in corrosivity potential.

Most soils are readily grouped into corrosivity potential classes, but interpretations have been required in some cases since not all soils meet every requirement of a particular class. For example, the Mason silt loam fits all of the high corrosivity potential requirements except resistivity and is placed in the high corrosivity potential class because it meets 4 of the 5 class requirements. Another example is the formerly oil- and brine-wetted soils. Data are not available to determine a corrosivity class for these soils, so an estimate has been made of their corrosivity potential. The formerly oil- and brine-wetted soils generally can be expected to have a high mineral content including chlorides, exhibit an acidic pH, and as a result have a very low resistivity. The formerly oil- and brine-wetted soils, therefore, are grouped in the high corrosivity potential class under a separate category based on the estimated properties of the soil and on field observation of pipe corrosion in similar soils outside the study area.

Recreational Suitability Map

The determination of the recreational suitability of a soil (Plate 10) is based on trafficability, soil texture, permeability of the least permeable layer, and depth to bedrock. Trafficability, a function of both texture and permeability, describes the reaction of a soil to human and vehicular loading. Clayey soils are considered to be of low trafficability because loading results in compaction. Soil compaction prevents water and air from entering the soil, causing plants to die. Sandy soils also are considered to be of low trafficability because loading causes the soil to move down and laterally. This downward and lateral movement of the soil tears the roots of plants resulting in loss of vegetation. This loss of vegetation, particularly on moderate to steep slopes, contributes to erosion by running water and by wind. A soil with good recreational suitability has good trafficability, high permeability, depth to bedrock greater than 3 ft., and 30 to 40 per cent silt and clay. Using the characteristics described above, soil types and their characteristics were compiled in tabular form to facilitate evaluation and grouping.

In most cases, soils fall readily into recreational suitability classes, but in some cases interpretations were required to assign soils recreational suitability ratings. For example, the Bates fine sandy loam has a moderate trafficability, averages 48 per cent silt and clay, has moderate permeability, and locally is less than 3 ft. above bedrock. The soil could be grouped in either the good or moderate recreational suitability class depending upon whether slope is a primary consideration. The Bates fine sandy loam is placed in the good class, where slope ranges from 2 to 5 per cent and in the moderate class where slope is greater than 5 per cent. Formerly oil- and brine-wetted soils are placed in the low recreational suitability class under a separate category primarily to avoid distrubing these soils. If these soils were exposed to erosion, the mineral salts and any residual oil in the deposit might be carried by sheet wash into the reservoir. Other soils downslope from the formerly oil- and brine-wetted soils also might be affected.

Map Showing Plasticity of Solum and of Subsoil

An engineering classification of the plasticity of the solum (A and B horizons) and of the subsoil (C horizon) was developed for this study. Plasticity data were compiled from existing laboratory test data on soils in Creek County including the Mannford area (see Table 13). The classification resembles one utilized in Illinois by Thornburn (1951). Each soil is assigned a 2-letter designation with the exception of the formerly oil- and brine-wetted soils. The first letter indicates the average plasticity of the solum and the second of the subsoil. The plasticity ranges employed are defined on the basis of liquid limit and plasticity index. These ranges can be found in the explanation of Plate

11. The plasticity ranges correspond rather closely with those defined on the widely used Casagrande plasticity chart (Means and Parcher, 1963, p. 121).

Geologic Constraint Map for General Land Use

The geologic constraint map is divided into major, moderate, and minor constraint zones based on a quantitative averaging technique. Corrosivity potential, plasticity, and depth to bedrock are each given a weighted value of 2 and erosion susceptibility a value of 1. Utilizing the weighted averages for each variable the following expression is employed:

$$\text{Geologic Constraint Index} = \frac{2[(\text{corrosivity potential}) + (\text{plasticity}) + (\text{bedrock depth})]}{4} + \frac{(\text{erosion susceptibility})}{4}$$

Numbers for corrosivity potential, plasticity, etc. (for a particular soil type) are assigned (*i.e.*, low, moderate, or high) on the basis of how that soil was classified on other factor maps. High categories (meaning that a soil is desirable for a particular use) are assigned a 2; moderate categories a 1; low categories a zero. When high means undesirable, the numerical scale is reversed. For example, soil A is of moderate corrosivity, high plasticity, and very shallow (less than 2 feet to bedrock), and highly susceptible to erosion. Soil B is of low corrosivity potential, low plasticity, between 2 to 4 ft. to bedrock, and moderately susceptible to erosion. The calculation of the appropriate class index is as follows:

Soil A: Geologic Constraint Index = $\frac{2[(1)+(0)+(0)] + 1\ (0)}{4} = 0.5$

Soil B: Geologic Constraint Index = $\frac{2[(2)+(2)+(1)] + 1\ (1)}{4} = 2.7$

Soil A's geologic constraint class quotient is typical of the major geologic constraint class while Soil B's quotient is typical of the minor geologic constraint class. Each soil in the study area was analyzed by this procedure and listed in order from highest quotient to the lowest. The quotient distribution was clustered near the middle of the distribution with a few soils on either end. Soils with minor geologic constraints averaged a quotient index of 2 or greater. Soils with moderate geologic constraints ranged from 1 to 2 and those of major geologic constraints, other than those with a high flood potential, generally were less than 1.

Interpretations were required on some soils having a quotient greater than 2 because many are alluvial soils and therefore susceptible to flooding. The 2 soils of the Verdigris Soil Series both have index quotients above 2 which places them in the minor geologic constraint class, but they are highly susceptible to flooding. As a result, the Verdigris Soil Series is given a major geologic constraint rating. Plate 12 shows geologic constraint zones between the maximum flood control pool (indicated by the dashed line on Plate 12) and the reservoir as if they were not susceptible to flooding. This procedure was utilized because some construction, exclusive of housing, may be allowed by the U.S. Army Corps of Engineers in these areas. It should be stressed, however, that all land between the U.S. Army Corps of Engineers maximum flood control pool (754 ft.) and the reservoir is potentially subject to flooding during periods of high precipitation in the Arkansas and

Cimarron River drainages.

Plate 7 (depth to bedrock), Plate 8 (erosion susceptibility), Plate 9 (corrosivity potential for uncoated steel pipe), Plate 10 (recreational suitability), and Plate 12 (geologic constraint map for general land use) are generalized, interpretative, and should be used with considerable care. It should be stressed that more detailed studies are necessary for the evaluation of individual sites.

VITA

Phillip Randall Kemmerly

Candidate for the Degree of

Doctor of Education

Thesis: ENVIRONMENTAL GEOLOGY OF THE MANNFORD AREA, OKLAHOMA

Major Field: Higher Education

Biographical:

Personal Data: Born in El Dorado, Kansas, October 14, 1944, the son of Mr. and Mrs. Paul R. Kemmerly.

Education: Graduated from El Dorado High School, El Dorado, Kansas, in May, 1962; received the Bachelor of Science Degree from Kansas State University, Manhattan, in January, 1966, with a major in Secondary Education (Chemistry); received the Master of Science Degree with a major in Earth Science from Kansas State University, Manhattan, in August, 1968; completed requirements for the Doctor of Education Degree at Oklahoma State University in May, 1973, with a major in Higher Education.

Professional Experience: Earth Science Teacher, the Shawnee-Mission High School District, Shawnee-Mission, Kansas, 1966-69; Undergraduate Teaching Assistant, Department of Geology, Oklahoma State University, 1969-72. Instructor, National Science Foundation Earth Science Institute, Oklahoma State University, 1969-72. Member of the Society of Sigma Gamma Epsilon. Assistant Professor of Geology, Austin Peay State University, Clarksville, Tennessee, 1972 - .

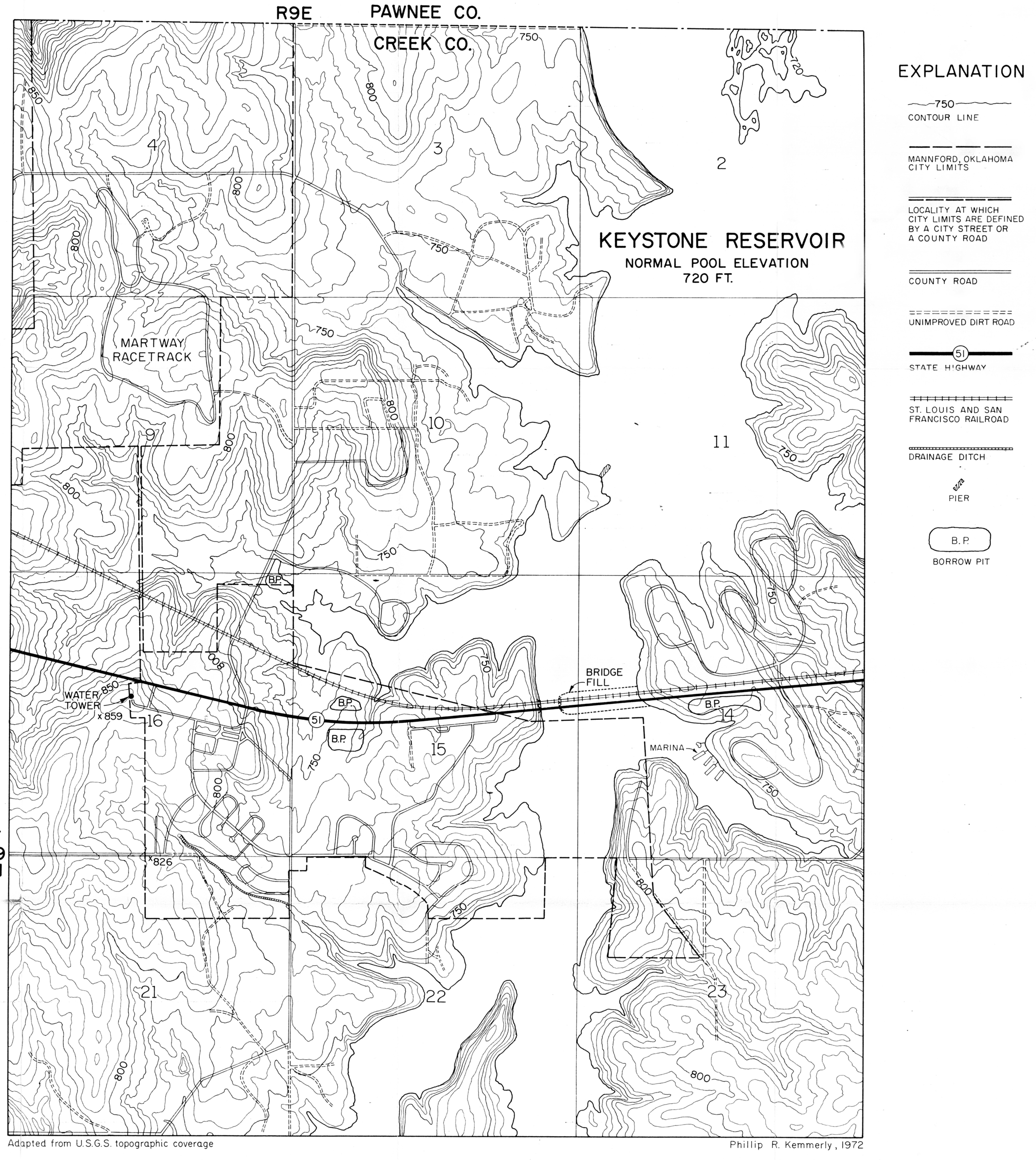
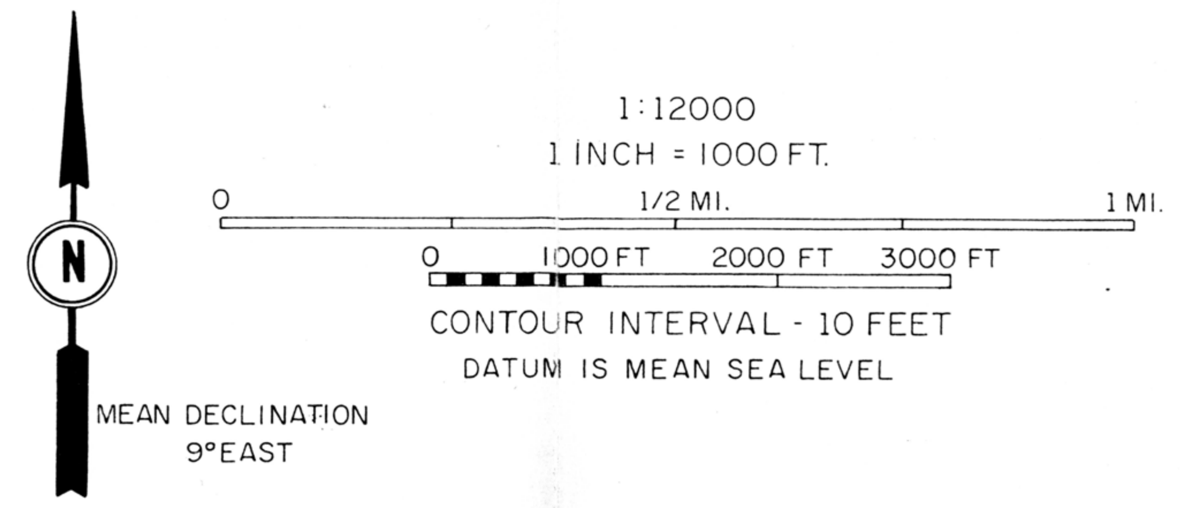
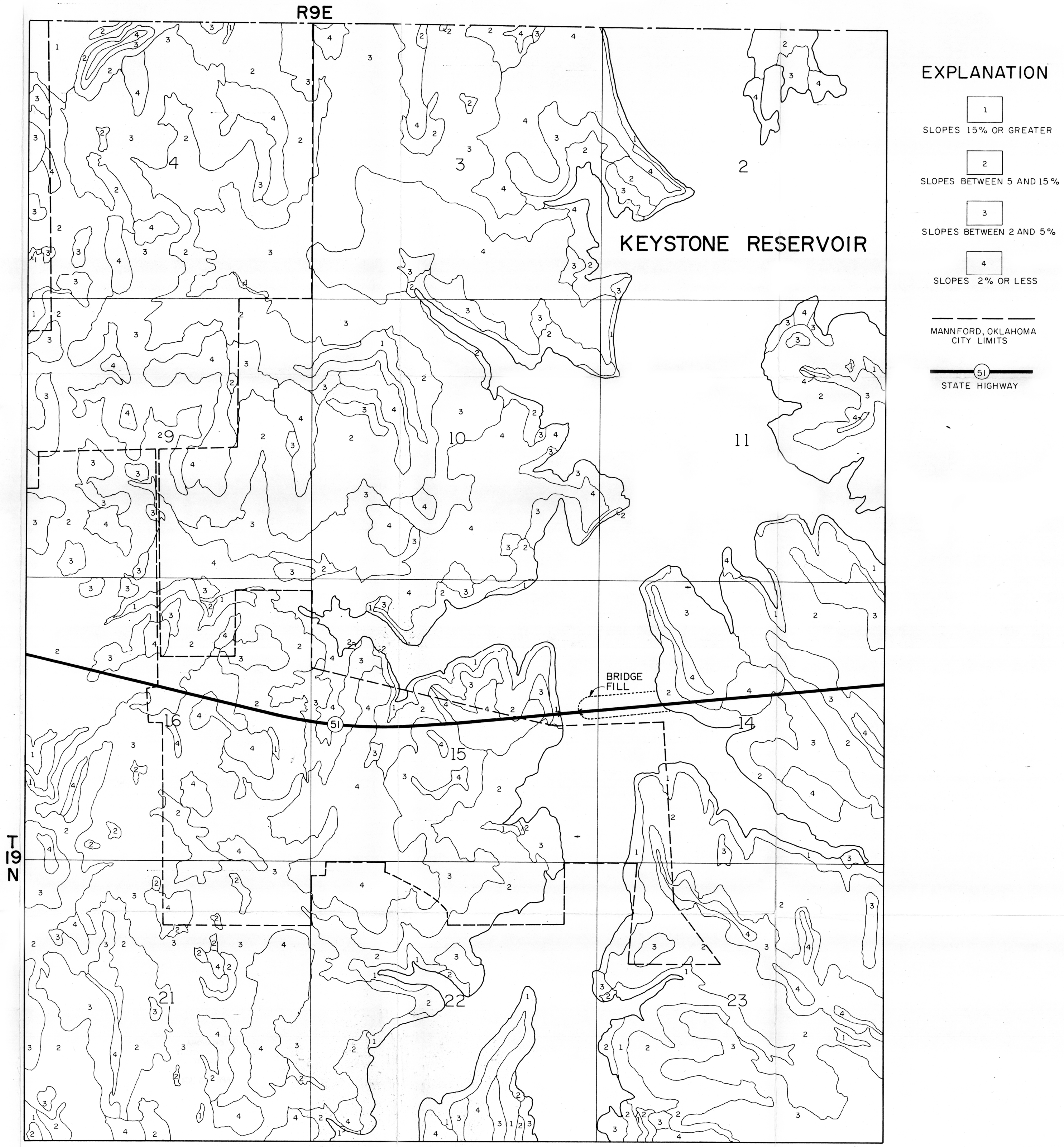


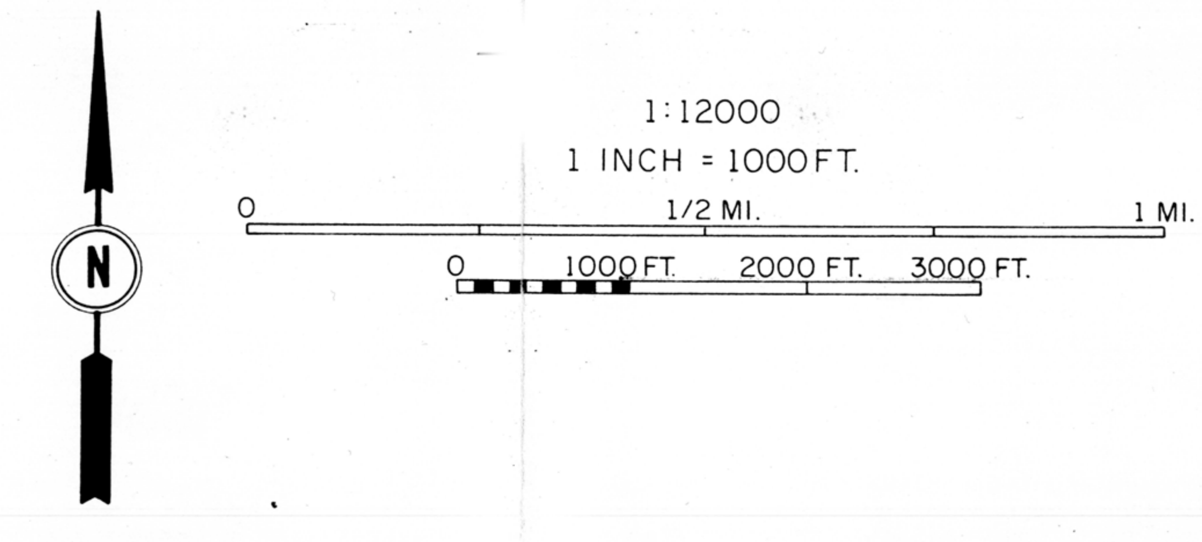
PLATE 1. - TOPOGRAPHIC MAP OF THE MANNFORD AREA, OKLAHOMA





Phillip R. Kemmerly, 1972

PLATE 2.- SLOPE MAP OF THE MANNFORD AREA, OKLAHOMA



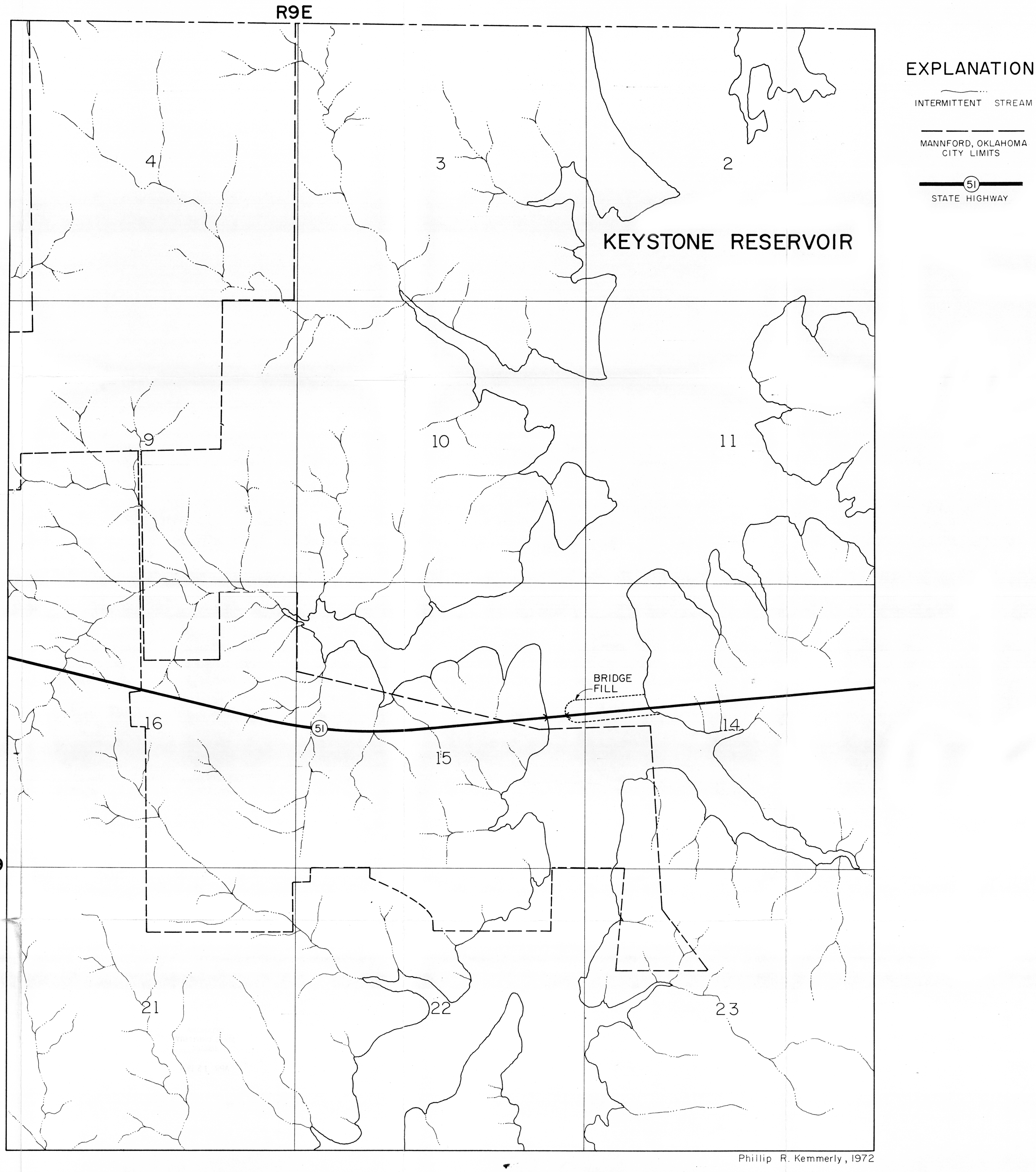


PLATE 3.-DRAINAGE MAP OF THE MANNFORD AREA, OKLAHOMA

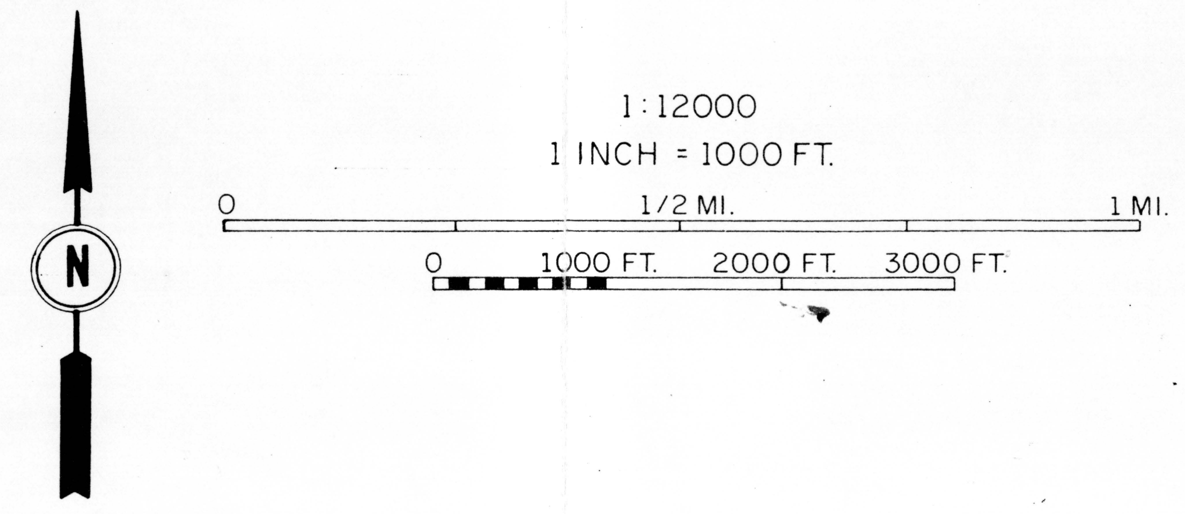
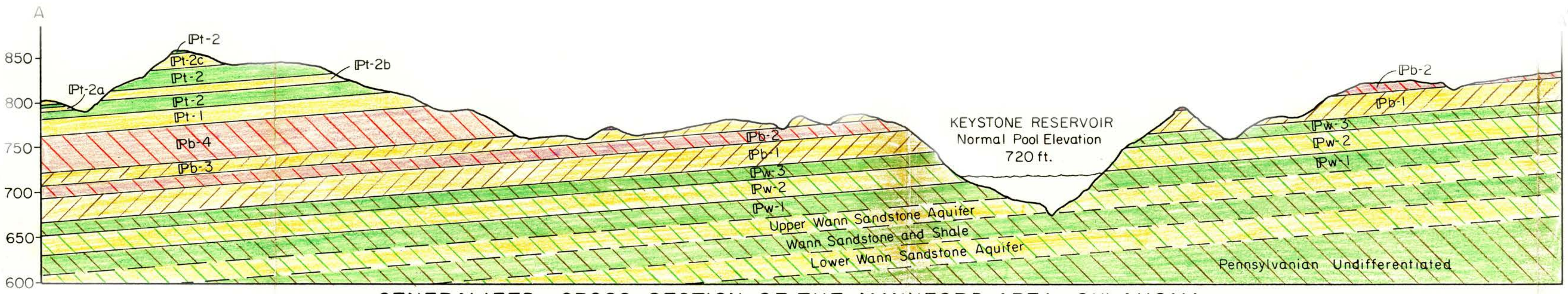
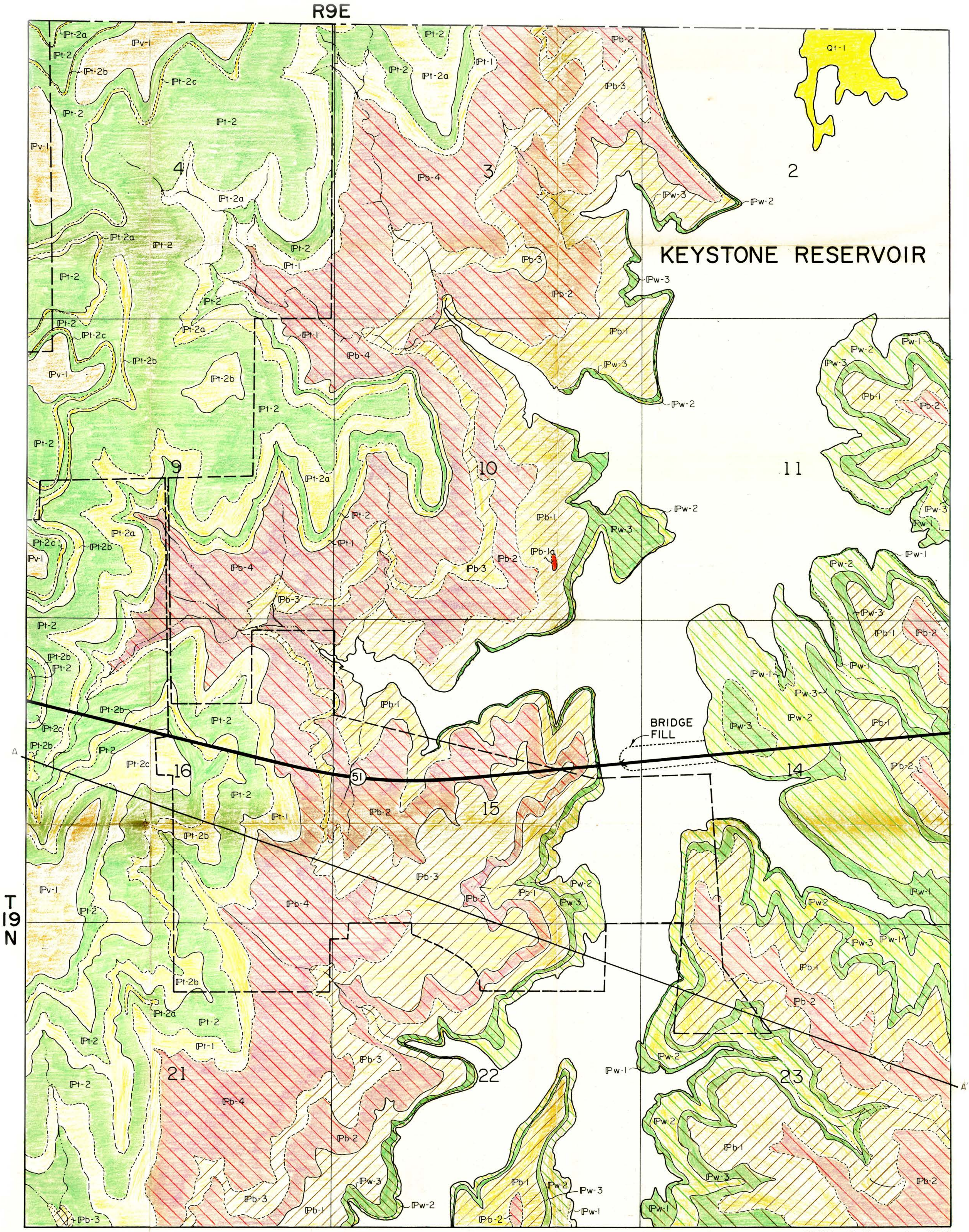


PLATE 4



GENERALIZED CROSS SECTION OF THE MANNFORD AREA, OKLAHOMA
Vertical Exaggeration: 10
Horizontal Scale: Same As Map



Phillip R. Kemmerly, 1972

EXPLANATION*

Qt-1

TERRACE ALLUVIUM

Brown to reddish yellow, loamy fine sand; thickness: 3-15 ft.

IPv-1

VAMOOSA FORMATION

Buff to reddish brown, coarse- to fine-grained, massive to thin-bedded sandstone; thickness: 20-25 ft.

IPt-2c IPt-2c
IPt-2b IPt-2 IPt-2b
IPt-2a IPt-2a
IPt-1

TALLANT FORMATION

IPt-2, reddish to olive green, sandy to silty shale with interbeds of buff to tan sandstone; thickness: 50-60 ft. Sandstone lenses within IPt-2 are not consistently at the same stratigraphic position. IPt-2c, buff to gray, fine- to very fine-grained, massive to thick-bedded, lenticular sandstone; thickness: 2-20 ft. IPt-2b, buff to reddish tan, fine- to very fine-grained, massive to thick-bedded, lenticular sandstone; thickness: 0-10 ft. IPt-2a, buff to reddish tan, fine- to very fine-grained, massive to thick-bedded lenticular sandstone; thickness: 0-20 ft. IPt-1, brown to reddish tan, medium- to fine-grained, massive to thin-bedded sandstone; thickness: 10-20 ft.

IPb-4
IPb-3
IPb-2
IPb-1 IPb-1a

BARNSDALL FORMATION

IPb-4, tan to reddish, sandy to silty shale with interbeds of buff to tan sandstone; thickness: 30-40 ft. IPb-3, buff to tan, fine- to very fine-grained, massive to thin-bedded sandstone; thickness: 10-25 ft. IPb-2, tan to reddish, sandy to silty shale with interbeds of buff to tan sandstone; thickness: 15-20 ft. IPb-1, tan to gray, fine- to very fine-grained, massive to thin-bedded sandstone; thickness: 20-25 ft. IPb-1a, lens of gray, fine-grained dolomite; thickness: 0-3 ft.

IPw-3
IPw-2
IPw-1

WANN FORMATION

IPw-3, gray to reddish, sandy to silty shale with interbeds of buff to tan sandstone; thickness: 10-15 ft. IPw-2, tan to gray, medium- to fine-grained, massive to thin-bedded sandstone with interbeds of gray to reddish shale; thickness: 25-30 ft. IPw-1, gray to reddish, sandy to silty shale with interbeds of tan to gray sandstone; thickness: 25-30 ft.

IPw-1

CONTACTS

Lines show contacts between units. Solid lines indicate that contact is exposed or inferred with confidence. Dashed lines indicate that contacts are not exposed.

*Note: Bedrock geology shown as if all unconsolidated deposits had been removed (except for island in Keystone Reservoir which is mapped as alluvium).

MANNFORD, OKLAHOMA CITY LIMITS

51 STATE HIGHWAY

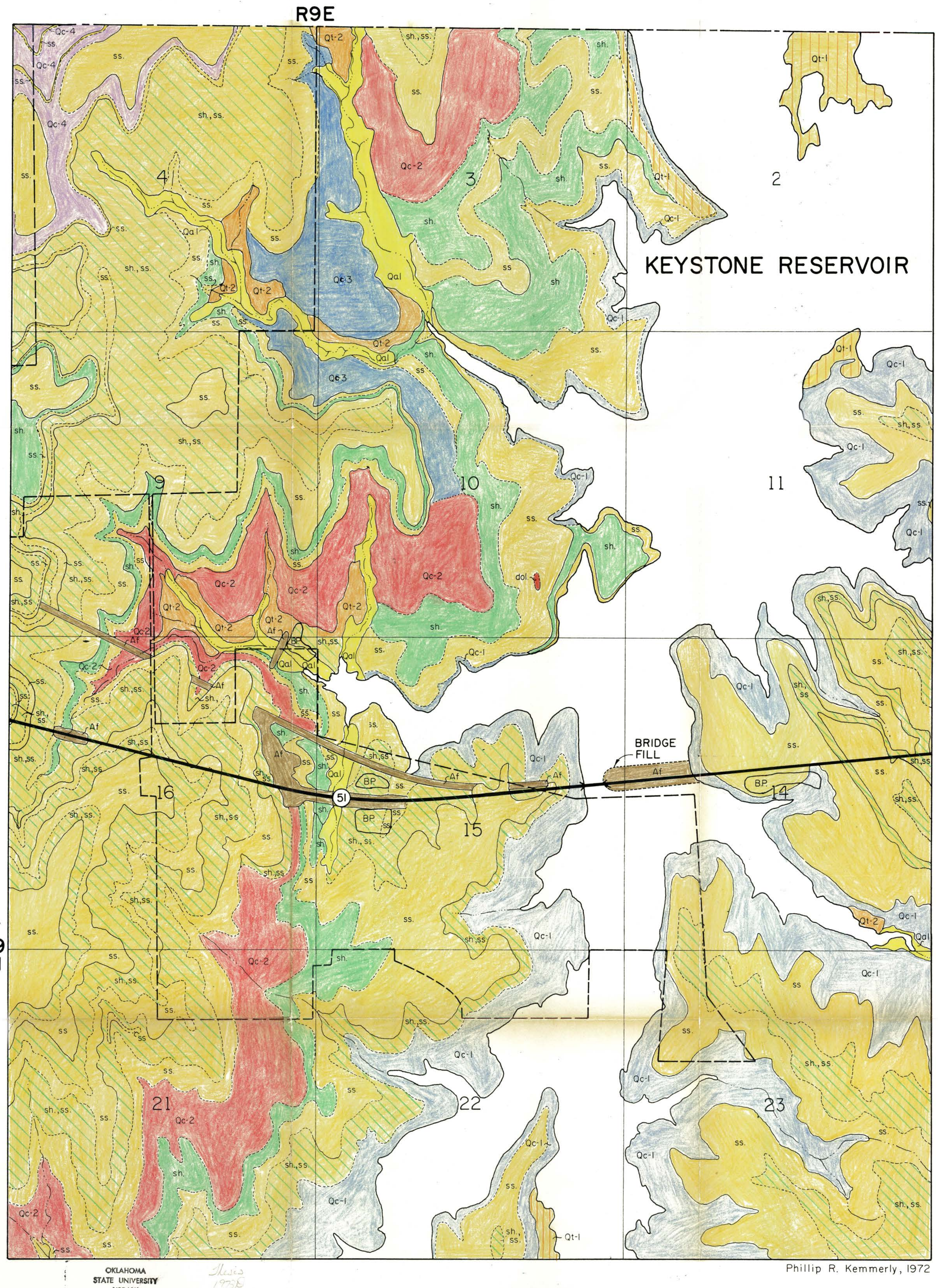
PLATE 4. - BEDROCK GEOLOGIC MAP OF THE MANNFORD AREA, OKLAHOMA

1:12000
1 INCH = 1000 FT.

0 1/2 MI. 1 MI.

0 1000 FT. 2000 FT. 3000 FT.

N



EXPLANATION*

Af

ARTIFICIAL FILL

Quite variable; man-made materials, clay to boulder sandstone blocks 3 ft. in diameter; artificial fill deposits for individual foundations not mapped.

QUATERNARY

Qal

FLOOD PLAIN ALLUVIUM

Brown to black fine sandy loam to silt loam. thickness: 3-12 ft.

Qt-1 | Qt-2

TERRACE ALLUVIUM

Qt-1, terrace alluvium of the Cimarron River and Salt Creek; Qt-2, terrace alluvium of Salt Creek tributaries; Qt-1, brown to reddish yellow loamy fine sand to silt loam; thickness: 3-15 ft. Qt-2, brown to grayish brown silty clay loam; thickness: 1-5 ft.

Qc-1 | Qc-2 | Qc-3 | Qc-4

COLLUVIUM

Qc-1, boulder- to cobble-sized sandstone fragments 0.5-5.0 ft. in diameter; blocky to angular in shape; derived from Wann and Barnsdall sandstones; thickness: <1.0-3.0 ft. Qc-2, grayish brown to brownish red sandy loam to loam; yellow to reddish mottling; iron and/or manganese oxide nodules; sandstone fragments range from pebble- to granule-sized; derived from Tallant Formation; thickness: 0.5-5.0 ft. Qc-3, brown to gray loam to silt loam; yellow to reddish mottling less pronounced; scattered iron and/or manganese oxide nodules; sandstone fragments range from pebble- to granule-sized; derived from Tallant and Barnsdall Formations; thickness: 0.5-4.5 ft. Qc-4, brown to grayish brown sandy loam; yellow to reddish mottling; derived from Vamoosa and Tallant Formations; thickness: 0.5-3.0 ft.

sh | ss. | dol. | sh.,ss.

BEDROCK

Individual bedrock units not identified on this map. More detailed information on bedrock geologic map (Plate 4); sh., dominantly shale; ss., dominantly sandstone; dol., dominantly dolomite; sh.,ss., shale with interbedded sandstone.

CONTACTS

Solid where known, dashed where approximate, dotted where inferred.

B.P.

BORROW PIT

*Note: Surficial geology shown as if all pedologic soils had been removed.

MANNFORD, OKLAHOMA CITY LIMITS

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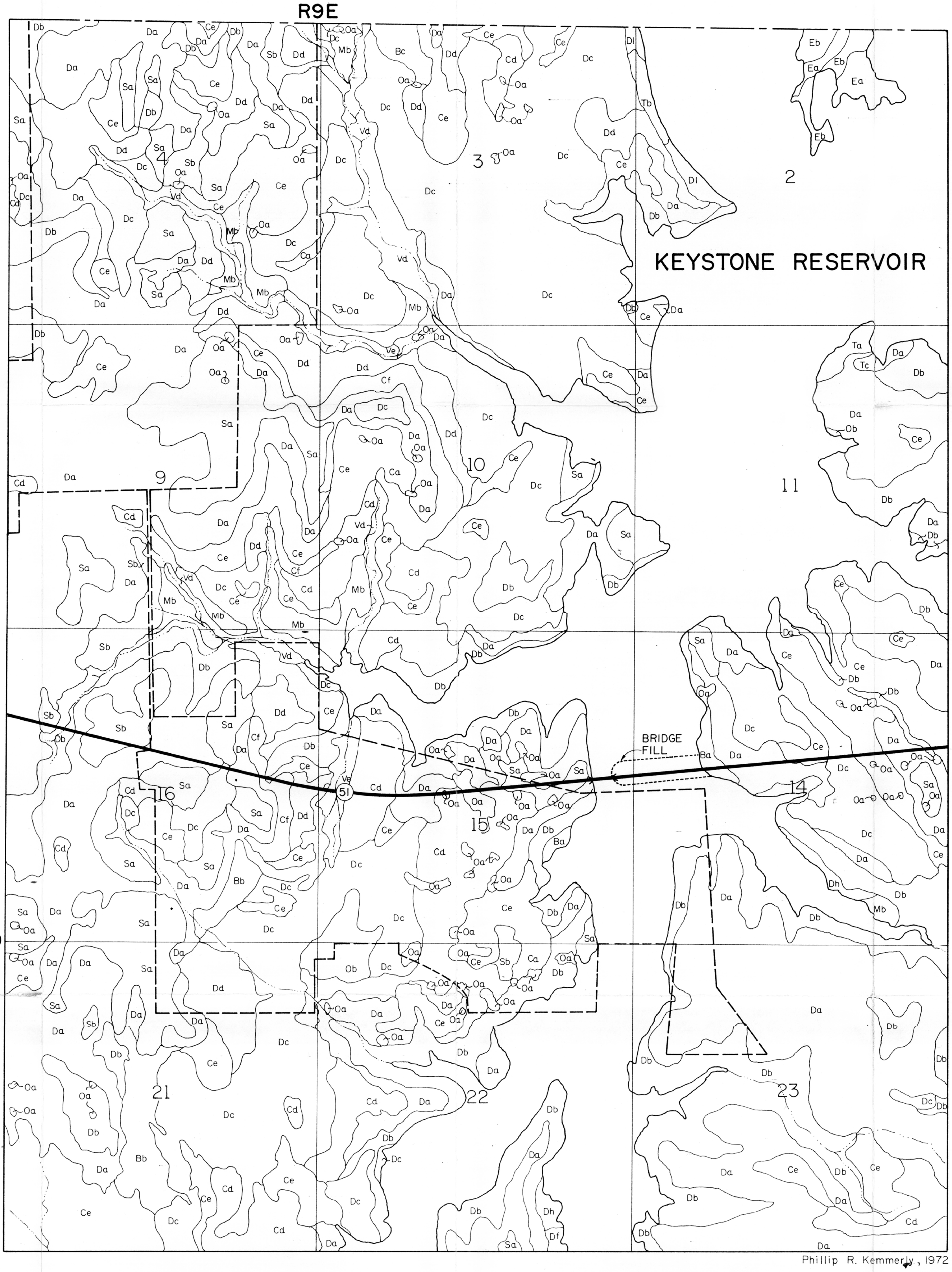
PLATE 5.- SURFICIAL GEOLOGIC MAP OF THE MANNFORD AREA, OKLAHOMA.

N

1:12000
1 INCH = 1000 FT.
0 1/2 MI. 1 MI.
0 1000 FT. 2000 FT. 3000 FT.



EXPLANATION

Ba Bates fine sandy loam, gently sloping
Bb Bates fine sandy loam, sloping
Bc Bates fine sandy loam, sloping, severely eroded

Cd Collinsville and Bates soils, gently sloping
Ce Collinsville and Talihina soils, sloping
Cf Collinsville and Talihina soils, strongly sloping

Da Darnell and Pottsville soils, sloping
Db Darnell and Pottsville soils, strongly sloping
Dc Dennis and Okemah loams, gently sloping
Dd Dennis and Okemah loams, sloping
Df Dougherty and Stidham fine sandy loams, gently sloping
Dh Dougherty and Stidham fine sandy loams, sloping
Dl Dougherty and Stidham loamy fine sands, nearly level

Ea Eufaula loamy fine sand, gently sloping
Eb Eufaula loamy fine sand, strongly sloping

Mb Mason silt loam

Oa Formerly oil- and brine-wetted soils
Ob Okemah and Woodson clay loams

Sa Stephenville and Darnell fine sandy loams, gently sloping
Sb Stephenville and Darnell fine sandy loams, sloping

Ta Teller silt loam, gently sloping
Tb Teller silt loam, nearly level
Tc Teller silt loam, sloping

Vd Verdigris fine sandy loam
Ve Verdigris silt loam

INTERMITTENT STREAM

MANNFORD, OKLAHOMA CITY LIMITS

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PLATE 6. - SOIL MAP OF THE MANNFORD AREA, OKLAHOMA

1:12000
1 INCH = 1000 FT.
0 1/2 MI. 1 MI.
0 1000 FT 2000 FT 3000 FT
AFTER HARVEY C. OAKES, 1959

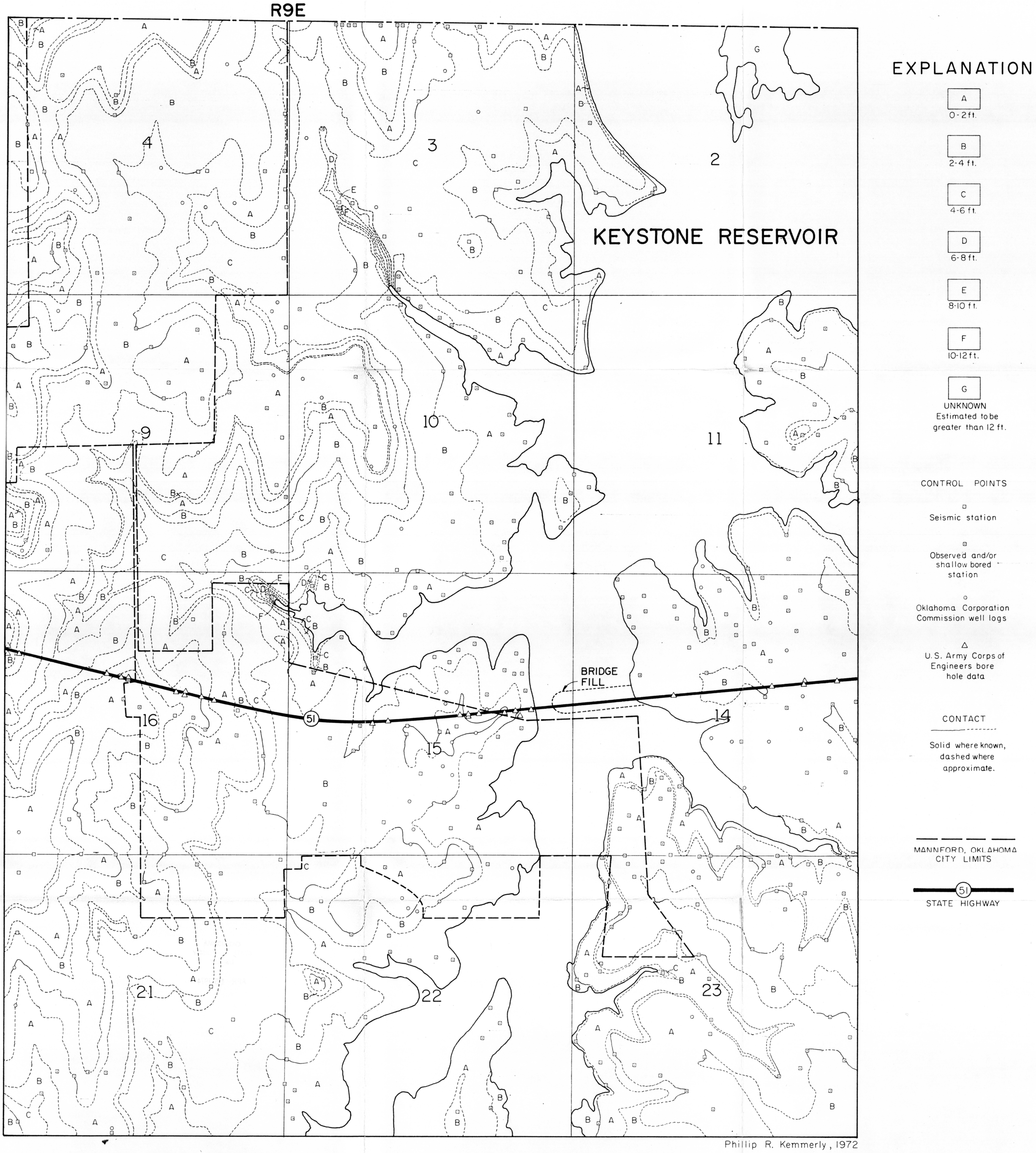
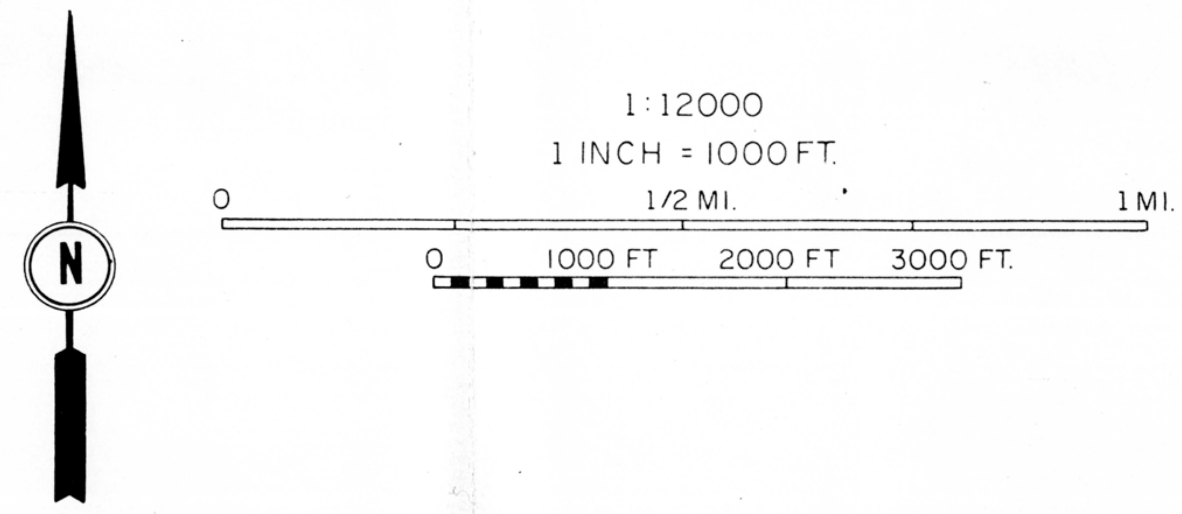


PLATE 7. - DEPTH TO BEDROCK MAP OF THE MANNFORD AREA, OKLAHOMA.



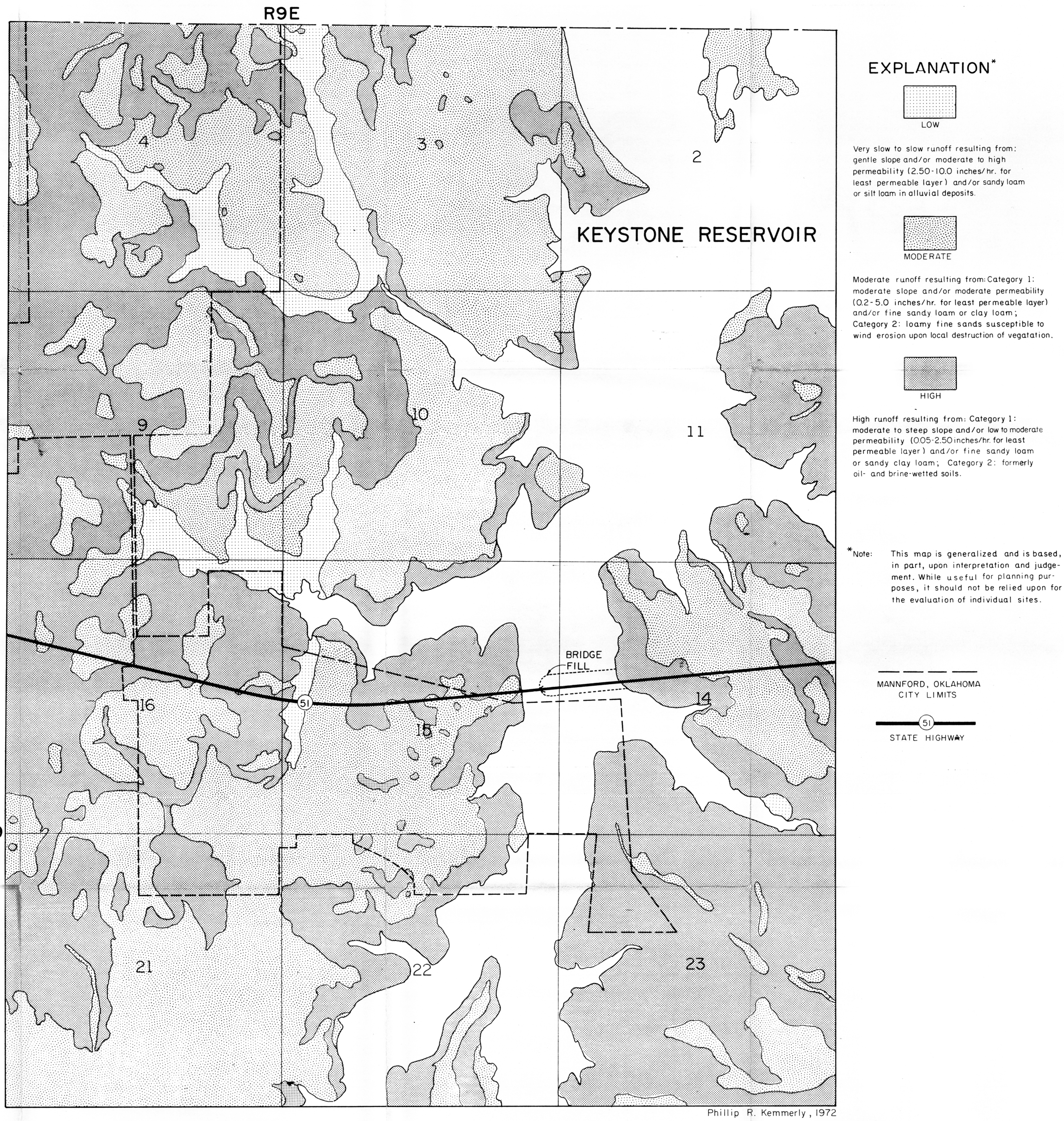
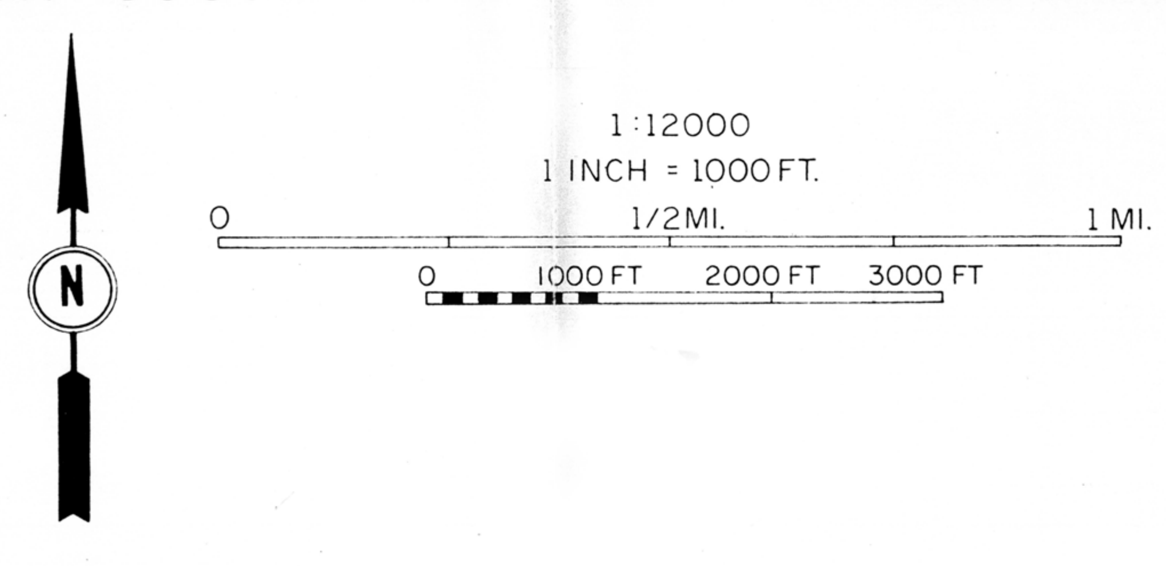
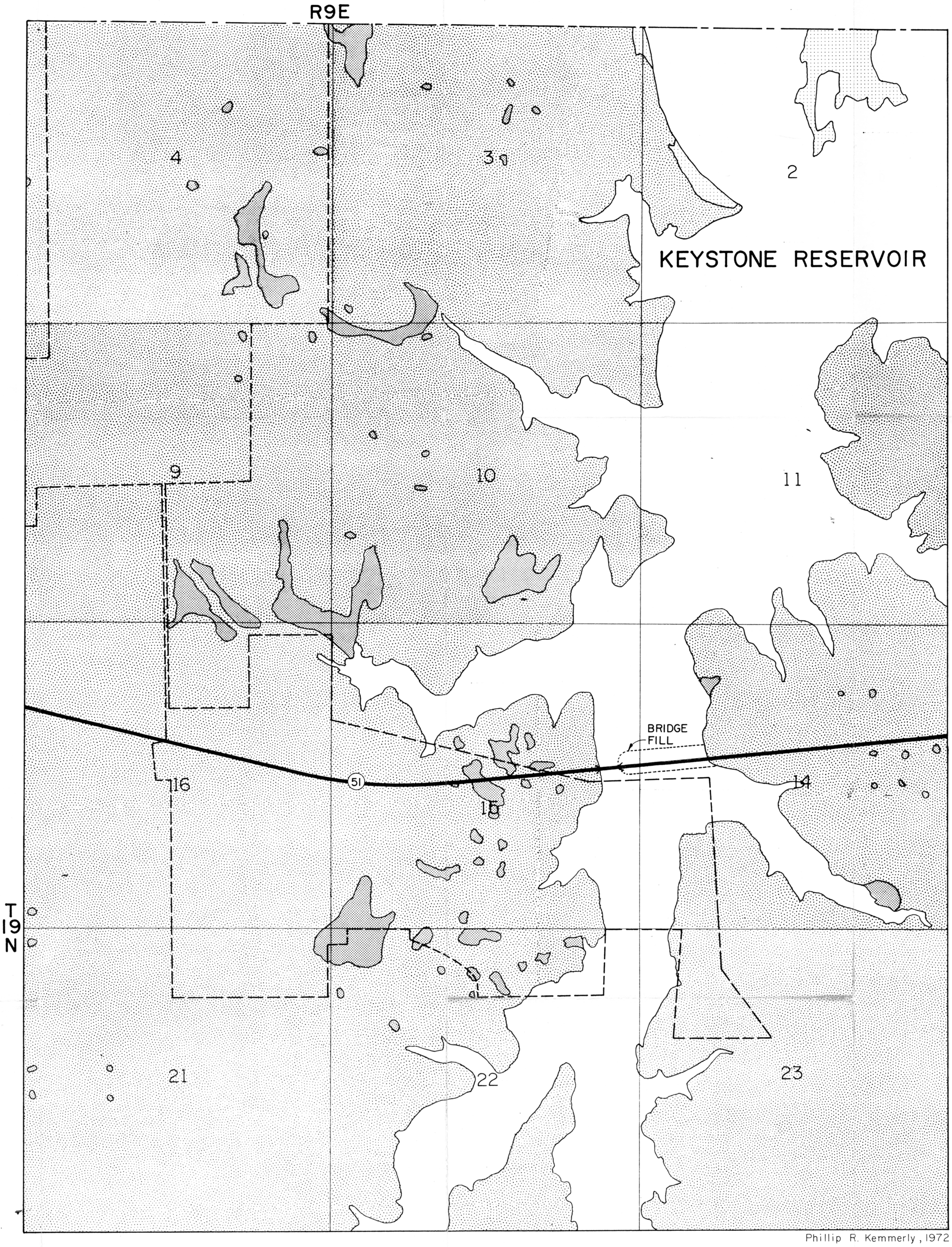


PLATE 8. - EROSION SUSCEPTIBILITY MAP OF THE MANNFORD AREA, OKLAHOMA





EXPLANATION*

LOW

Internal drainage: high; permeability of the least permeable layer: 2.5-10.0 inches/hr; pH: 5.9-7.0; resistivity: >5000 ohms/cm. at field capacity; texture: loamy fine sands.

MODERATE

Internal drainage: moderate; permeability of least permeable layer: 0.05-2.5 inches/hr; pH: 5.1-6.5; resistivity: 2000-5000 ohms/cm. at field capacity; texture: fine sandy loam to silt loam.

HIGH

Category 1: formerly oil- and brine-wetted soils; Category 2: internal drainage: poor; permeability of least permeable layer: 0.05-0.80 inches/hr; pH: 5.0-6.0; resistivity: less than 2000 ohms/cm. at field capacity; texture: silt loam to clay loam.

*Note: This map is generalized and is based, in part, upon interpretation and judgement. While useful for planning purposes, it should not be relied upon for evaluation of individual sites.

MANNFORD, OKLAHOMA CITY LIMITS

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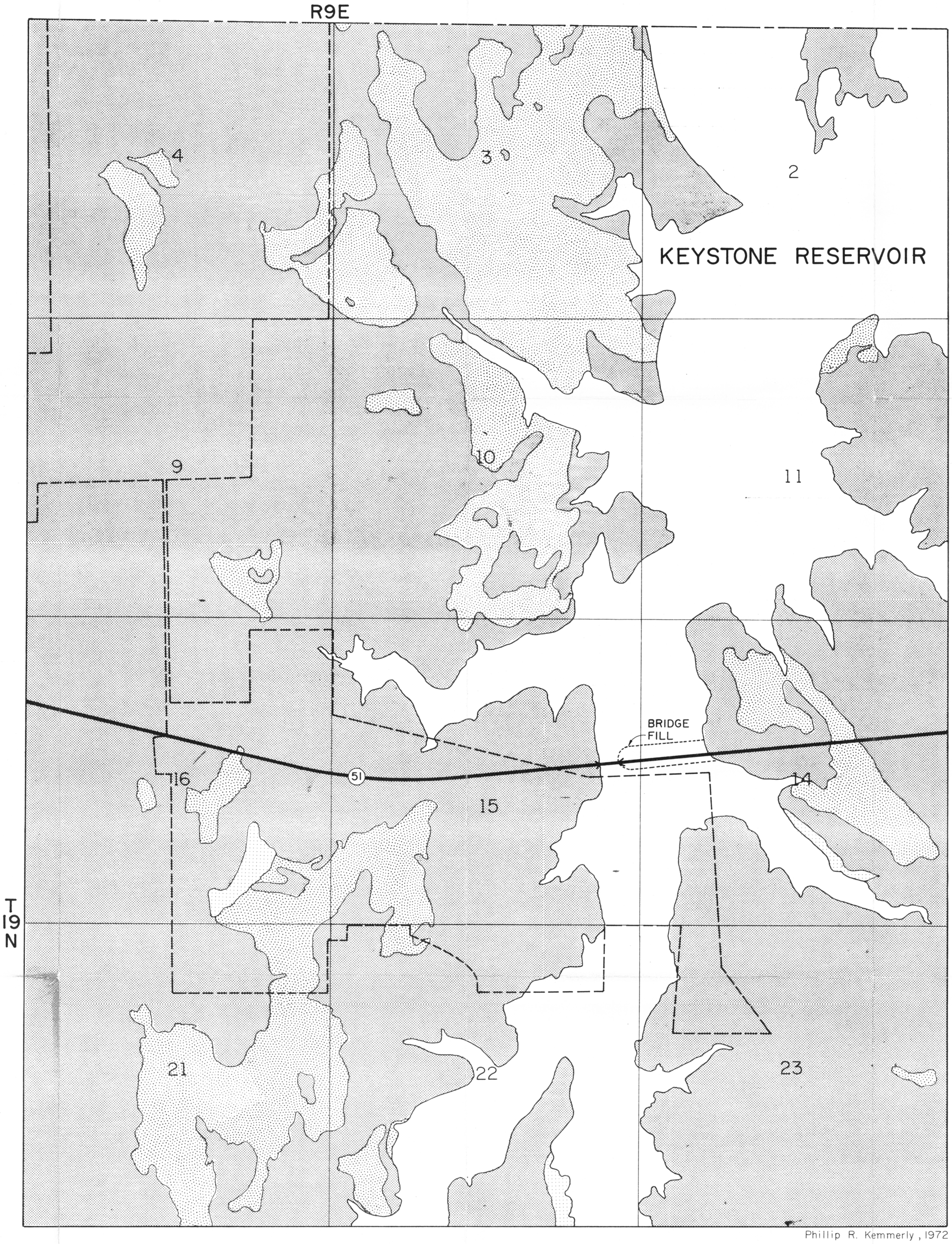
PLATE 9. - MAP OF CORROSIVITY POTENTIAL FOR UNCOATED STEEL PIPE IN THE MANNFORD AREA, OKLAHOMA.

N

1:12000
1 INCH = 1000 FT.
0 1/2 MI. 1 MI.
0 1000 FT 2000 FT 3000 FT



EXPLANATION*

GOOD

Trafficability: good; silt + clay★: 30-50%; permeability of least permeable layer: 0.8-2.5 inches/hr; bedrock depth: generally 2-6 ft.

MODERATE

Trafficability: moderate; silt+clay: 50-75%; permeability of least permeable layer: 0.2-2.5 inches/hr; bedrock depth: generally 2-5 ft.

LOW

Category 1: flood potential: high; trafficability: low, unstable when dry; silt+clay: less than 30%; permeability of least permeable layer: 5.0-10.0 inches/hr; bedrock depth: generally greater than 5 ft; Category 2: trafficability: low, susceptible to compaction; silt+clay: 50-90%; permeability of least permeable layer: 0.05-2.5 inches/hr; bedrock depth: generally 0-3 ft; Category 3: formerly oil- and brine-wetted soils.

*Note: 1. Recreational land use is operationally defined as one of the following: parks, golf courses, baseball or football fields, campgrounds, and nature trails; slope is a marginal factor in determination of recreational suitability.

2. This map is generalized and is based, in part, upon interpretation and judgement. While useful for planning purposes, it should not be relied upon for the evaluation of individual sites.

★Note: 1. ASTM textural classification i.e., average percent of material passing the No. 200 sieve.

MANNFORD, OKLAHOMA CITY LIMITS

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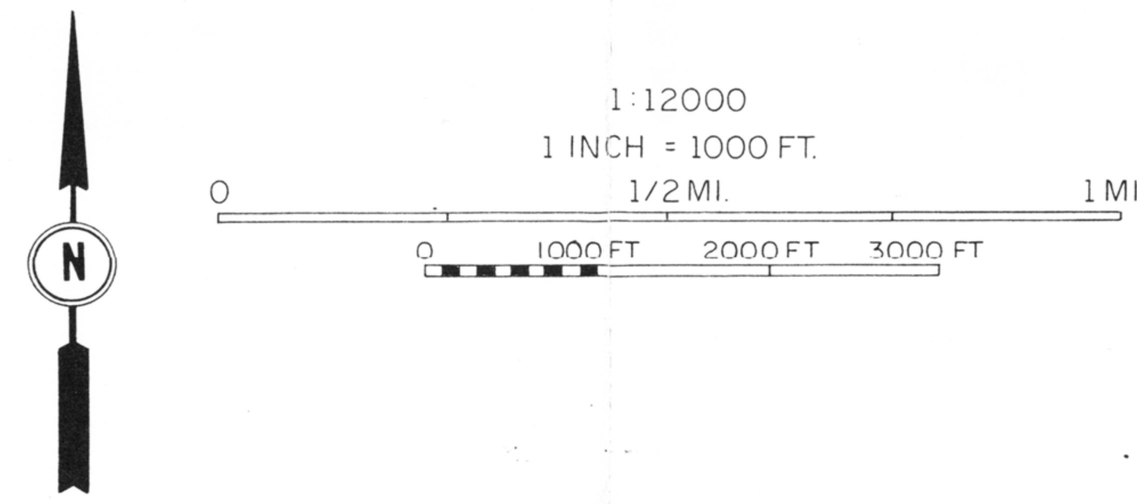
PLATE 10. - RECREATIONAL SUITABILITY MAP OF THE MANNFORD AREA, OKLAHOMA



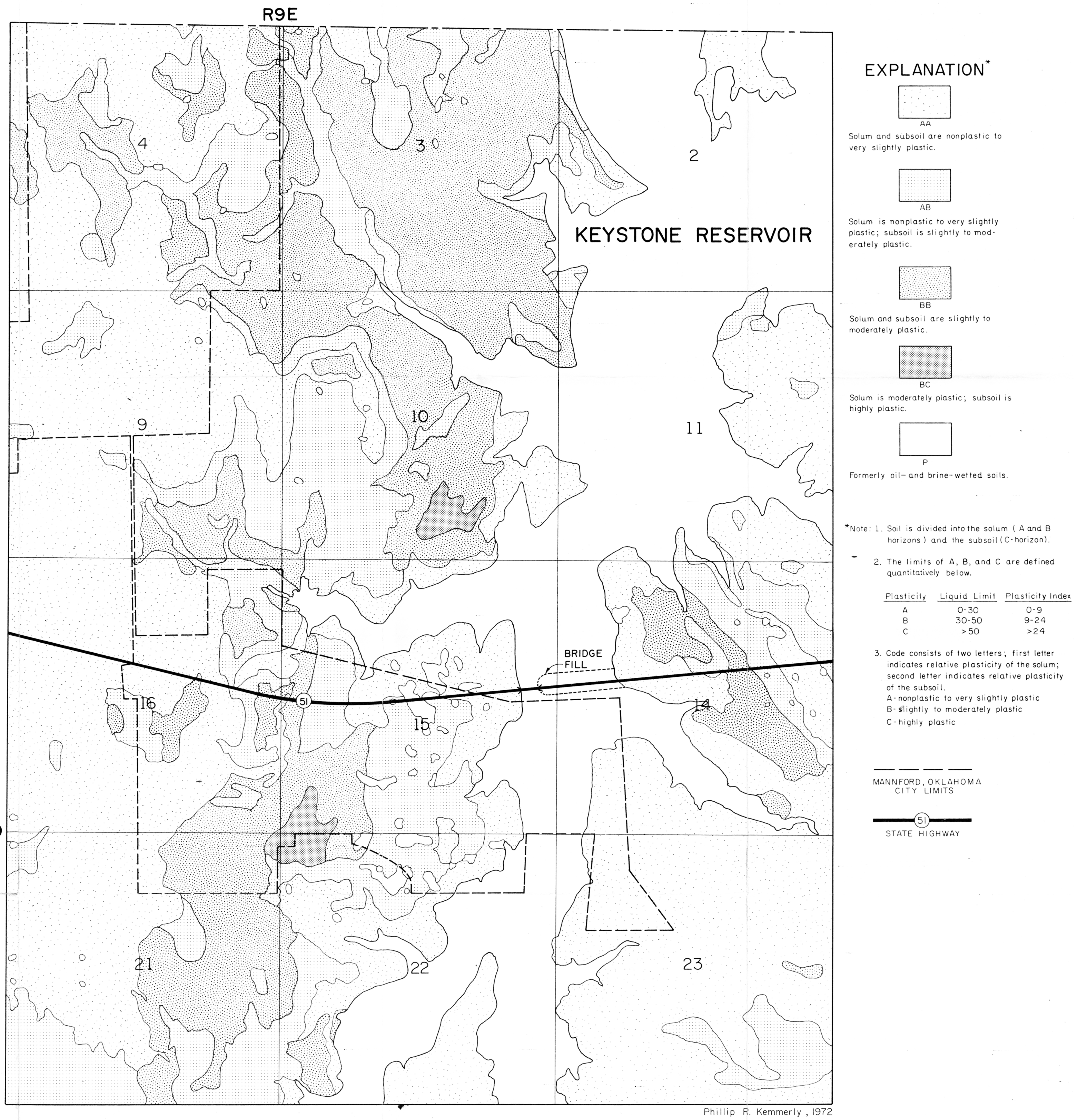
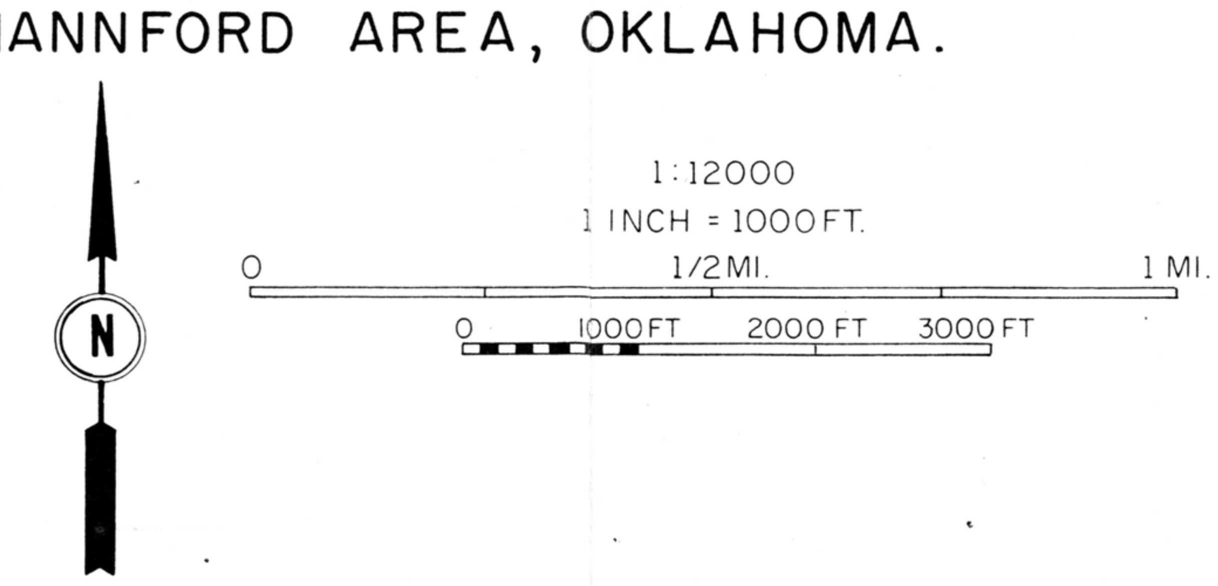


PLATE 11.-MAP SHOWING PLASTICITY OF SOLUM AND OF SUBSOIL IN THE MANNFORD AREA, OKLAHOMA.



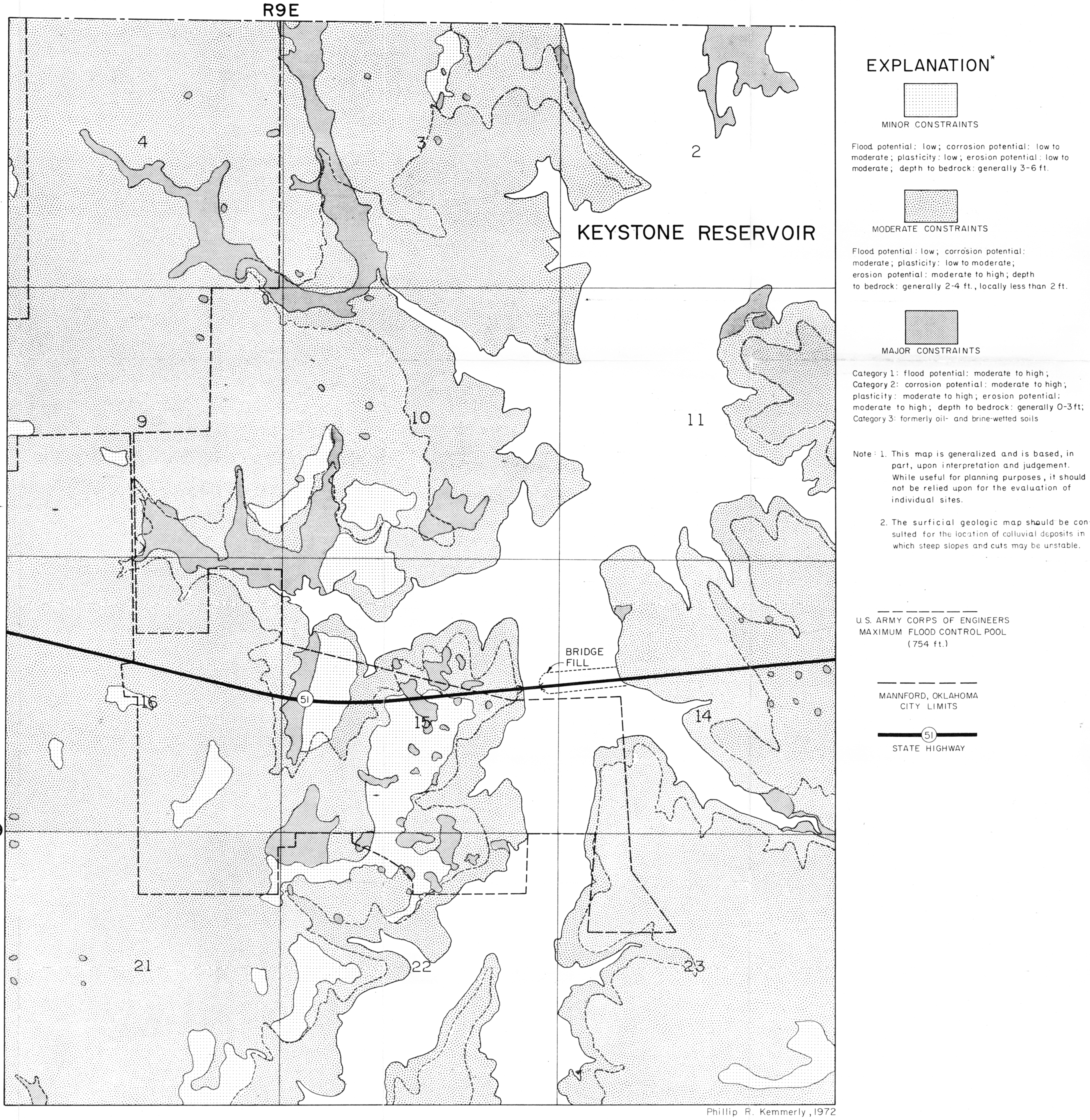


PLATE 12. – GEOLOGIC CONSTRAINT MAP FOR GENERAL LAND USE IN THE MANNFORD AREA, OKLAHOMA.