AN APPROACH FOR THE EVALUATION OF ENVIRONMENTAL IMPACT

By

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PREFACE

Section 102 (2) (c) of the National Environmental Policy Act of 1969 (Public Law 91-190) requires that a document discussing the results of analysis of environmental considerations be included in every recommendation or report on proposals for legislation and other major Federal actions significantly affecting the quality of the human environment.

This thesis describes how geology can be used to supply qualitative and quantitative data for the preparation of environmental impact statements. Factor maps used for an environmental inventory are described. Feasibility of a proposed project and alternatives and their expected impact on the environment is discussed in relation to the environmental inventory. Application of this approach to a hypothetical project is presented in matrix form. However, only the physical and hydrologic factors are considered.

The writer wishes to thank Dr. Douglas C. Kent for his invaluable assistance and guidance in the research project and the preparation of this thesis. His support and advice throughout the writer's residence in Stillwater is appreciated. Thanks also to Dr. Gary F. Stewart for his suggestions and editorial comments on the maps and text. Dr. Richard N. DeVries and Dr. Alex R. Ross provided valuable insight and constructive criticisms.

Appreciation is extended to Mr. Wayne Morgan, U. S. Army Corps of Engineers, Tulsa Division, who made special efforts to supply the author with various types of data, was instrumental in helping the author understand the Corps' procedure on Environmental Impact Assessments, and provided valuable editorial comments on the manuscript. Thanks are also extended to the Oklahoma State University Research Foundation and Department of Geology, without whose financial assistance this study would have been impossible.

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The writer also owes a special debt of gratitude to his wife, Jean, for her patience, reassurance, sacrifice, and understanding throughout the author's graduate career.

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CHAPTER I

ABSTRACT

A general approach was created to systematically relate physical factors with the objectives of environmental impact assessment. The approach was formulated by researching the laws (and their intent) requiring environmental impact statements, examining existing procedures, and utilizing geologic skills to develop a series of factor maps to qualitatively and quantitatively describe present environmental conditions.

A hypothetical project on the Deep Fork River in the Arcadia Area, Oklahoma County, Oklahoma, was used to test the approach. Factor maps developed for the area include (1) Physical Geology; (2) General Soil Association; (3) Ground-water Availability; (4) Natural Physical-Economic Resources; (5) General Land Slope - "A" Horizon Permeability; (6) Physical Soil Properties; (7) Distribution of Alluvial Thickness; (8) Hydrogeology of the Shallow Aquifer System; (9) Detailed Current Land Use; and (10) Soil Interpretative Constraints. These factor maps were used to make an environmental inventory, to determine the feasibility of a project and its alternatives, and to evaluate their impact on the environment.

CHAPTER II

INTRODUCTION

Objectives

The primary objective of this study is to develop a practical and systematic method for evaluating physical factors pertinent to environmental impact assessments. The relationship between geology and the evaluation procedures is specifically emphasized. With minor modifications, the method presented is intended to be for general application in most areas where water-resources projects are conducted. A second objective is to test the applicability of the method to an actual geographical area where a hypothetical water resource project is proposed. Those physical parameters which are particularly important to the development of the general methodology are identified and described.

Method of Approach

The first step in the development of a method to evaluate the physical factors relating to environmental impact statements (EIS) was to investigate the laws (and their intent) creating the requirement for environmental impact statements. Following a review of the political history which led to the development of the EIS, the Corps of Engineers guidelines for preparation of environmental statements were selected to represent an agency's attempt to meet the requirements of the National Environment Policy Act of 1969 and Flood Control Act of 1970. Methods for the implementation of these guidelines with emphasis on physical science considerations were proposed and used in the approach presented in this thesis.

A hypothetical water-resources project on the Deep Fork River, (see Figures 1 and 2) Central Oklahoma, was selected and used to evaluate the applicability of the proposed methods. A series of factor maps displaying the important physical parameters of the environment are used to prepare an environmental inventory. The following factor maps were prepared:

(1) Physical Geology;

(2) General Soil Associations;

(3) Ground-water Availability;

(4) Natural Physical Economic Resources;

(5) General Land Slope - "A" Horizon Permeability;

(6) Physical Soil Properties;

(7) Distribution of Alluvial Thickness;

(8) Hydrogeology of the Shallow Aquifer System;

(9) Detailed Current Land Use; and

(10) Soil Interpretative Constraint Maps.

Differences in areal extent covered by these maps reflect the varying degrees of detail required to present the pertinent data. The "project area", "upper basin", and "total basin" coverage are used to represent data in descending order of detail. The areas represented by each degree of coverage are shown in Figure 3.

The factor maps are also used to select feasible alternatives to the proposed project. The Corps of Engineers' suggested guidelines for an effects assessment are followed. The physical and hydrologic elements which are potentially affected by the project and alternatives are

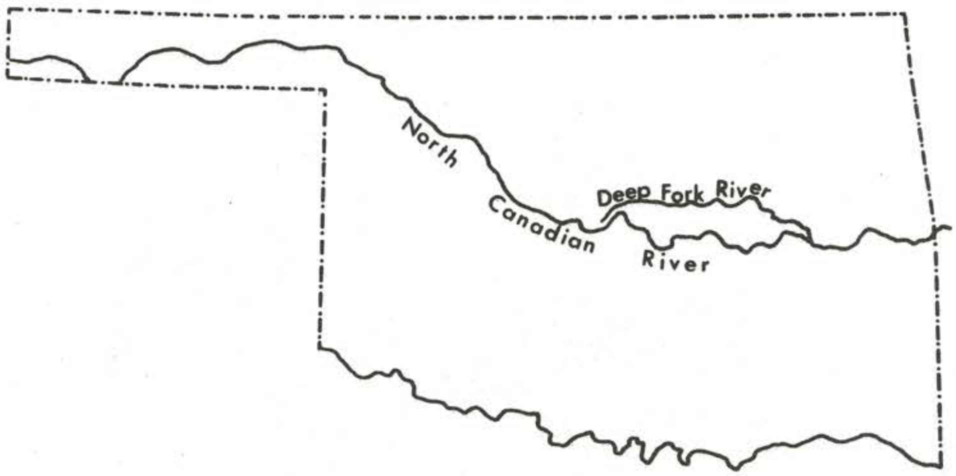

Figure 1. Location of the Deep Fork River, Oklahoma

Figure 2. The Deep Fork River near Arcadia, Oklahoma

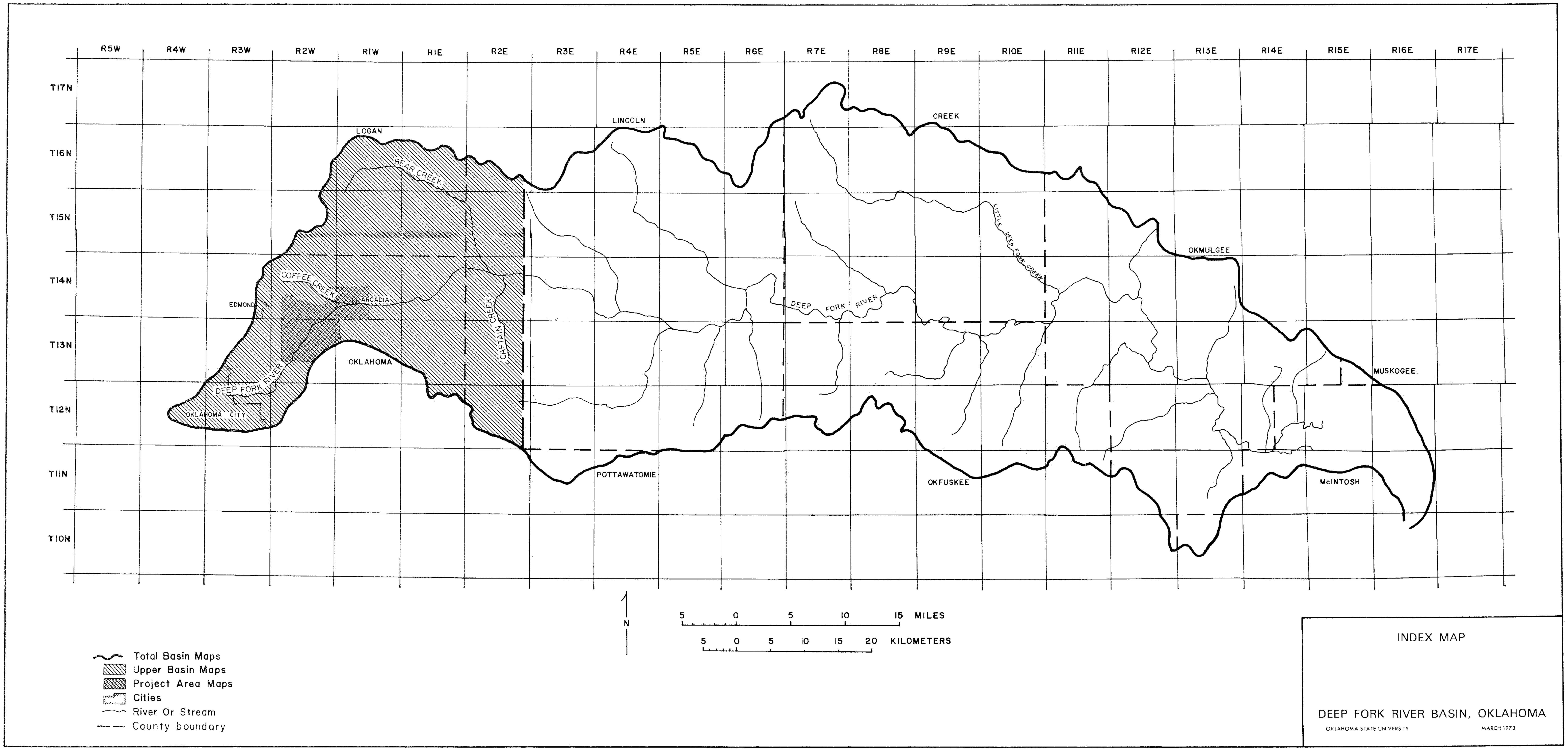

Figure 3. Index Map showing areal extent of coverage by each map type

determined, assessed (using the factor maps) and ranked on a matrix showing project and environmental elements for a hypothetical project.

CHAPTER III

GENERAL HISTORY AND DEVELOPMENT OF ENVIRONMENTAL IMPACT STATEMENT THEORY

Senate Document 97

The current environmental policies of our government are the product of an evolutionary process reflecting a growing national concern for environmental quality. The philosophies and development of the environmental impact statement, a product of this national concern, can be traced through a series of recently enacted laws.

One of the first documents in recent years reflecting this congressional awareness of the need for environmental planning was Senate Document 97 (U.S. Senate, 1962). Senate Document 97 is significant in that it represents an attempt by the Executive Branch, including the Bureau of the Budget (now the Office of Management and Budget), and the Legislative Branch to standardize evaluation procedures (Gardner and LeBaron, 1965). The document requires agencies which are formulating and reviewing plans pertaining to total river basins and/or individual projects that develop water and related land resources to consider environmental effects which may be caused by the project. Planning objectives delineated by the document center upon regional development and achievement of satisfactory levels of living. Resources are to be protected and rehabilitated to insure their availability for optimum future use. The document suggests the listing and justification of multiple purposes for water-resource use.

Johnson Era Laws

Numerous laws expressing concern for the environment were enacted during the administration of President Lyndon B. Johnson in the middle 1960's. Federal Water Project Recreation Act of 1965 (Public Law 89-72) encourages consideration of fish and wildlife enhancement. The Clean Water Restoration Act of 1966 (Public Law 89-753) provides for comprehensive water quality control and abatement plans for river basins. The Wild and Scenic Rivers Act of 1966 (Public Law 89-753) encourages consideration of wild, scenic, and recreational river areas. The National Flood Insurance Act (Public Law 90-448) requires adequate planning to prevent flood damage. The law denies insurance on loans for water-resource projects that are shown to be inadequately planned.

National Environmental Policy Act of 1969

The National Environmental Policy Act of 1969 (NEPA) (Public Law 91-190) can be considered the "Father of the Environmental Impact Assessment". The objectives of this act include the assurance of healthful, productive, and aesthetically and culturally-pleasing surroundings for all Americans. Sec 102 (2) (c) of the NEPA requires that a document be prepared which takes into account an evaluation of environmental factors affected by the project. The document must be included in every recommendation or report on proposed projects subject to legislation and which will significantly affect the quality of the human environment. The document submitted must discuss the following items:

(1) the environmental impact of the proposed action;

(2) unavoidable adverse effects should the proposal be implemented;

(3) alternatives to the proposed action;

(4) the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity; and

(5) any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented.

NEPA also stipulates that a review process be used by a federal agency which has jurisdiction by law over a proposed project requiring an environmental impact statement. The comments and views resulting from the reviewing process must be made available to the President, the Council on Environmental Quality, and the public, and must accompany the proposal through the agency reviewing processes. Gillette (1972) believes the two fundamental purposes of NEPA are to

> ... expose to the public a major source of information about the way in which the governments' activities affect the environment, and, in doing so, encourage the federal government into adopting a more sympathetic attitude toward a fragile biosphere.

Environmental Quality Improvement Act of 1970

The Environmental Quality Improvement Act of 1970 (Title II of Public Law 91-224) places primary responsibility for improving the environment on state and local governments. In this act, the Congress emphasizes a national policy providing for the enhancement of the environment. The numerous statutes previously enacted relating to water and land resources, transportation, economic and regional development and the prevention, abatement, and control of environmental pollution are cited as evidence of this congressional commitment.

Flood Control Act of 1970

Section 209 of the Flood Control Act of 1970 (Public Law 91-611) stipulates that the quality of the total environment, including its protection and improvement, should be included in federally-funded water-resource projects and in the evaluation of benefits and costs attributable to them. The most feasible alternative means of accomplishing the four objectives which include environmental quality, well being of the people of the United States, and national and regional economic development should also be considered. Section 122 of this act requires an effects assessment of identified impacts. This act represents an extension and broadening of the policies presented in NEPA.

U. S. Army Corps of Engineers Guidelines

In compliance with Section 102 of the National Environmental Policy Act of 1969, the Council on Environmental Quality set forth guidelines for the preparation of the required environmental statements. Many Federal agencies such as the Corps of Engineers, Environmental Protection Agency, Atomic Energy Commission and the Bureau of Reclamation have established implementation procedures and guidelines for the preparation of environmental statements. To discuss the procedures and guidelines of all these agencies is beyond the scope of this report. The procedures developed and followed by the Corps of Engineers, however, are presented as one agency's approach to meeting the requirements set forth by Sec 102 (2) (c) of NEPA and Section 122 of the Flood Control Act of 1970. The

Crops guidelines are complete, well ordered, and can be specifically applied to water-resources projects.

The Corps' first step in an environmental statement is to formulate a project description. The project name, location, purpose, and authorizing document are presented. Current status and benefit-cost ratio of the project are also included in this description.

A discussion of the environmental setting without the project follows the basic project description. This section contains a detailed description of the geology, hydrology, water quality, flora and fauna characteristic of the basin. History, prehistory (including archeological sites), and the social and economic aspects of the basin are discussed. The interrelationships of the environment with other projects in the basin are also discussed.

Following a discussion of the environmental setting without the project, the Corps considers the probable impact on the environment (Environmental Impact) by the proposed project and alternatives. In the section, impact is predicted to be either beneficial or adverse in nature. Remedial, protective, and mitigating measures related to impact are considered, and, when possible, enacted.

The adverse environmental effects which could not be avoided if a proposal were to be implemented are listed and discussed. This section of the environmental statement should predict the nature and extent of the effect. Impact from projects proposed or constructed by other agencies should also be included.

The environmental statement should contain a discussion of the alternatives to the proposed action. After each alternative is described, the environmental impact predicted to be caused by each alternative is considered. The predicted environmental impact and benefit/cost ratios of the proposed project and each alternative are used for ranking and final selection of the most acceptable project.

The final section of the environmental statement describes coordination with other individuals, agencies, and groups. Following a public participation summary, a list of government agencies and citizen groups, and their comments, is presented. The responses to these comments by the Corps are also included. This section also contains records of all correspondence and reconciliations.

Selected Approaches

Geological Survey Circular 645

Leopold et al. (1971) suggested an approach for implementing guidelines such as those discussed above. Figure 4 is the flow chart by Leopold et al. (1971) and represents a sequence of events leading to the preparation of an environmental impact statement. Briefly, their approach includes the following steps.

A) statement of the major objective of the project;

B) analysis of the technologic possibilities for achieving the objective;

C) discussion of the proposed actions and alternatives for achieving the objective. Equal effort should be expended in studying the proposed actions and alternatives;

D) preparation of a report characterizing environmental conditions prior to project initiation;

E) presentation of engineering proposals for each plan

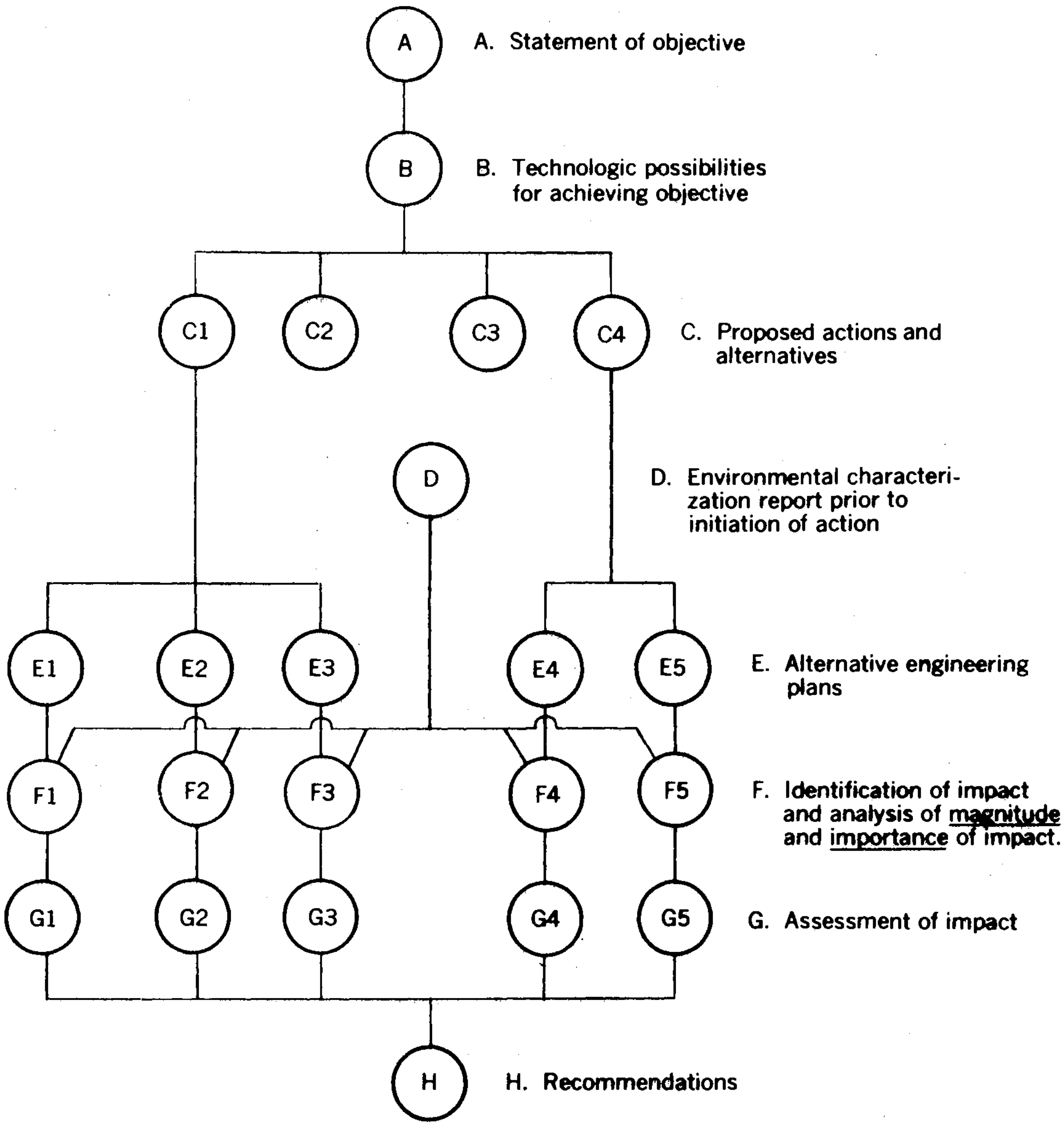

Figure 4. Flow chart for development of action programs (Leopold et al., 1971)

of action. Benefit and cost analysis is included for each plan;

F) use of D and E, above, to evaluate the environmental impact of the proposal;

G) assessment of impact; and

H) recommendations.

Leopold et al. (1971) recommend dividing the discussion of environmental impact into magnitude and importance of the effects of a proposed action on the environment. Magnitude represents the degree, extensiveness or scale of impact. Importance represents the relative significance of the impact on the environment. Importance is generally more subjective and qualitative than is magnitude. A weighting of magnitude and importance is accomplished by assigning numerical values from 1 to 10 (one being least, ten being greatest). For example, fertilizing the bottomlands of a valley may have a high (8) magnitude of impact on the ground-water quality, but, if the bottomlands comprise a small percentage of the potential recharge area, and if almost all ground-water production is from deeper bedrock aquifers, the importance of impact would be low (2). Because of their subjectivity, the numerical values ranging from 1 to 10 are not used in this thesis. In order for such a range in values to be realistic, a thorough understanding of the environmental factors and their interrelationships would have to be assumed.

Leopold et al. (1971) suggest using a general matrix (two-dimensional array) to display results of an environmental study. It is argued that a matrix can be used as a reference checklist or a reminder of the full range of actions and impacts on the environment that may relate to proposed actions. A matrix also serves as an abstract showing parameters considered, and lists the relative magnitude and importance of various impact effects. Interactions among project action and environmental aspects can also be displayed with a matrix. Thus, a matrix analysis leads toward an unbiased approach to impact analysis.

Environmental Geologic Atlas of the Texas Coastal Zone

Another approach to evaluating the environment is presented by Fisher et al (1972). They recognized an urgent need for a thorough regional analysis of the natural processes, environments, lands, water bodies and other factors of the Texas Coastal Zone. A complete environmental inventory is considered essential for further specialized scientific studies and regional planning for improved management of coastal resources. Using mapping as the basis for their approach, Fisher et al. (1972) prepared the following maps to describe the Texas Coastal Zone environments:

(1) Environmental Geology;

(2) Physical Properties;

(3) Environments and Biologic Assemblages;

(4) Current Land Use;

(5) Mineral and Energy Resources;

(6) Active Processes;

(7) Man-made Features and Water Systems;

(8) Rainfall, Discharge, and Surface Salinity; and

(9) Topography and Bathymetry.

These maps can provide basic data used for the environmental inventory, and can be used to predict future changes and rates of change in the environment. Areas or points of specific interest can be studied by overlaying maps representing the appropriate basic data.

It is the intention of this investigation to follow the Corps of Engineers Guidelines by applying and modifying the aforementioned methods of approach.

The purposes, methods of construction, and problems will be discussed for each of several factor maps describing the physical environment. However, to use the information presented on the basic factor maps solely for describing the physical inventory would be myopic. Thus, these maps will be referred to later when the feasibility and environmental impact of the project and alternatives are considered. The application of these maps in the evaluation of project and alternative feasibility and environmental impact is schematically presented in Figure 5.

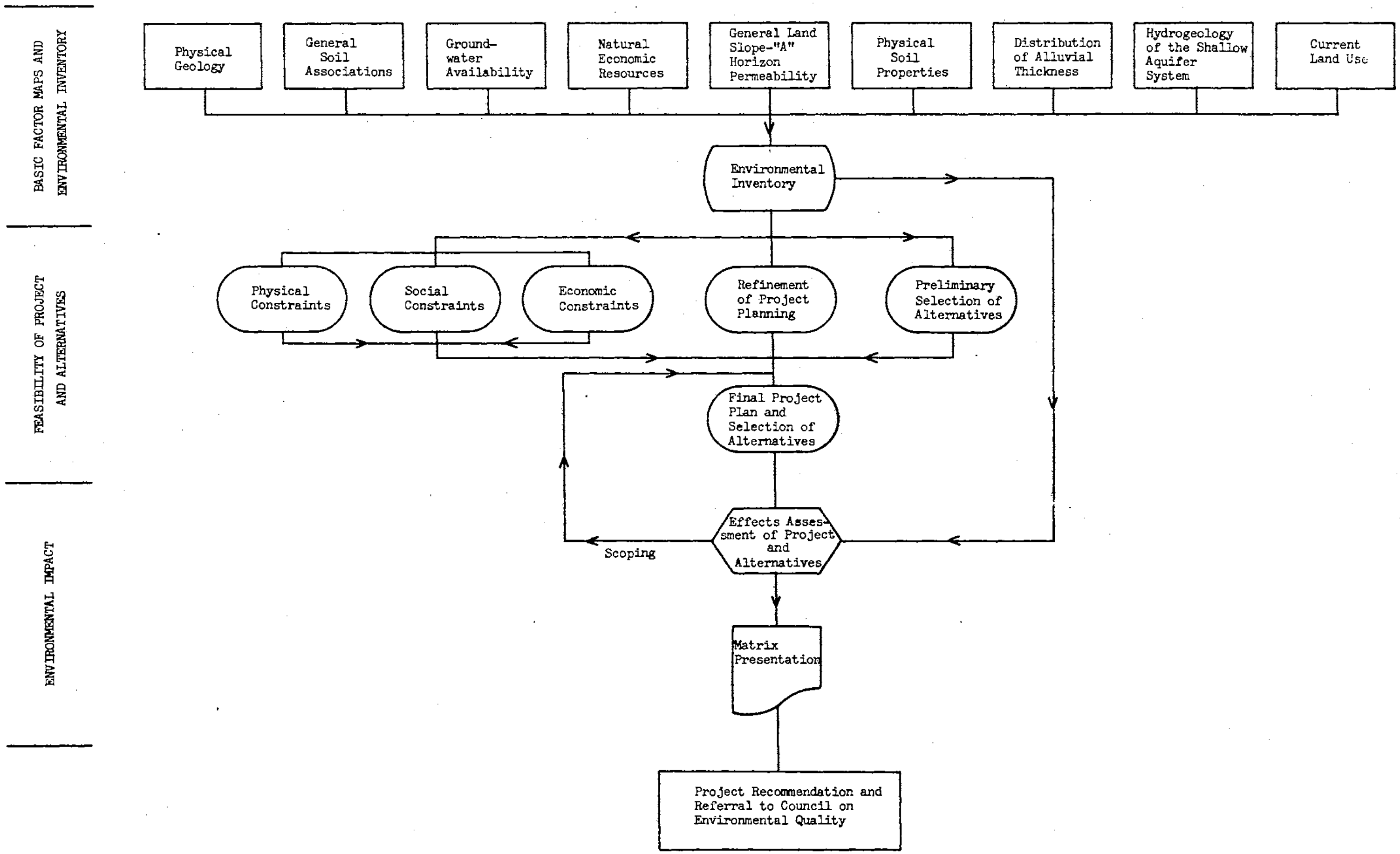

Figure 5. Schematic diagram of approach

CHAPTER IV

ENVIRONMENTAL INVENTORY

Introduction

Consistent with the U. S. Army Corps of Engineers Guidelines, an early step in the preparation and formulation of an environmental statement is the inventory and evaluation of environmental aspects associated with the project and its river basin. A discussion of the physical factors indigenous to the basin comprises an essential component of the total environmental inventory.

A series of factor maps have been developed to show the varying aspects of the physical environment within which the proposed project would be constructed. Maps are used to depict the physical geology, general soil associations, ground-water availability, natural economic resources, land slope and soil permeability, detailed physical properties of the soil and rock, alluvial thickness, the shallow ground-water system, and detailed current land use.

Development of Basic Factor Maps

Physical Geology Map

Purposes. A general geologic map of the entire drainage basin was prepared to identify rock formations outcropping at the surface (see Figure 6). Major, fundamental trends and surficial structures are shown on this map. The identification of fault trends can be helpful in selecting general areas for proposed and alternative project sites within the basin. Because of a preference for construction on resistant, stable-rock formations, knowledge of these factors should aid in project site selections.

A general cross-section (Figure 7) showing the regional subsurface relationships and dips of formations accompanies the geologic map. Relative thicknesses and depths of formations, as well as potential recharge areas for subsurface aquifers, can be determined from the cross-section. For example, Figures 6 and 7 indicate that water wells should be drilled progressively deeper toward the west in order to intersect the base of the Wellington Formation within the Garber-Wellington aquifer.

Methods. The geologic map and cross-section were slightly modified for the ones shown in the publication by the Oklahoma Water Resources Board (1971). Except for the following changes, all information presented in Figures 6 and 7 is exactly as shown in the reference:

(a) The southern half of the area covered in the reference is not included;

(b) The Chickasha Formation and Duncan Sandstone were not included because they do not crop out within the Deep Fork River drainage basin;

(c) To prevent unnecessary complexity, members of formations were not included in the geologic map or cross-section;

(d) A coal seam identified in the Senora Formation was excluded;

(e) The Upper, Lower, and Middle parts of the

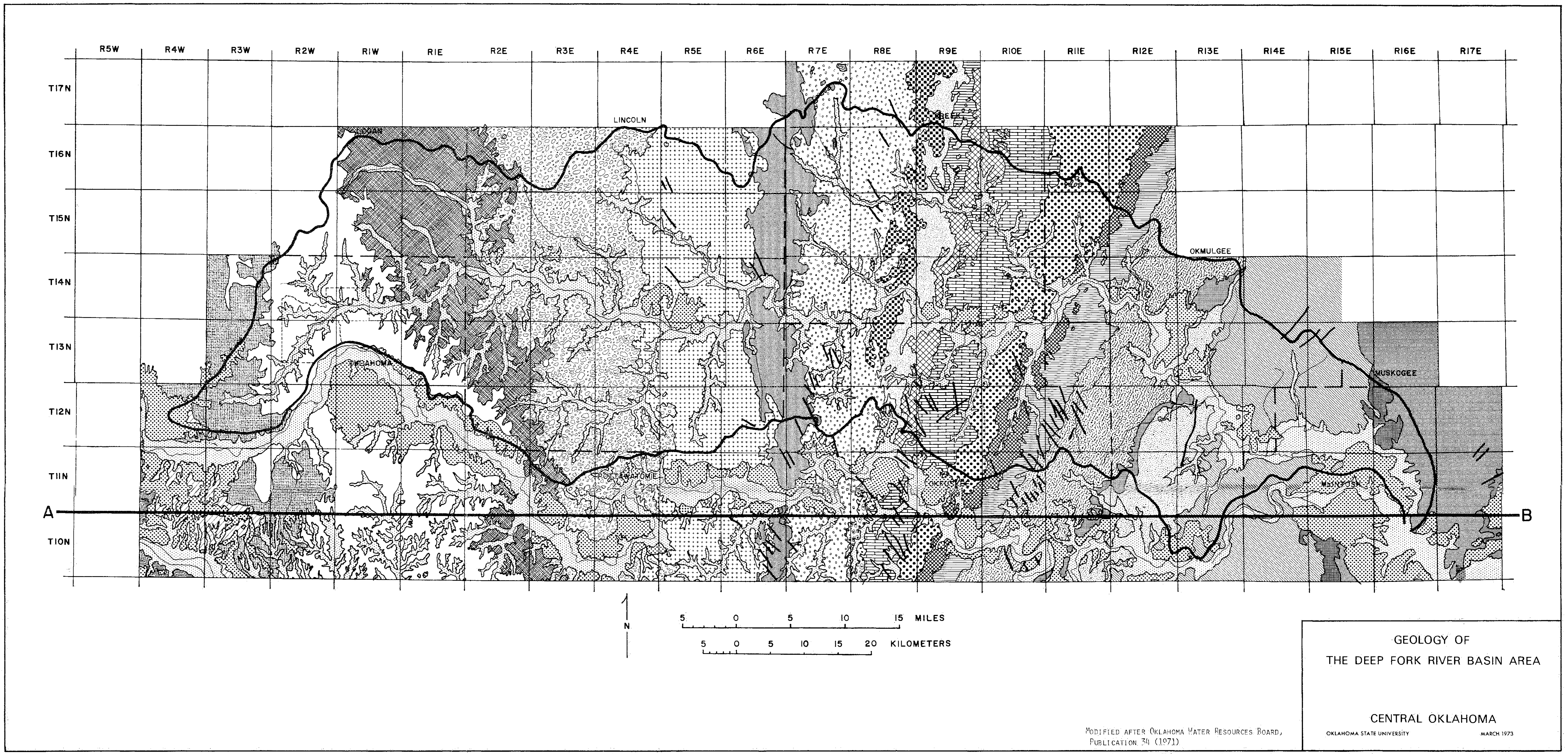

Figure 6. Physical Geologic Map

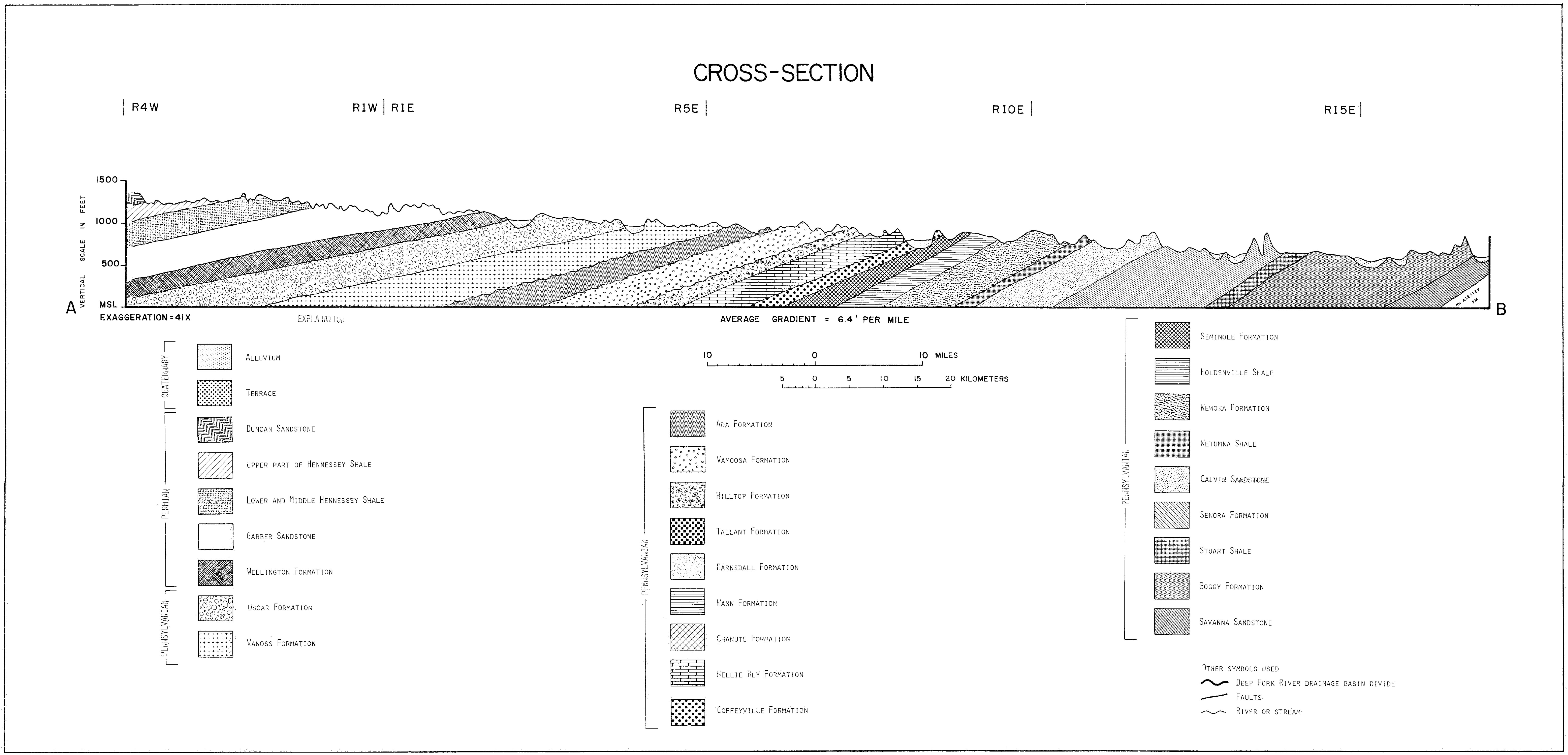

Figure 7. Cross-section of the Geologic Map

Hennessey Shale were combined; and

(f) The McAlester Formation and metric scale were added to the cross-section.

Problems. The major problem encountered in preparing the Physical Geology Map was finding adequate coverage of the basin at a convenient scale. Use of published data (when available) is helpful in a project of this type because extensive refinement of the information by geologic field mapping is disproportionately expensive in consideration of the objectives.

General Soil Associations Map

Purposes. A soil association normally consists of one or more predominant soils and at least one soil of minor areal extent. The association name reflects the major soil.

A generalized soil associations map (Figure 8) can be useful in providing an overview of the soils within the upper basin where proposed and alternative project sites are to be considered. The General Soil Association Map also provides a contrast among soils in various parts of the basin, and may be useful in the evaluation of regional land use practices such as the location of large tracts which are suitable for a certain kind of farming or other land use (Fisher and Chelf, 1969). Because of the variations of properties within any one soil association, the use of a general soil association map for local management planning is not recommended.

Methods. The General Soil Association Map (Figure 8) was compiled from the Soil Surveys of Oklahoma (Fisher and Chelf, 1969), Logan

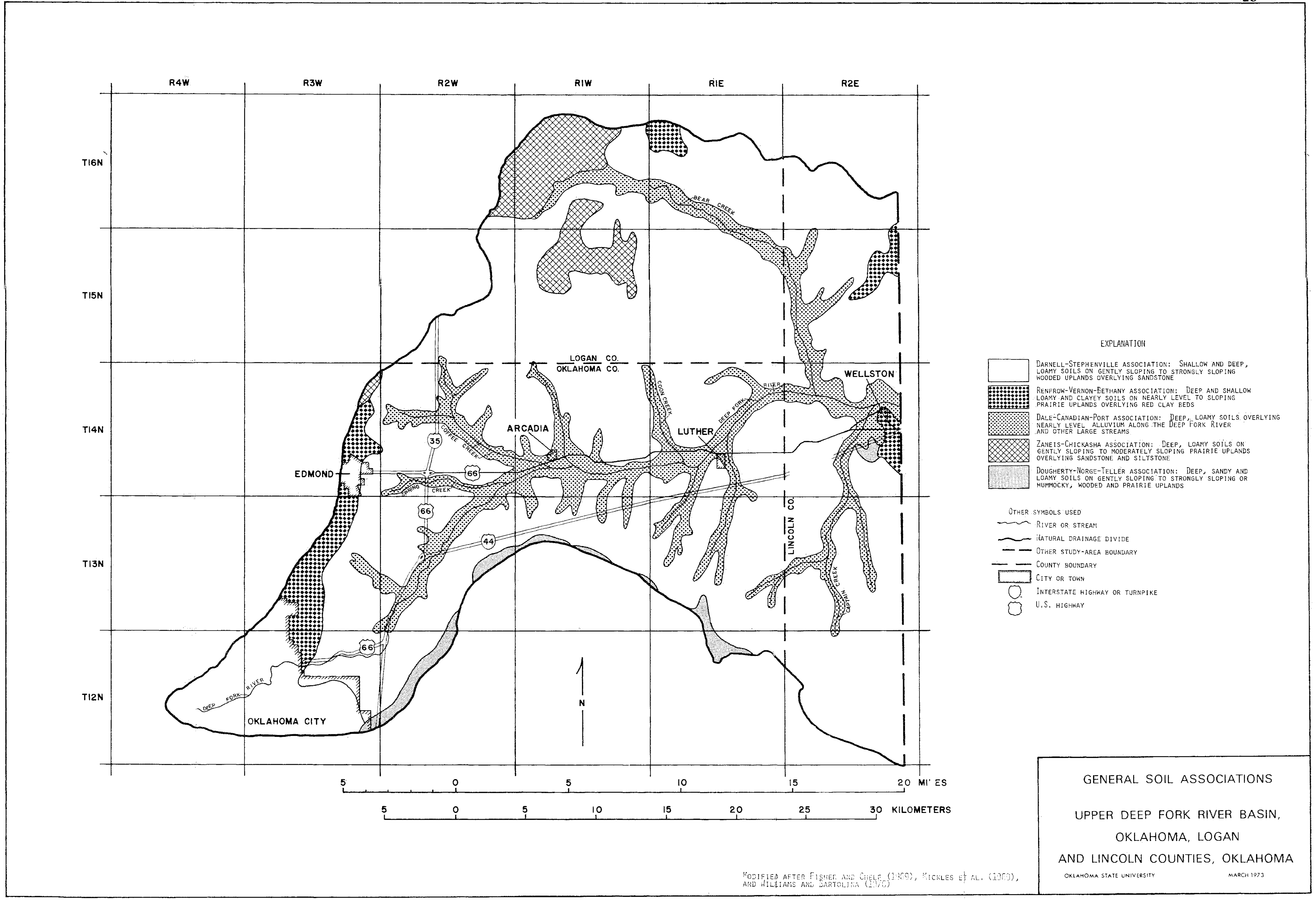

Figure 8. General Soil Association Map

(Mickles et al., 1960), and Lincoln (Williams and Bartolina, 1970) Counties, Oklahoma. This map covers all areas in the upper basin that are potential sites for a proposed project and alternatives.

Problems. A major potential problem that might be encountered when preparing a map of this type is the lack of uniformity of scale on recent soil survey maps. This problem can be solved (with an insignificant loss in detail) by using reducing and enlarging equipment to attain scale uniformity. Minor soils composing an association vary from one county to another in some instances. This variation presents the illusion of a problem; however, within the context of a study of the kind under discussion here, variation among minor soils within an association is a matter of little importance.

Availability of Ground-Water - Base of Fresh Water Map

Purposes. Ground-water aquifers represent a valuable potential resource for an urban and/or industrialized area. An understanding of the extent and potential yields of an aquifer is essential for an accurate evaluation of the ground-water supply. Areas of maximum fresh-water thickness can be located using the contours of the salt water-fresh water contact (Figure 9). This contact can also be useful in establishing depths at which casing in oil wells and waste-disposal wells should be set to prevent contamination of fresh water (Hart, 1966). Although the base of the fresh water may be deep in some areas, penetration of many permeable units and good production cannot be assured. An example of this is the Garber-Wellington aquifer in the upper Deep Fork River basin. It is comprised of interbedded, loosely-cemented sandstones and shales

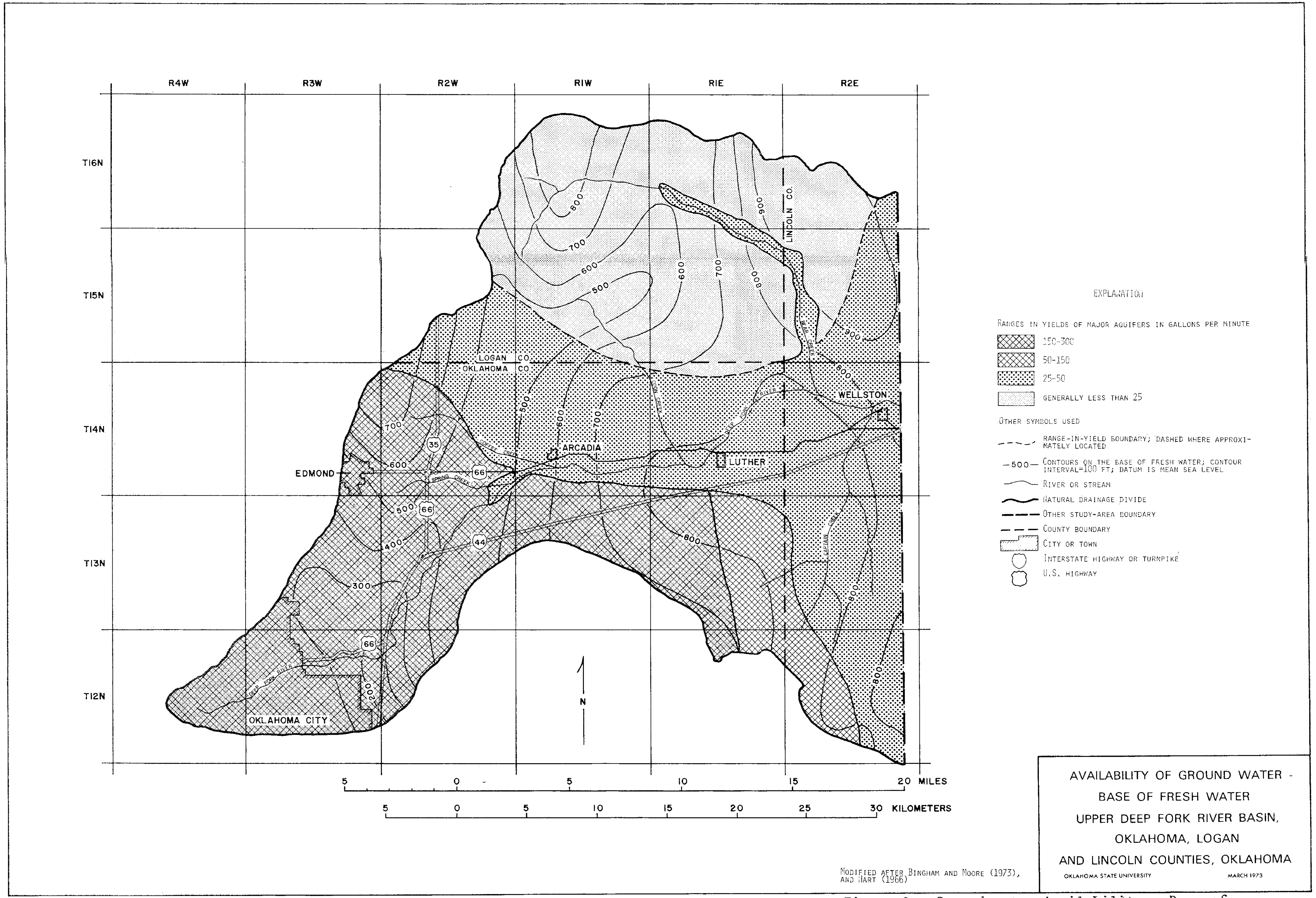

Figure 9. Ground-water Availability - Base of Fresh Water Map

(Wood and Burton, 1968). Lensing of the units, such as evidenced in Figures 10 and 11, may cause a condition to exist where one well will penetrate many saturated sandstones, while another well, less than one fourth of a mile away, will penetrate few permeable zones. Thus, in addition to the saturated fresh-water thickness, ideally the true geometry of the aquifer must be known before the capability of an aquifer can be determined.

Because well yield is a function of the depth of penetration and net thickness of permeable zones, it is possible to determine a "ball park" estimate of the aquifer's ability to satisfy present and future water-supply demands. For example, an average of the highest yield-range in Figure 9 is 225 gallons per minute. The number of wells necessary to supply an estimated demand of water can be calculated by dividing the water-supply demand by the average yield per well (225 gpm in this case). An estimated depth of wells can be obtained by noting the average well depth in an area having a specified range of yield (see Table I). In addition, the depth to salt water can be estimated by calculating the difference between the elevation of the salt-water contact as shown in Figure 9 and the average surface elevation as shown on a topographic map. A hypothetical case showing the number of wells necessary to meet the City of Edmond's future water supply needs is presented in Table I. These data are used to compute the estimated costs of developing an alternative ground-water supply and of developing the proposed reservoir as the only source of water supply.

Methods. Bingham and Moore (1973) compiled the water level and well yield data referred to in Figure 9. Their sources included field investigations, the Oklahoma Water Resources Board, and U. S. Army Corps of

Figure 10. Channel-fill sandstone, Arcadia Area, Oklahoma County, Oklahoma. Arrows indicate contact where form of ancient channel is preserved.

Figure 11. Sandstone lens, Arcadia Area, Oklahoma County, Oklahoma. Note seepage and plants along base of sandstone.

TABLE I

ESTIMATED NUMBER OF WELLS TO MEET FUTURE MUNICIPAL DEMANDS OF THE CITY OF EDMOND

Year	Amount of Water Required (in mgpd)	Avg. Yield Per Well (in gpm)	Number of Wells Necessary to Meet the Demand	Avg. Depth of Wells (in ft.)
1980	3	225	9	725
2000	11	225	33	725
2020	21	225	62	725

Engineers records. Bingham and Moore (1973) delineated range-yield boundaries with the assumptions that (1) if the lithology is similar, well yields throughout the geologic unit will be similar, and (2) drilled wells penetrate the total thickness of the aquifer.

Hart (1966) made the contour map of the base of the fresh water. His major sources of information were electric well-logs. Driller's records from water wells, test holes, and information contained in geologic and hydrologic reports were also used.

Problems. The greatest problem in the development and interpretation of a ground water - salt water contact map can be absence of any previous work from which to draw information. The large area covered in this study limits interpretation because of the lack of sufficient data. Yields from individual wells in an area can be higher than the average range-in-yield values for that particular area. Finally, the assumption that the wells from which yields are determined all penetrate the total aquifer thickness is sometimes not true.

Natural Economic Resources Map

Purposes. The mineral resources occurirng within a river basin can be shown on an Economic Resources Map (for example, see Figure 12). The areal coverage of this map includes the entire drainage basin, and relates the regional socio-economic aspects of the environmental assessment to the effects caused by the project and alternatives. The coverage of the total basin is also necessary because the effect of potential downstream flooding on the resources must be considered.

A Natural Economic Resource Map can illustrate resources that will be obscured by a project. For example, a proposed lake may flood

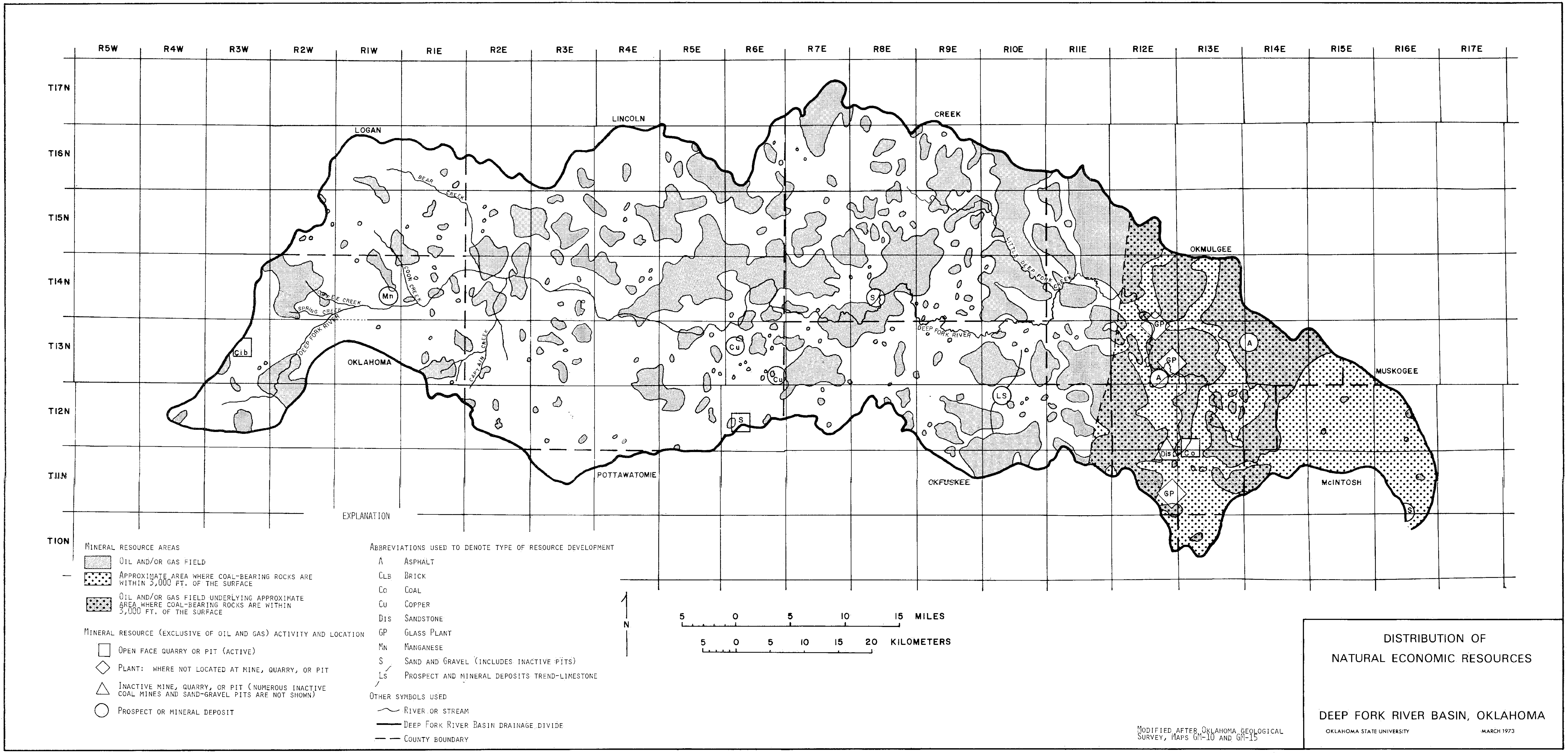

Figure 12. Natural Economic Resources Map

valuable sand and gravel pits, or may inundate an area overlying a valuable oil field. Availability of resources may be important in the potential development of an area. Since the Economic Resources Map shows the distribution of extant resources throughout the basin, it can be a tool to be used for predictions of future regional development (including potential project and alternative site locations).

Resources that are potential problems for the project are also shown on an Economic Resources Map. For example, a proposed reservoir may inundate an area overlying a once productive oil and gas field. Therefore, oil-brine seepage from poorly-capped or poorly-cased wells can become a potential source of pollution of the lake. Kemmerly (1973) notes that such a problem exists in the Keystone Reservoir near Tulsa, Oklahoma.

Methods. The Natural Economic Resources Map (Figure 12) was compiled from maps showing the distribution throughout Oklahoma of oil and gas fields (Oklahoma Geological Survey, 1966) and other minerals (Johnson, 1969) throughout Oklahoma. Publications of the U. S. Bureau of Mines (1969) and Roberts (1970) were also consulted.

Problems. Perhaps the most significant problem potentially encountered in preparing the Natural Economic Resources Map is that the basic information may not be current. Use of the large scale necessary to describe the distribution of economic deposits throughout the basin prohibits detailed display of resource boundaries. However, the map is not intended for specific resource planning or development. There may also be potential oil and gas fields and mineral deposits such as copper within the basin that have not been discovered.

General Land Slope - "A" Horizon Permeability Map

Purposes. A map grouping general land slopes and "A" horizon permeabilities was prepared (Figure 13). General land slopes are included on the maps because of their importance in evaluating runoff, erosion, and landslide potential. Also, knowledge of slope grades, when used in conjunction with economic analysis, can be useful in determining constraints for the prediction of growth relative to urbanization and industrialization. The "A" horizon includes that part of the soil profile in contact with the soil-air interface. Permeability of this horizon is an important consideration in determining the amount of runoff and the degree of erosion and landslide potential.

Musgrave (1947) found from plotted data that erosion (E) is empirically related to the physical features of the land by:

$$E = ks^{1.35}L^{0.35}P^{1.75}$$

where

s = land slope in percent;

L = length of slope in feet;

P = maximum annual 30-min. rainfall in inches; and

k = vegetal cover factor.

Linsley et al. (1958) point out that the above equation represents the results of small test plots, and suggest that additional information is required for estimates of the sediment yield from natural watersheds. The General Land Slope - "A" Horizon Permeability Map can provide data to evaluate quantitatively the s and L factors in the above equation. The Corps of Engineers, however, predict sedimentation in a lake by measuring

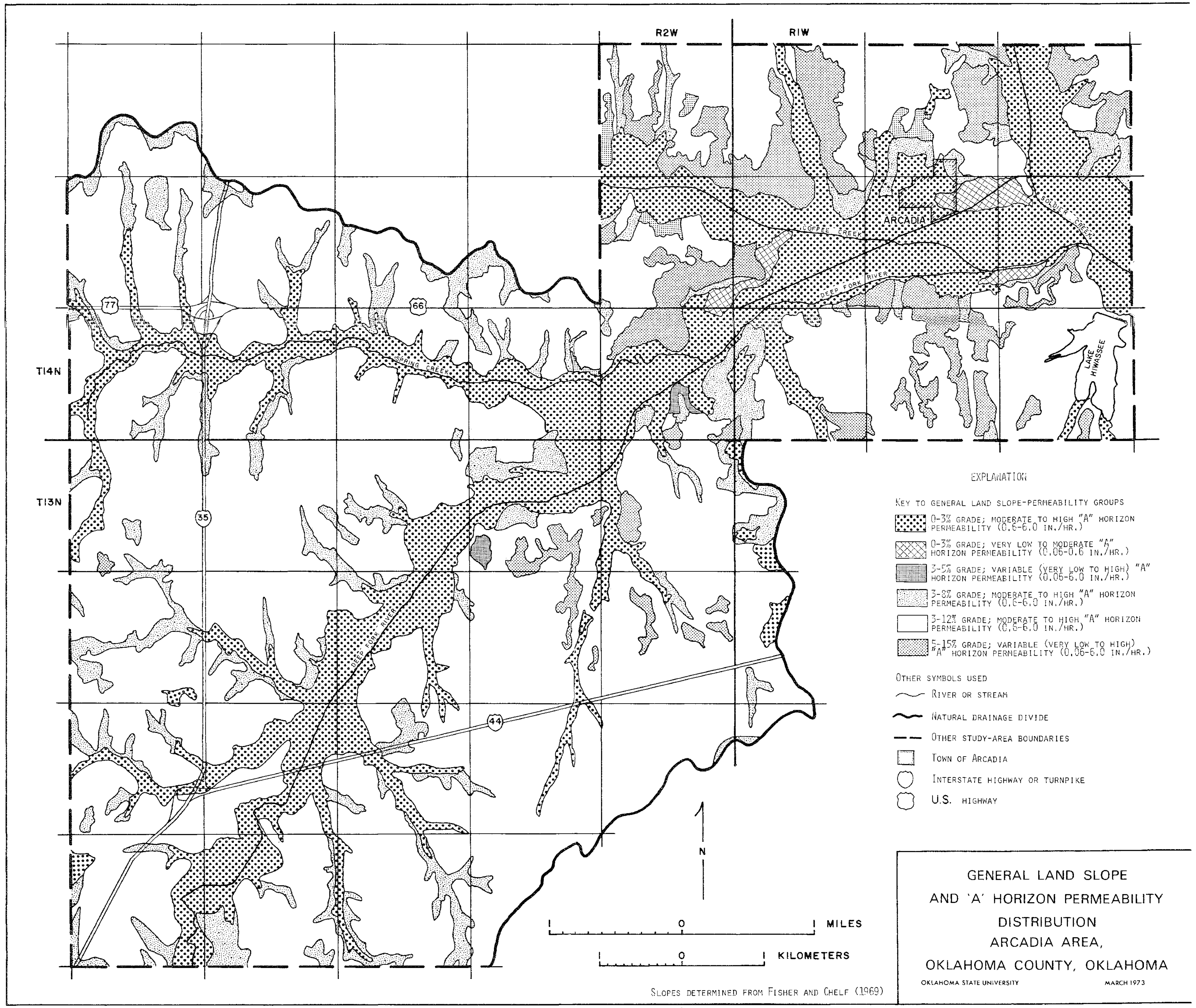

Figure 13. General Land Slope - "A" Horizon Permeability Map

sediment yield of the river upstream from the proposed reservoir site (D. Flasch, written communication, 1973). Since this measurement represents suspended sediments, ten percent is added for bed load to obtain total yield.

Estimates of runoff for small basins can be obtained by developing a unit hydrograph or by solving the "rational formula" given in Linsley et al. (1958) by

$$Qp = CiA$$

where

Qp = discharge in acre-inches per hour;

i = average rainfall intensity in inches per hour for a duration equal to the time of concentration over the basin;

A = area of the basin in acres; and

C = expression of the proportion of the total rainfall which runs off and effect of overland flow and channel storage on the peak.

The General Land Slope - "A" Horizon Permeability Map can provide qualitative impact for relating the influence of infiltration rates and degree of slope to C (imperviousness factor) in the surface runoff equation. A highly impermeable "A" horizon would be expected to retard infiltration and therefore increase runoff potential. The above equation, however, should be used with extreme caution since it does not adequately recognize all the complications of the runoff process. The Corps of Engineers (Dr. R. N. DeVries, oral communication, 1973), however, prefers to use a unit hydrograph for prediction of runoff.

Methods. The General Land Slope - "A" Horizon Permeability Map covers the immediate project area of a hypothetical proposed water-resources project site and some alternative sites. When a feasible alternative is outside the map area, an inset can be used. The map scale for the project area was chosen because of the need for greater accuracy to evaluate project feasibility and environmental effects. Slopes of soils occurring throughout the immediate project area were grouped into four categories.

The "A" horizon permeability of every soil occurring in the immediate project area was listed, and three basic permeability groups were established. Soils belonging to the permeability groups were then compared with the soil-slope categories. Two new major categories, in addition to the four existing categories, were created. These two new categories maintained the slopes of their original grouping, but reflected different soil-permeability ranges.

Problems. The major potential problem in preparing a land slope-permeability map is the possible absence of a current soil survey for the project area. Another potential problem is overinterpreation by the user of the map. The physical properties of any soil series vary locally. On-site investigation is essential before final decisions for construction are reached.

Ideally (for runoff evaluation potential), the slope-permeability map should cover the entire area upstream of a proposed project site. The size of such a map would, in many cases, be prohibitive at the scale used. This problem, however, can be solved by extrapolating information from the immediate project area to surrounding areas.

Physical Soil Properties Map

Purposes. The Physical Soil Properties Map (Figure 14) offers data describing the physical soil properties of the "B" horizon, depth-to-bedrock, and bedrock type. Engineering data are selected and presented in map form to permit engineers to make general judgements easily. Plasticity, shrink-and-swell potential, depth-to-bedrock, and bedrock type have specific application to activities involving construction, excavation, drilling, and channelization. Permeability, depth-to-bedrock, and bedrock type are also important in evaluating waste-disposal potential. Faults can also be shown on this map.

The Physical Properties Map can be a useful tool in area planning. Knowledge of the properties affecting the various previously mentioned activities can help indicate areas of favorable development. This map is also an invaluable aid in developing the more specialized physical constraint maps (to be discussed later).

Another purpose of the Physical Properties Map is to show current and future effects of physical factors on land use. For example, Figure 14 suggests that the extensive farming in the bottomland (Units I-D-4 and VI-D-4) could not be extended to the uplands because of the predominance of very shallow soil (Unit I-A-1).

Finally, the Physical Properties Map can be used in determining the areas conducive to potential ground-water recharge by using average rainfall distribution together with delineated soil permeability zones from the Physical Properties and General Land Use - "A" Horizon Maps.

Methods. The first step is to list all of the physical properties (including the A. A. S. H. O. and Unified Classifications) of each soil

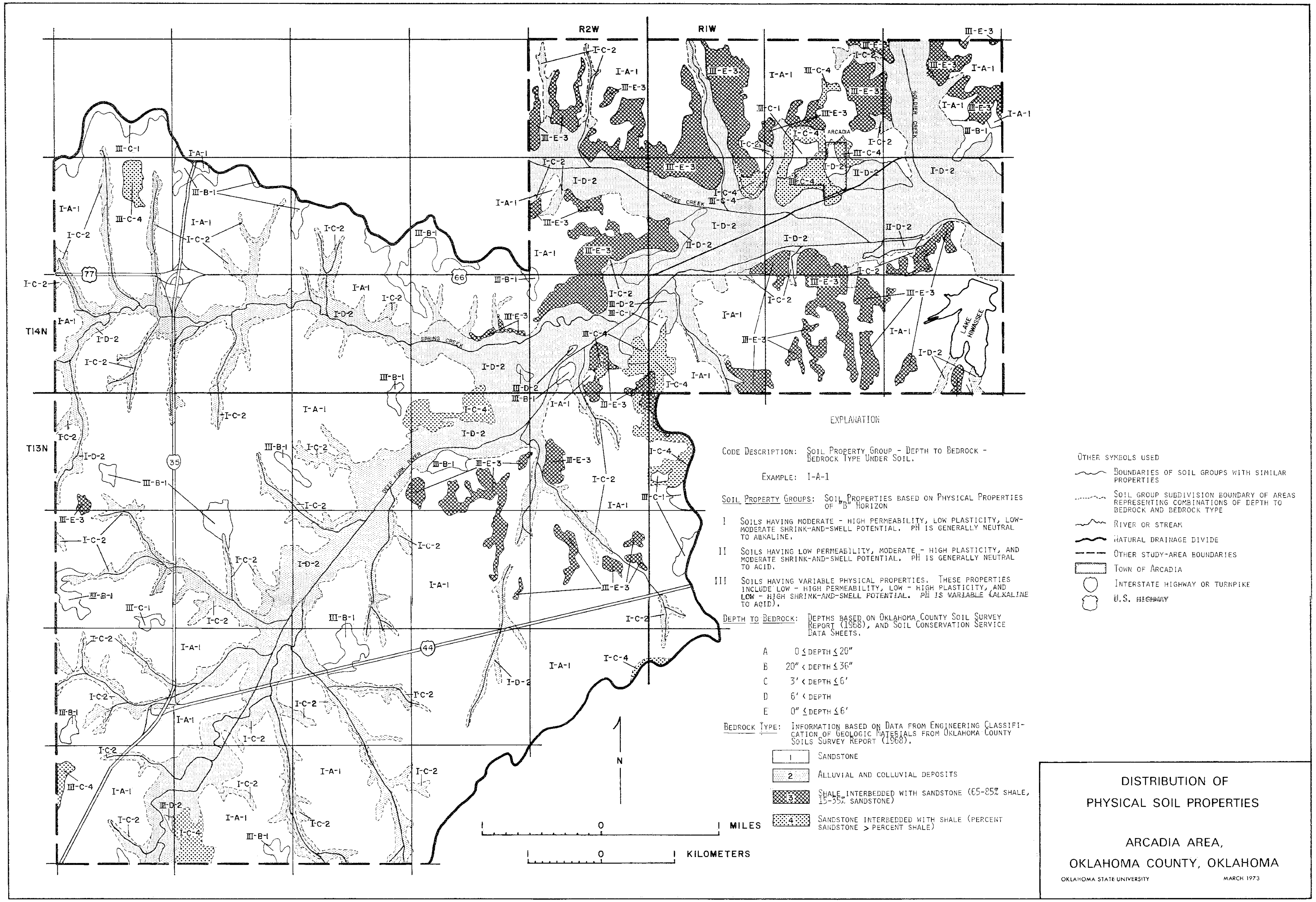

Figure 14. Physical Soil Properties Map

occurring in the immediate project area. Using the Unified Soil Classification values, the First Order of classification was developed by dividing the soils into groups having a unique combination of plasticity ranges, "B" horizon permeability, shrink-and-swell potential, and pH. Certain incongruencies were satisfied by creating a soil-property group having variable physical properties. Depth-to-bedrock ranges for soils occurring in the area were grouped and are represented as a Second Order of the classification. A Third Order was created to describe bedrock type underneath the soil. In the project area, bedrock types include interbedded sandstones and shales, flood plain and terrace alluvium, and colluvial deposits.

The original soils classification of each reclassified soil occurring within the project area is shown on Table II. The results of the reclassification representing the physical soil properties, depth-to-bedrock, and bedrock type underneath soil for the project area were plotted on a mosaic air photo base map pieced together from the "Soil Survey of Oklahoma County, Oklahoma", by Fisher and Chelf (1969).

Further characterization of the bedrock can be made by measuring sections in order to determine the percent of rock type occurring within the top ten feet of bedrock. The percentage is calculated in the following manner:

1) The total footage within the first ten feet from the surface of each outcrop is added.
2) The total footage of each rock type is divided by the total footage of all rock types measured.

The resultant is an estimated percentage of a rock type encountered within the top ten feet of bedrock. A survey of 36 outcrops in the immediate

TABLE II

PHYSICAL PROPERTIES CLASSIFICATIONS FOR SOILS IN THE ARCADIA AREA, OKLAHOMA

Soil	Code Description
Chickasha loam	III-C-1
Darnell-Stephenville fine sandy loam	I-A-1
Darnell-Stephenville complex, severely eroded	I-A-1
Eroded loamy land	I-C-4
Miller clay	II-D-2
Miller-Slickspots complex	II-D-2
Nobel fine sandy loam	I-C-2
Port clay loam	I-D-2
Port loam	I-D-2
Pulaski fine sandy loam	I-D-2
Pulaski soils, wet	I-D-2
Stephenville fine sandy loam, 1-3% grades	III-B-1
Stephenville fine sandy loam, 3-5% grades	III-B-1
Stephenville fine sandy loam, 3-5% grades, eroded	III-B-1
Teller fine sandy loam, 1-3% grade	III-D-2
Teller fine sandy loam, 3-5% grade	III-D-2
Vernon-Lucien complex	III-E-3
Vernon-Zaneis complex	III-E-3
Zaneis loam, 1-3% grade	III-C-4
Zaneis loam, 3-5% grade	III-C-4

project area indicated approximately 30% shale and 70% sandstone within the top ten feet of bedrock. To avoid crowding data already represented on the map, outcrop locations are not shown on the physical properties map. Percentages derived by this method compare favorably with rock-type percentages in the area estimated by Wood and Burton (1968).

Problems. Care should be exercised to avoid overinterpretation of the data presented. The physical properties of any one soil can vary slightly within any one mappable unit. Certain units may not be mapped because of a small areal extent. A sizable portion of the study area is classified as having variable physical properties. It should be stressed that more detailed studies are advisable for the evaluation of individual construction sites.

Distribution of Alluvial Thickness Map

Purposes. An understanding of the distribution of alluvial thickness is essential in evaluating the potential ground-water storage within the alluvium. If homogeneity is assumed, areas of greater alluvial thickness will possess the greatest potential yields for alluvial wells (assuming the total saturated thickness of alluvium is penetrated).

Seepage underneath proposed project and alternative dam sites can also be determined from the alluvial thickness shown on the Distribution of Alluvial Thickness Map (Figure 15), and from using an average permeability coefficient value, and by knowing the proposed depth of the dam's storage pool and impervious core. The following modified form of the Darcy Equation shown in Todd (1959) can be employed using flow net analysis techniques.

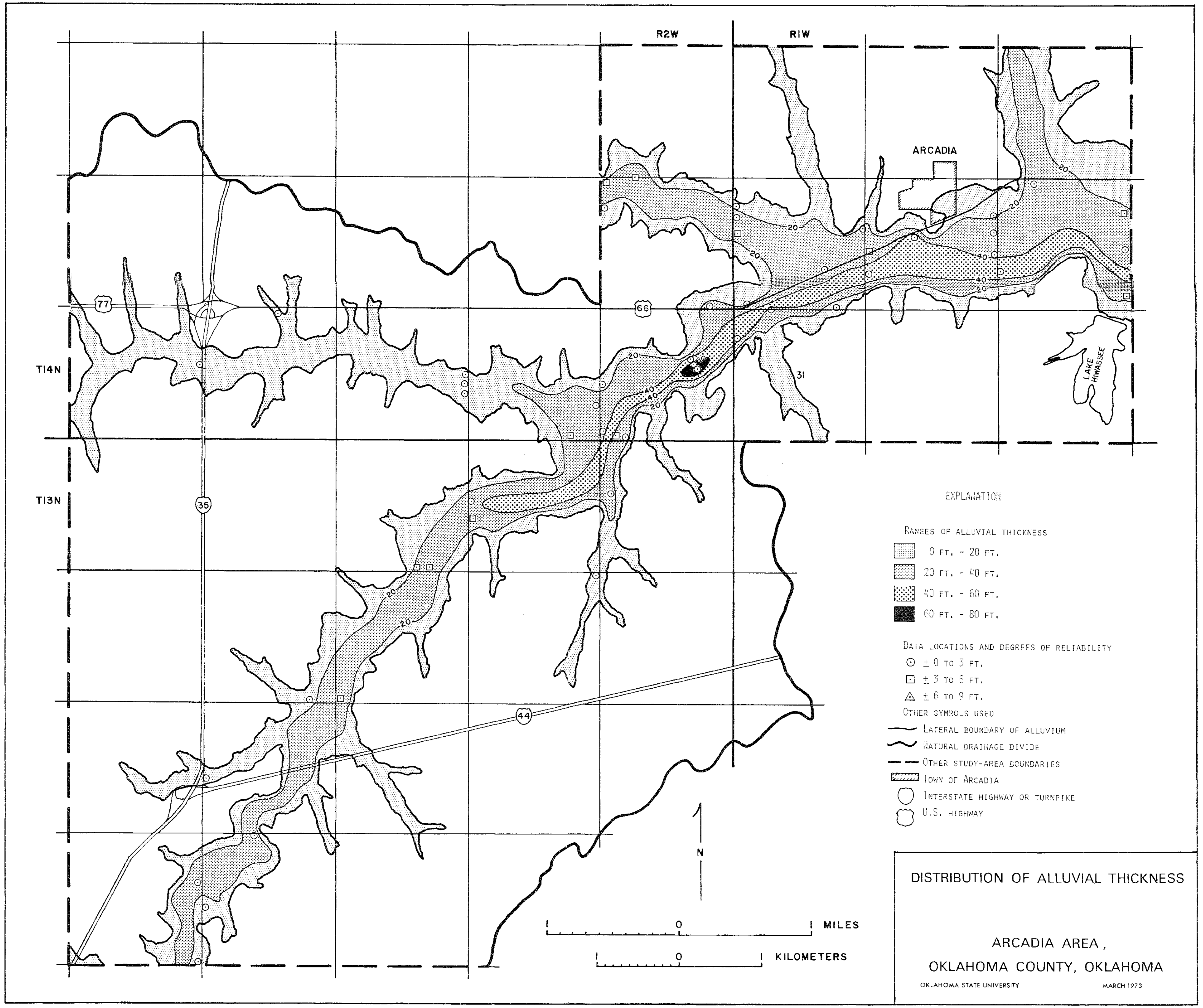

Figure 15. Distribution of Alluvial Thickness Map

$$Q = Kh \frac{F}{N}$$

where

Q = total flow through all the flow paths;

K = coefficient of permeability;

h = drop in lead from upstream to downstream side of dam;

F = number of flow paths in the net; and

N = number of "squares" (1 ft. equipotential drop increments) between any two adjacent flow lines.

This equation is used to estimate seepage through a unit length of the dam. Seepage under the entire length of a dam can be estimated by multiplying the product in the above equation by the width of the flood plain at the dam site. For example, using a hypothetical dam with a core penetrating 50% (20 ft.) of the alluvial thickness in the project area, the calculated seepage would be approximately 1.55 million gallons per day. A flow net was used in this calculation in lieu of the conventional Darcy Equation because the flow net can more accurately represent the flow path and therefore the distribution of the hydraulic gradient of seepage existing underneath the dam.

<u>Methods</u>. The first step in preparing the alluvial thickness map is to determine the alluvium-bedrock contact. Existing maps of the area, supplemented by aerial photographs and field checking, provide an adequate base for determining the lateral boundary.

An investigation of existing alluvial-thickness records follows determination of the bedrock-alluvium contact. Potential sources for depth of alluvium information in the project area included the following organizations:

(1) U. S. Army Corps of Engineers;

(2) Oklahoma Geological Survey;

(3) U. S. Geological Survey;

(4) Oklahoma Water Resources Board;

(5) Oklahoma Highway Department; and

(6) Oklahoma Turnpike Authority.

Lack of existing alluvial thickness data necessitated a field study using the Electro-Tech Model ER-75-12 portable seismic-refraction instrument (see Figure 16). To test the instrument's accuracy, the first seismic station of the field study was located adjacent to a well of known depth-to-bedrock. At this location, the alluvial thickness determined by the seismic instrument compared favorably with the thickness listed on the well log. Other seismic stations were selected based on accessibility to roads and capability of geophone alignment parallel with the general stream course. The latter condition was sought to avoid necessary dip corrections for each geophone. Spacing between geophones varied from one station to another depending on relative depth-to-bedrock. The "rule of thumb" used to determine geophone spacing is based upon the critical distance formula (Dobrin, 1960). Briefly, the "rule of thumb" is to (1) multiply the estimated depth-to-bedrock by four in order to determine the total length to be spanned by the geophones, and (2) divide this product by the number of geophones, (twelve in this case). The resulting quotient is the estimated spacing.

After a four-foot hole was augered and a geophone spacing was chosen, the geophones were spaced evenly along the chosen alignment. Commercial dynamite (40% Nitroglycerin) was packed into the hole; the instrument was leveled and connected to an instantaneous blasting cap in

Figure 16. The Electro-Tech Model ER-75-12 portable seismic-refraction unit

the dynamite. Following detonation, a polaroid picture was developed showing signal traces from the twelve geophone channels, detonation instant, and timing lines. A computer program written by Kent (1969) was used to calculate depth-to-bedrock and estimated error.

Problems. The major difficulty encountered in preparation of the Distribution of Alluvial Thickness Map was a lack of bore-hole control. Thus, seismic data could be verified using bore-hole data at only one location.

In order to align the geophones parallel to the stream course, it was necessary to obtain access permission from many landowners in the area. Unfortunately, some landowners were reluctant to grant access to their property. A fear of dynamite and concern for freshly plowed fields were cited as reasons for their reluctance.

Weather presented another problem to the seismic survey. Susceptibility to moisture of the instrument and geophone cables precluded investigations during wet conditions. Sub-freezing temperatures also made augering and geophone implacement difficult.

Hydrogeology of the Shallow Aquifer System Map

Purposes. The general character of ground water in the immediate project area can be described with the Hydrogeology of the Shallow Aquifer System Map (Figure 17). A distinction between the shallow and deep aquifer systems is made because of confining conditions encountered at depth in the project area.

A hydrogeology map can be used to determine the presence of influent or effluent stream conditions. Generally, if the contours point upstream, effluent conditions exist; the opposite is true for an influent stream.

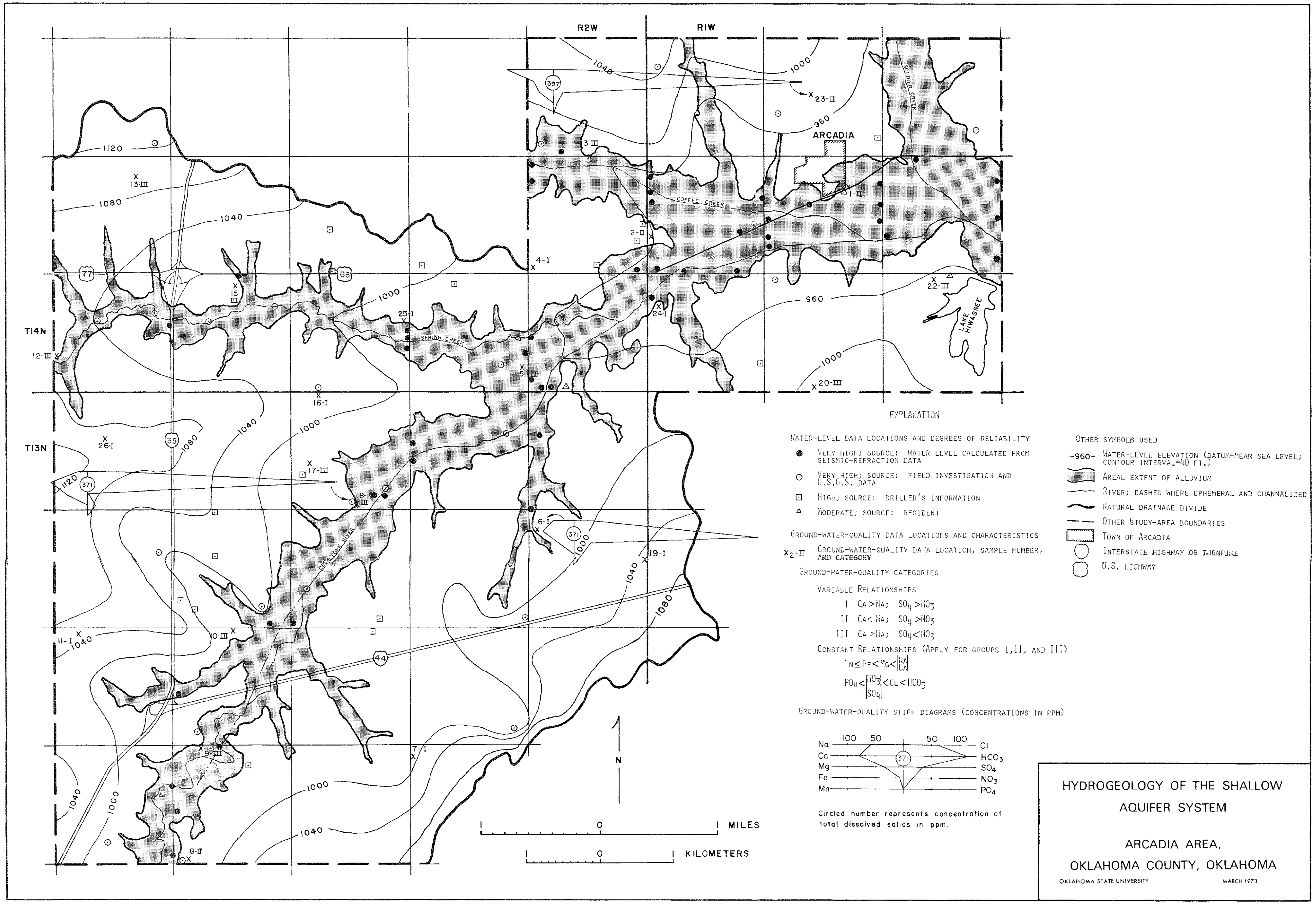

Figure 17. Hydrogeology of the Shallow Aquifer System Map

The shape of the contours suggest that ground water in the project area flows from the bedrock into the alluvium and finally into the Deep Fork River and its tributaries. This represents an effluent stream condition during normal flow periods.

The relative position of contour lines within the alluvium and bedrock suggests the presence of a hydraulic continuity between the bedrock and the alluvial deposits. A hydraulic continuity between two adjacent formations exists when the water bearing properties of the formations are similar. This aspect will be discussed later.

The hydrogeology map provides the basic data necessary for an estimate of the present ground-water reserves for domestic well supply. Also, by overlaying the hydrogeology map onto a topographic map, the general depth-to-water for any location in the project area can be determined.

Ground-water quality can also be displayed on the hydrogeology map. Determination of ground-water suitability for a particular use is a major goal for a water-quality analysis. Principle uses of ground water include: (1) domestic or household purposes; (2) agricultural purposes; and (3) industrial purposes. Although standards have been established for the general uses mentioned above, it should be noted that combinations and/or specialized uses may require substantially higher standards. The effect of the dissolved solids in ground water on pump mechanisms must also be considered.

A ground-water quality analysis is important to an environmental impact assessment because it represents base-line conditions before project construction. Predictions of future ground-water quality can be estimated based on surface water quality within the stream and future lake-water quality.

Methods. Preparation of the hydrogeology map of the project area began with a thorough survey of existing water-well records. Sources investigated included:

(1) U. S. G. S. Water Resources Division records;

(2) Oklahoma Geological Survey Publications;

(3) Oklahoma Water Resources Board data;

(4) City of Edmond water-well data; and

(5) Private drillers' records.

After compiling existing data, a first approximation map was constructed in order to delineate areas devoid of control. Field measurements in domestic wells using a Soil Test electronic water-level recorder supplemented existing records. Water levels were also calculated from data obtained from the refraction survey. These additional data were used to construct a second approximation map. Wells with a total depth greater than 250 ft. were deleted from the map because they were believed to be under confining conditions, and would therefore not represent the water-table aquifer characteristic of the shallow aquifer system.

Before contouring the second approximation of the hydrogeology map, the reliability of data points was considered (see Figure 17). Water levels determined from field measurements, U. S. G. S. data, and seismic-refraction calculations were assigned very high degrees of reliability. The local driller's contributions were relegated to a lower degree of reliability because his data was retained by memory and not recorded on paper. Water levels reported by residents were considered to be only moderately reliable.

Further characterization of the aquifer system included permeability tests and grain size analysis. Fifteen samples were collected from the alluvium in the project area and analyzed for permeability and grain size distribution. These samples were collected in 1.5 in. I. D. metal tubes. To prevent loss of moisture, the sample containers were wrapped in plastic "baggies" and sealed with masking tape.

The coefficient of permeability (K) of the samples was determined by the falling-head, constant-head, and flow-tube methods using the Soil Test Model K-670 Permeameter. To calculate permeabilities, a computer program was written by the author and modified by Lyle Silka (written communication, 1973). The program and results of permeability calculations are shown in Appendix A. Grain size distribution was determined with a visual accumulation tube. Results of grain size distribution analyses are shown in envelope form in Figure 18. The average permeability of the samples (alluvium) is 42.7 gpd/ft^2. Wood and Burton (1968) calculated the coefficient of permeability of the Garber Sandstone and Wellington Formation near Edmond to be 35 gpd/ft^2. The similarity in permeability value for the alluvium and bedrock substantiate the evidence for hydraulic continuity (also shown by contours) between bedrock and alluvium.

Analysis of ground-water quality was considered to be an essential segment of the hydrogeology map. Published ground-water quality data were examined. However, there was very little current ground-water quality data in the proposed project area. In order to supplement existing records, a field investigation involving the sampling of water wells was initiated. A random geographic distribution of sampled wells throughout the area was determined and followed.

First, three sampling bottles for each well to be tested were

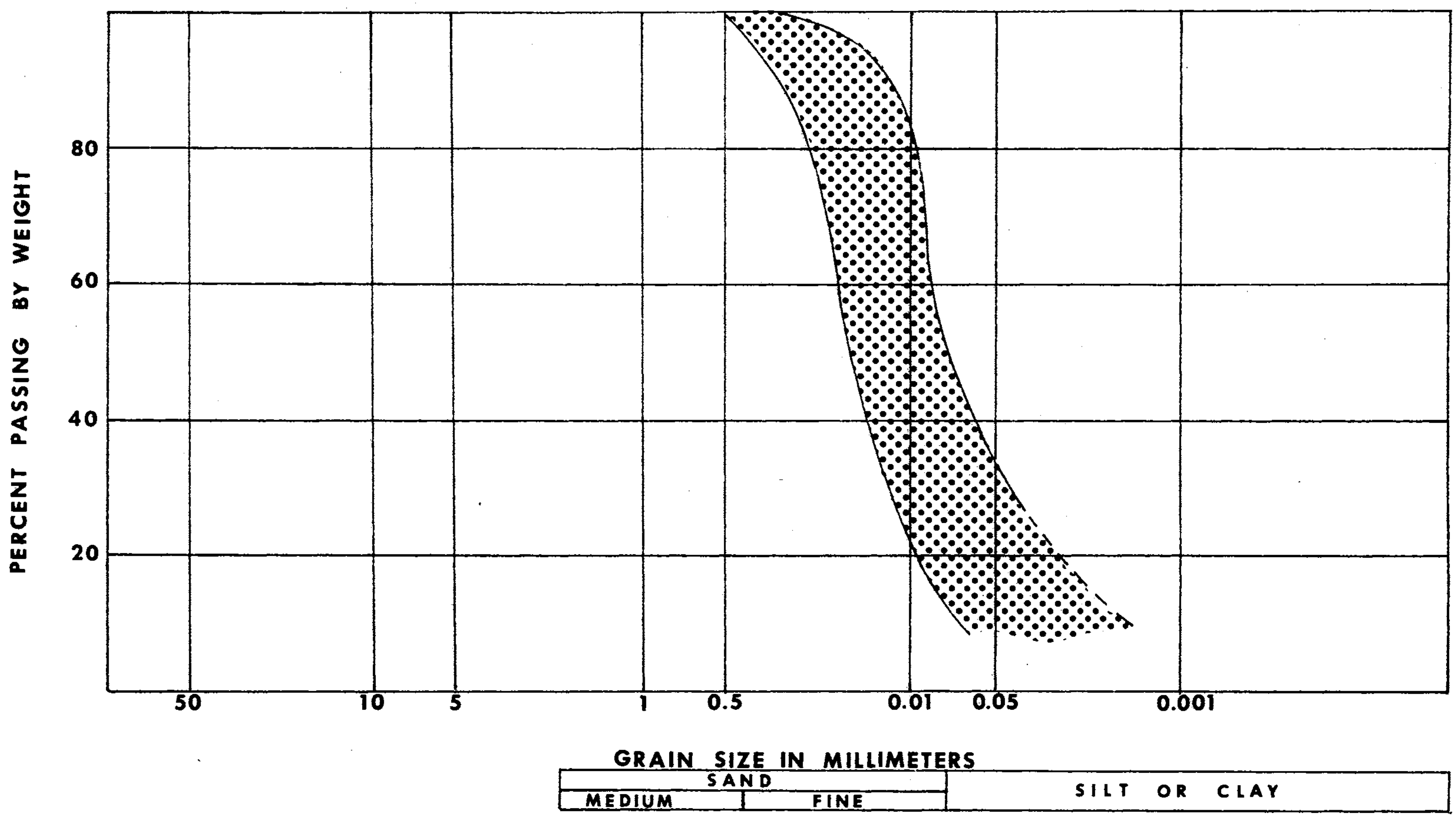

Figure 18. Grain-size distribution envelope for samples of Deep Fork River alluvium near Arcadia, Oklahoma

sterilized in the laboratory. The first bottle was treated with 2 ml of 2N HNO_3 which acted as a preservative for the testing of lead. The remaining two bottles for each location were not treated, although one was designated for refrigeration. After collection, water samples which were to be tested for nitrates, carbonates, bicarbonates, sulphates and phosphates were placed in coolers containing dry ice. The non-refrigerated samples were analyzed for calcium, magnesium, sodium, chloride, iron, and manganese. The following sampling procedures were strictly adhered to at each well:

(1) Well was allowed to run freely for approximately five minutes;

(2) Sample bottles were filled to the top (and run over) very slowly to prevent entrapment of air bubbles;

(3) Samples designated for refrigeration were immediately placed in coolers;

(4) pH was checked in the field with a Hach Model 17-H Phenol Red pH Tester.

Chemical analyses (exclusive of lead and field pH) were performed by the U. S. D. A. Soil and Water Service Analytical Laboratory at Oklahoma State University. Lead concentrations were determined by S. L. Burkes of the Zoology Department, Oklahoma State University. Methods and techniques of analysis are discussed in Appendix B. Results of analysis are listed in Table III.

Chemical analysis results can be displayed on a map by using Stiff diagrams (Stiff, 1951). Although a Stiff diagram was prepared for every well tested (see Appendix C), most diagrams were not included on the map in order to avoid cluttering.

TABLE III

GROUND-WATER QUALITY ANALYSIS OF THE PROJECT AREA
(Values in ppm)

Well Location	Depth of Well (Feet)	Geologic Formation at Total Depth	Date of Collection	Ca	Mg	Na	Cl	Fe	Pb	Mn	SO_4	CO_3	HCO_3	NO_3	PO_4	SAR	Field pH
#1, 14n, 1w, 29, aca	64	Permean Garber Sandstone and Wellington Formation	1/27/73	60.0	34.0	63.0	53.0	.1	0	0	18.0	0	427.0	6.6	.06	2.0	6.9
#2, 14n, 1w, 30, cbb	140		1/27/73	27.1	17.0	154.0	124.0	.1	0	0	28.0	0	403.0	7.5	.06	5.7	7.7
#3, 14n, 2w, 25, abb	87		1/27/73	60.5	40.0	47.7	36.0	.3	0	.22	0	0	543.0	<4.4	.06	1.2	7.1
#4, 14n, 2w, 25, ccc	200		1/27/73	55.0	33.0	27.7	71.0	.10	0	0	28.0	0	317.0	11.0	.06	.7	7.2
#5, 14n, 2w, 35, dda	160		1/27/73	32.0	31.0	112.0	53.0	0	0	.13	18.0	0	512.0	6.0	.38	3.4	7.4
#6, 13n, 2w, 12, bbc	(est)		1/27/73	54.0	28.0	36.3	36.0	0	0	.01	28.0	0	329.0	14	.06	1.0	7.0
#7, 13n, 2w, 23, bbb	46'		1/27/73	50.0	17.5	16.6	36.0	0	0	.01	28.0	0	250.0	15	.06	.5	7.0
#8, 13n, 2w, 28, bbb	90		1/27/73	2.3	1.0	205.0	71.0	0	0	0	34.0	0	500.0	4.4	.06	8.9	6.9
#9, 13n, 2w, 21, bba	51		1/27/73	62.5	31.0	10.0	53.0	0	0	0	0	0	360.0	4	.06	.2	6.9
#10, 13n, 2w, 16, baa	150		1/27/73	59.0	35.0	17.1	89.0	0	0	0	18.0	0	293.0	62.0	.58	.4	6.9
#11, 13n, 2w, 17, bba	128		1/27/73	64.5	36.0	9.4	18.0	0	0	0	18.0	0	415.0	8.0	.06	.2	6.9
#12, 14n, 2w, 32, cbc	160		1/27/73	112.0	52.0	49.0	142.0	.10	tr	0	78.0	0	329.0	286	.64	.9	6.6
#13, 14n, 2w, 29, abd	212		1/27/73	50.0	26.0	11.8	53.0	.2	0	0	28.0	0	250.0	35.0	.06	.3	6.9
#14, 14n, 2w, 22, ccc	100		1/27/73	44.0	23.0	8.8	36.0	.2	0	0	18.0	0	262.0	10	.06	.4	6.8
#15, 14n, 2w, 33, abb	90		1/27/73	61.5	31.0	14.2	36.0	0	0	0	0	0	403.0	7.0	.06	.4	7.0
#16, 13n, 2w, 3, bba	225		1/27/73	39.1	21.6	9.8	0	0	0	0	18.0	0	238.0	7.0	.06	.3	6.5
#17, 13n, 2w, 3, cbc	210		1/27/73	60.0	32.0	11.9	18.0	0	0	0	0	0	390.0	6.0	.06	.3	7.0
#18, 13n, 2w, 3, dcc	(est)		1/27/73	64.5	36.5	16.5	53.0	0	0	0	0	0	445.0	15.0	.06	.4	6.9
#19, 13n, 2w, 12, add	(est)		1/27/73	62.5	26.5	22.0	0	0	0	0	18.0	0	390.0	<4.4	.06	.6	7.0
#20, 13n, 1w, 5, abb	(est)		1/27/73	55.0	31.5	16.2	36.0	0	0	0	18.0	0	317.0	30.0	.06	.4	7.3
#22, 14n, 1w, 33, abb	100		1/27/73	51.5	34.5	17.7	53.0	0	0	0	0	0	329.0	4.4	.06	.5	7.2
#23, 14n, 1w, 20, bdd	123		1/27/73	36.5	24.0	83.0	53.0	.5	0	0	18.0	0	445.0	7.0	.06	2.6	7.1
#24, 14n, 2w, 31, bcb	94		1/27/73	57.5	36.0	40.5	71.0	0	0	.01	28.0	0	415.0	4.4	.06	1.0	7.2
#25, 14n, 2w, 34, add	40		1/27/73	49.0	23.5	19.0	18.0	0	0	0	18.0	0	305.0	15.0	.06	.5	7.2
#26, 13n, 2w, 5, bdd	(est)		1/27/73	66.5	36.5	23.4	71.0	0	0	0	28.0	0	342.0	18.0	.06	.6	6.6

Locations shown in map in Figure 17
Tr denotes Trace
Analyses Performed By O.S.U. Soils Lab.

Special categories describing the relationships of the anions and cations act as substitutes for Stiff diagrams. Three Stiff diagrams, however, are included on the map as representatives of the three major categories. Certain constant relationships among cation concentrations of all samples were noted: manganese was always less than or equal to iron; iron was always less than magnesium; and magnesium was always less than both sodium and calcium. Constant relationships were also present among the anions; phosphate was less than nitrate and sulphate; the latter two were less than chloride; and chloride was always less than bicarbonate.

The variable relationships among calcium and sodium and sulphate and nitrate provided the basis for distinction of the ground-water quality categories. Samples belonging to Group I have concentrations of calcium greater than sodium and sulphate greater than nitrate. Group II is categorized by concentrations of calcium less than sodium and sulphate greater than nitrate. Concentrations of calcium greater than sodium and sulphate less than nitrate describe Group III.

Problems. There was a lack of ground-water quality data for wells totally within the alluvium. Unfortunately, alluvial wells in the area have long since been abandoned in favor of higher-yielding deeper wells.

Slight chemical changes occurring during transport from the field to the laboratory, and errors in water quality analysis are inherent problems in a water-quality study. When used for comparative purposes, however, results of the chemical analyses are believed to be reliable and practical.

Detailed Current Land Use Map

Purposes. The Current Land Use Map (Figure 19) shows the distribution, amount, and type of present land use in an area. It serves as a reference for projection of future land use. Comparison with the Physical Properties Map can demonstrate the compatibility of present use with the physical capabilities of the land. Fisher et al. (1972) suggest that comparison with a map showing physical and biological environments will elucidate type, amount, and purpose of natural land utilization. They considered that this comparison can also be used to define those areas of future development where growth will least upset natural environments. Constraint maps, which will be discussed later, can be used to further isolate the compatibility of present and projected land uses with physical constraints related to physical soil and rock properties.

Another important purpose of the Current Land Use Map is to provide basic information which can be used to project future agricultural yields. The dollar values assigned to these yields are imperative for meaningful benefit/cost analyses. These analyses provide essential data used in the justification of appropriations for water-resources projects.

Methods. The Current Land Use Map appearing in Figure 19 was modified by John Pollack and Paul Bolsted, Oklahoma State University, after a map constructed by Eubanks and Carpenter (1971-72). U. S. Army Corps of Engineers air-photo mosaics (1969-71) were also used to modify the land-use map.

Specific land-use categories were assigned to each square-mile tract. Although one section might have more than one land use, the principle one was used to represent the entire section.

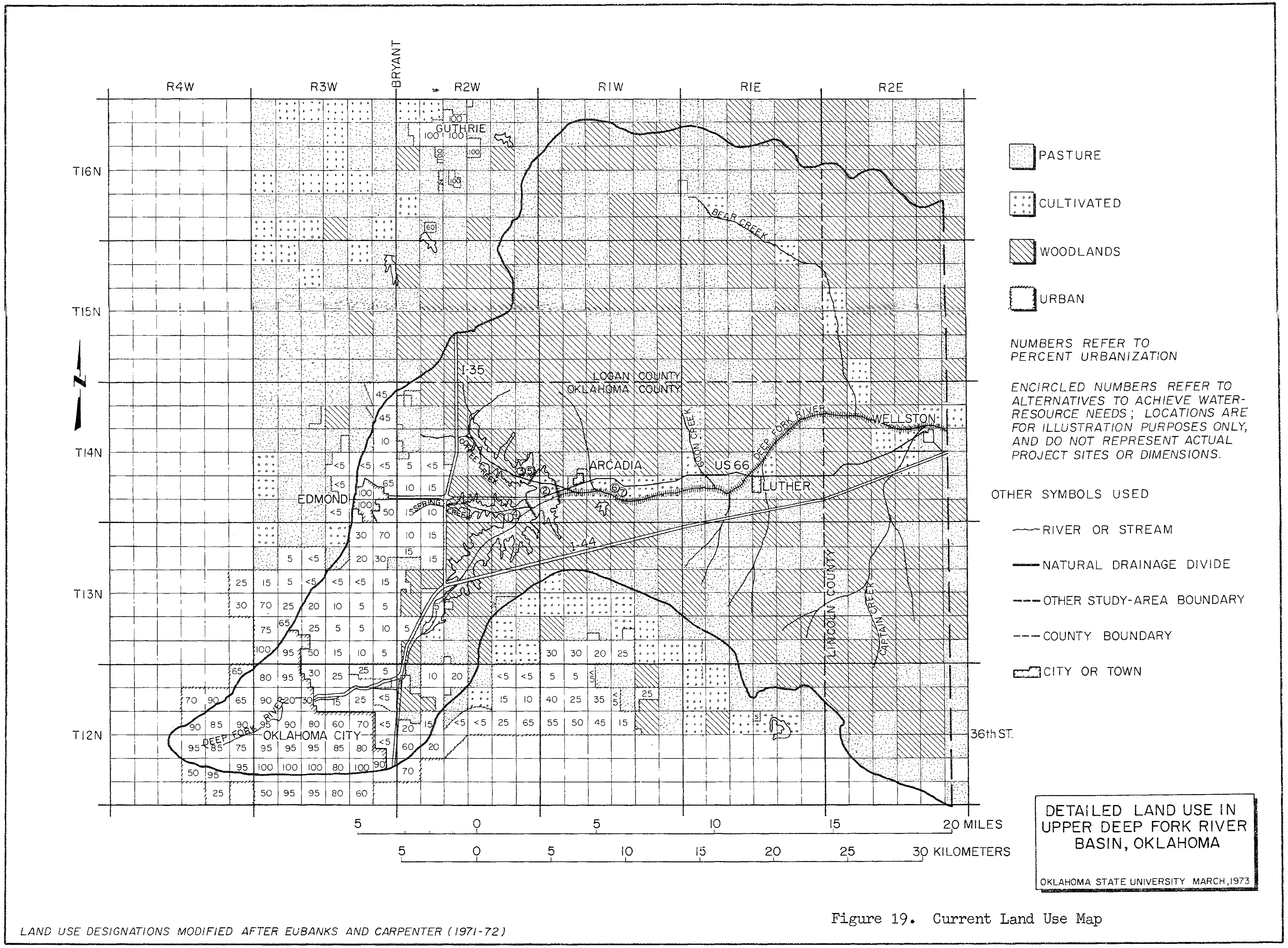

Figure 19. Current Land Use Map

The four major land-use categories delineated on the map are pasture lands, cultivated lands, woodlands, and urban areas. Pasture lands include those areas where forage plants are used for grazing practices. Cultivated land includes lands in tillage and rotation, orchards, and lands formerly in such uses. Woodlands represent lands which are either (a) stocked by at least 10% of forested land capable of producing timber (or other wood products), or capable of exerting an influence on the water regime; (b) or lands which have not been developed for other uses after trees have been removed; (c) or which are forested areas; (d) or are areas covered by dense thickets of shrubs. Urban areas include cities, villages, and built-up areas of more than ten acres; also included are industrial sites (exclusive of strip mines and borrow and gravel pits), railroad yards, airports, cemetaries, shooting ranges, golf courses, institutional and public administrative sites, and other similar areas. The numbers inside the urbanized areas on Figure 19 represent U. S. Census Bureau (1970 Tracts) estimates of the present percent of the total urbanization possible for that particular section.

Problems. A certain degree of accuracy is lost by mapping the principle land use in a section. However, the expediency and practical use of a current land-use map for regional socio-economic considerations in environmental assessment justify the general manner of data presentation.

Changes occurring after development of a land use map can also present potential problems. In rapidly developing areas, a period of six months is ample time for the occurrence of significant changes. A field survey immediately prior to publication can minimize discrepancies created by new development.

CHAPTER V

FEASIBILITY OF PROJECT AND ALTERNATIVES

Introduction

Before the final environmental impact statement is prepared for any project, feasibility of the originally proposed project and all viable alternatives must be evaluated. Information from the environmental inventory is helpful in the determination and location of alternatives to the proposed project (see Figure 5). The manner in which the evaluation of the physical factors and constraints can aid in determining the engineering and economic feasibility of each project and major alternative is then discussed. The socio-economic factors which may influence the selection of the project and alternatives are also discussed.

Alternative Selection

Pursuant to the NEPA document and the U. S. Army Corps of Engineers guidelines, viable alternatives to a proposed project must be presented. These alternatives must be considered because they may provide a "better" method for meeting the purposes of the originally proposed project. "Better", in this case, may refer to less adverse effect on the environment, or may reflect the least expensive method of meeting project purposes, or may include a combination of the two considerations.

Many alternatives are formulated throughout the planning process and are included in the design memorandum for the originally recommended project prior to environmental assessment. Other alternatives may be conceived during the preparation of the environmental inventory. A wide variety of alternatives is customarily suggested. Alternatives for water-resources projects may include proposing different sites (perhaps moving a dam further upstream or downstream), building a system of small upstream lakes, dry lakes, or construction of levees. No action, flood plain management, and ground-water development may also be considered. To meet the multiple purposes required of today's water-resource projects, different combinations of conjunctive use of one or more alternatives are also considered as separate alternatives. For example, development of a ground-water supply could supplement the water-supply objective for many of the other alternatives listed above. This would provide a generally high quality water for water supply in addition to meeting recreation, low-flow augmentation and flood control requirements.

All alternatives are considered on an equal basis with the originally proposed project. Information required about alternatives include hydrologic and hydraulic data, benefits and costs, description of general setting and purposes, and assessment of effects.

Physical Factors Affecting Project and Alternatives

The feasibility of a project or its alternatives may be governed by physical factors indigenous to the area. Therefore, the factor maps used in the environmental inventory serve as one basis for evaluating the feasibility. For example, an area showing active faulting may present problems to dam stability. Active erosional and depositional processes must also be considered. The magntidue of the effect of active processes will vary with the geographic setting of the proposed project. Certain coastline areas may be characterized by a variety of significant active processes. In other areas, these processes may be unimportant or non-existent.

Slope stability (or instability) may also affect the feasibility of a project or its alternative. Forms of mass-wasting such as the rock falls shown in Figures 20 and 21 may significantly affect dam abutments and other project features. The importance of understanding the engineering-geological aspects in a project area cannot be over-emphasized when evaluating the feasibility of the project and alternatives.

The basic data available in the maps described in the environmental inventory can be used to evaluate the project and alternative feasibility. Interpreting the basic data and relating the data to specific activities such as recreation, construction and solid-waste disposal can be helpful in determining physical constraints for these activities.

A set of Soil-Interpretative Land-Use Maps were also prepared for the purpose of providing factual data necessary for land-use planning and evaluation which is necessary in the socio-economic evaluation of project and alternative feasibility. These maps consider the physical aspects of soil properties, and, based on these properties, delineate uses incompatible with projected urbanization and industrialization. The constraint maps synthesize data obtained from the Soil Survey reports and can be used to indicate areas of severe and slight to moderate limitations for specific uses. Thus, the constraint maps are designed to serve as guides for not only the socio-economist but also for land-use planners, and to encourage or discourage development of certain areas.

The Soil Interpretative Constraint Maps presented in Figures 22, 23,

Figure 20. Rock fall along roadside near Arcadia, Oklahoma

Figure 21. Mass wasting along fractures in sandstone

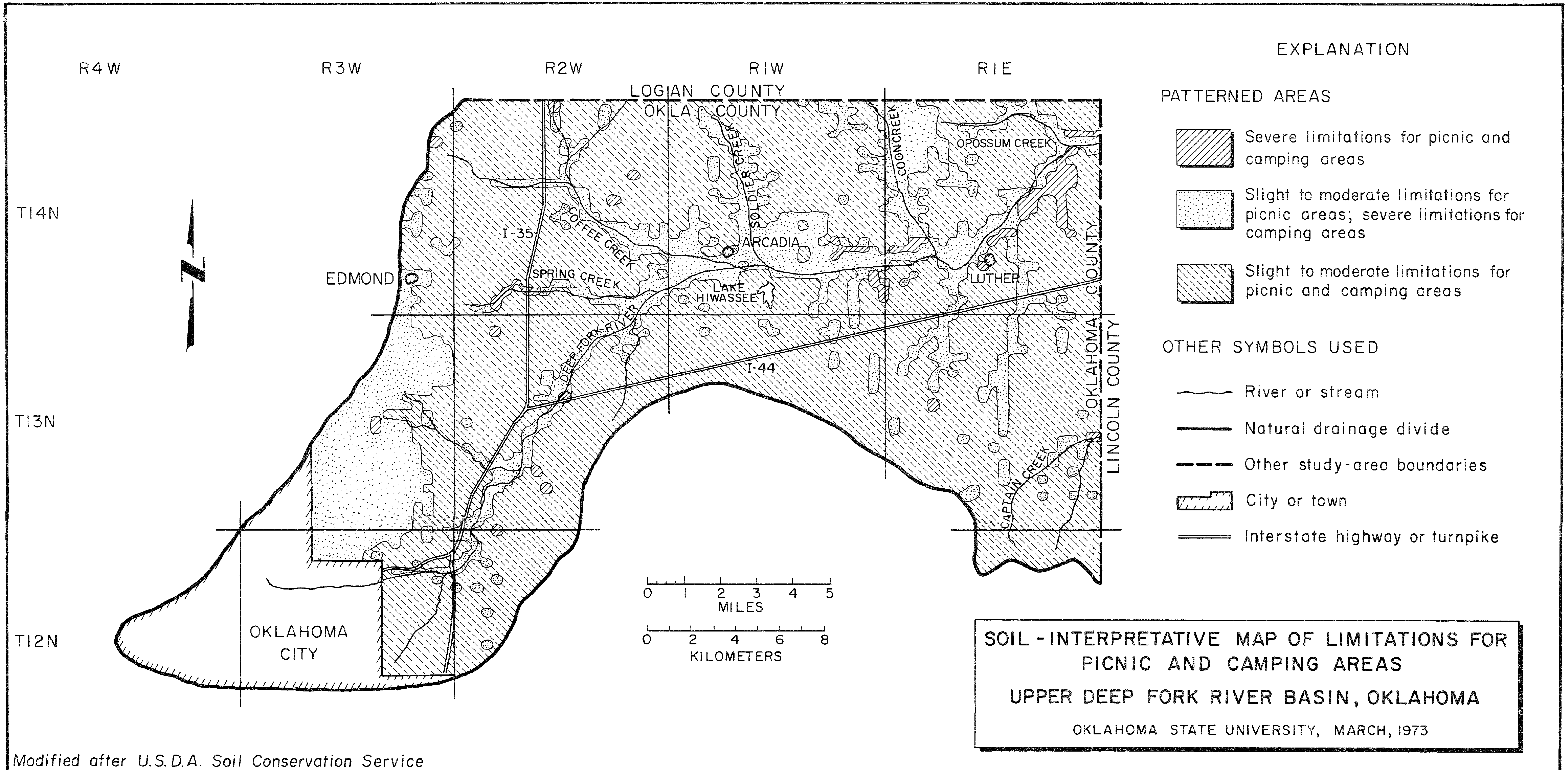

Figure 22. Soil Limitations for Picnic and Camping Areas

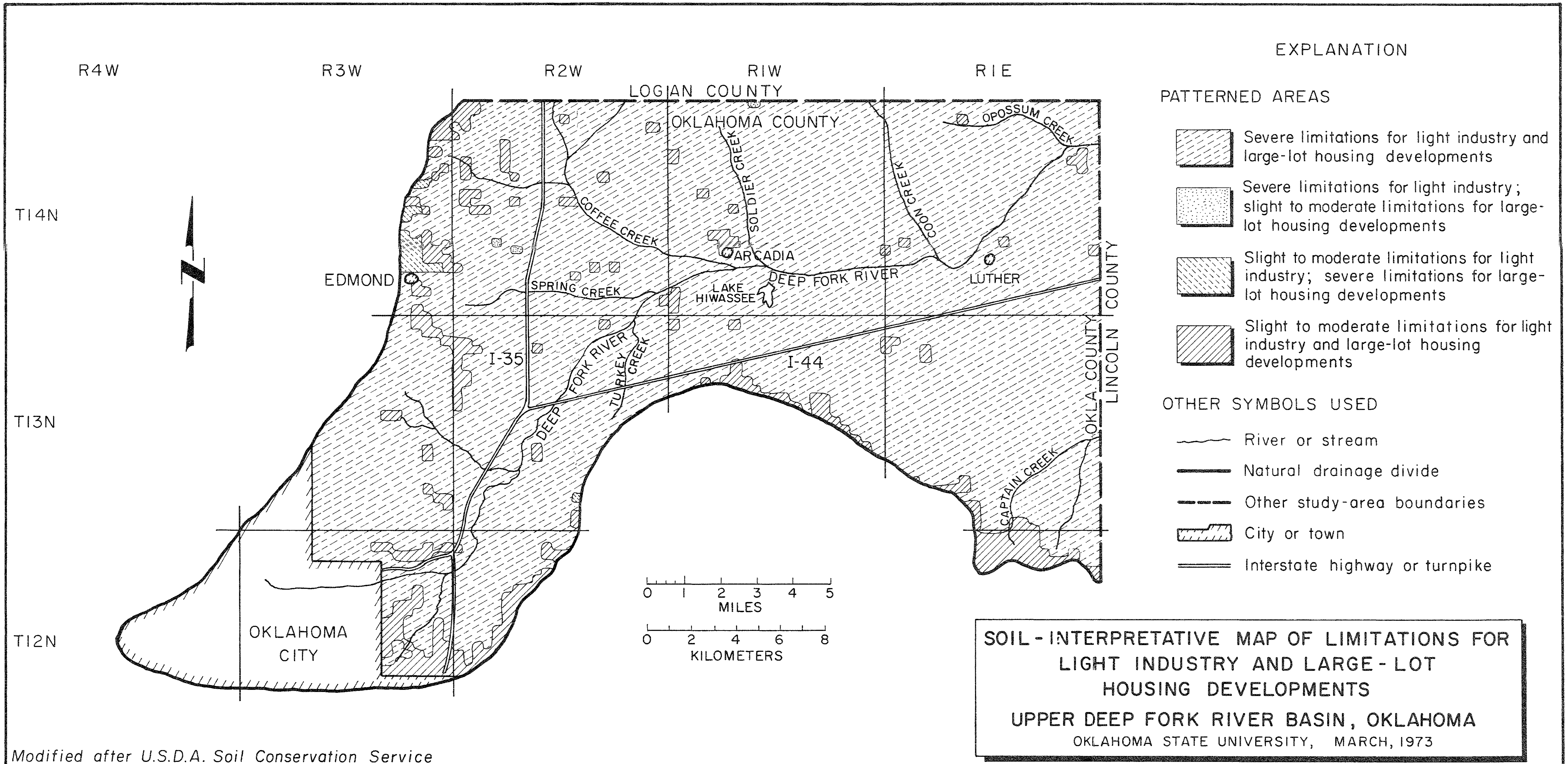

Figure 23. Soil limitations for light industry and large-lot housing developments

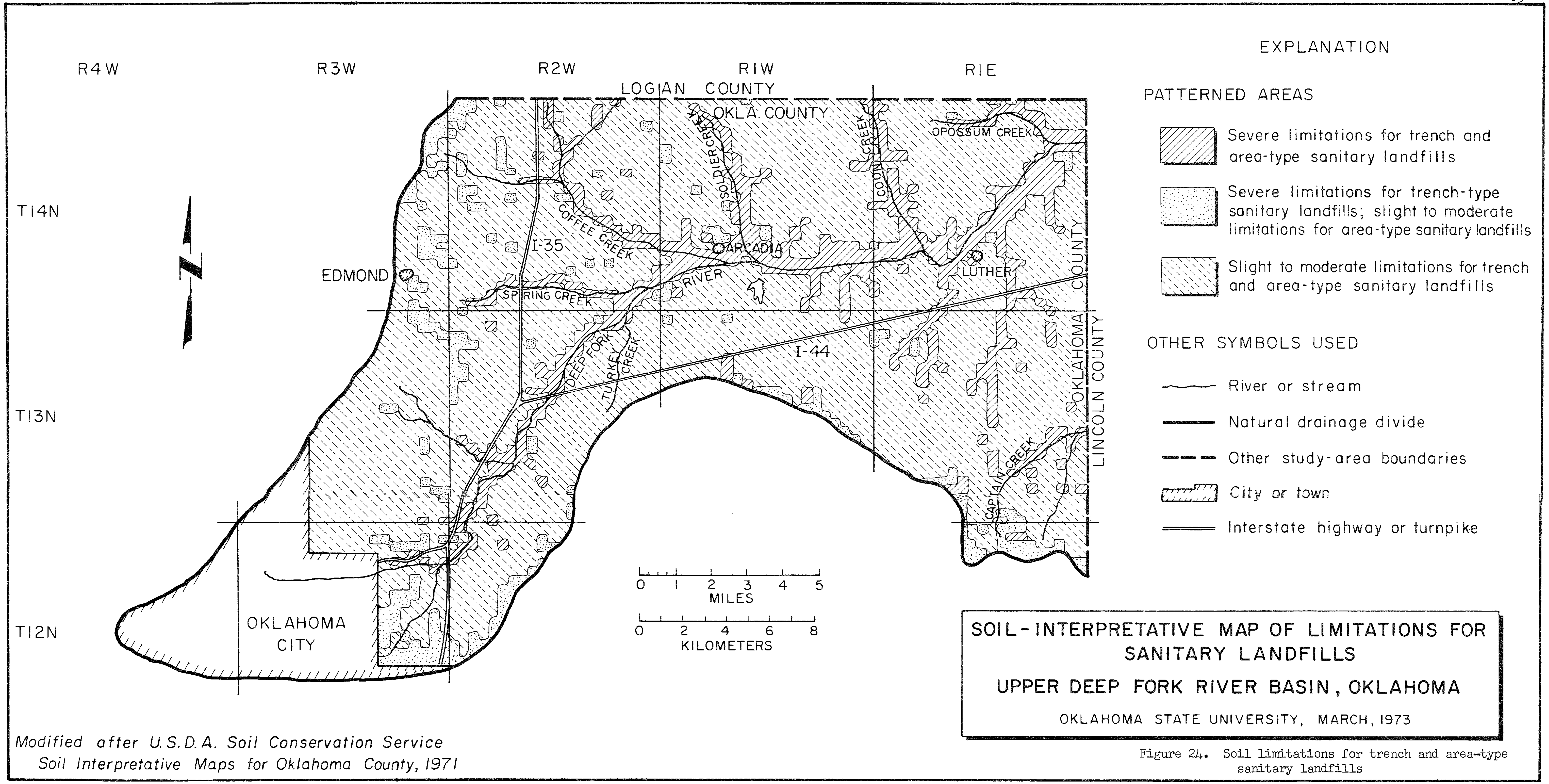

Figure 24. Soil limitations for trench and area-type sanitary landfills

and 24 serve as examples of three distinct types of land use. The activities of construction, solid-waste disposal and recreation are represented because of their diversity and because of their importance to mankind.

The Soil Interpretative Constraint Maps are combinations and modifications of U. S. D. A., Soil Conservation Service (SCS), computer print-out soil-interpretative maps of Oklahoma County, Oklahoma. As was the case with the Detailed Current Land-Use Map, the smallest unit delineated on the computer print-out map represents a forty-acre tract. The principle use of each forty-acre tract is indicated on the map.

The constraint map depicting limitations for recreation (Figure 22) was constructed from the SCS soil-interpretative maps for picnic and camping areas. The SCS maps representing limitations for light industry and large-lot housing developments were combined to produce the constraint map describing general construction (Figure 23). Limitations for trench and area-type sanitary landfills (Figure 24) were also derived from SCS computer print-outs.

The same procedure was followed in the construction of all three constraint maps. Severe limitations for one use (such as camping area) were contoured on matte acetate. Slight and moderate limitations were grouped into one category because severe limitations were considered the only degree of constraint which would change the course of a proposed action. Reasons for the SCS classifying limitations as severe, moderate, and slight are discussed in the Soil Conservation Service (1971).

The contoured areas representing limitations for one use were then overlain onto a computer print-out of limitations for another use. The resulting combinations using severe and slight-to-moderate limitations for each combination were grouped and shown on the final maps (Figures

22, 23, and 24). The inflexibility of using the artificial forty-acre tract represented on the SCS computer-fed print-outs does not permit a detailed study of soil limitations. Also, the variability of a soil's physical or engineering properties must be considered when classifying limitations. On-site investigations are essential before specific projects are initiated.

The terminology used to describe soil limitations may be misleading. As pointed out in the Soil Conservation Service (1971), the references to severe limitations can indicate that the problem caused by the physical constraint can often be overcome by financial expenditure. The cost of remedying the cause for a severe rating, however, cannot usually be justified. In cases where only one soil-property was the cause for an unfavorable rating, expenditures may be justified.

Human nature may also present problems for the use of soil-interpretative constraint maps. Many people are not required, nor are they even inclined, to heed advice presented on these maps. The preparation costs of constraint maps can only be justified when the facts presented are considered in the planning process.

Socio-Economic Factors Affecting Project and Alternatives

In addition to physical factors, the economic and social affects of project or alternative implementation (or non-implementation) must be considered during feasibility studies. Understandably, economics plays an important role when determining benefits and costs for a project and its alternatives. Each project has an economic life for which benefits and costs must be calculated. This economic life, which may last 100 years, may be a determining factor when evaluating project and alternative feasibility.

The social factors influencing project or alternative feasibility must also be considered. People, in addition to the physical and economic elements, are integrally involved in water-resources projects. Man conceives the project, man is affected by the project, and man dictates how the project will affect the environment.

Prediction of growth patterns directly affects project and alternative feasibility. By predicting population growth rates and patterns, future uses and demands placed on the project, alternatives, and the environment itself can be evaluated. The use of constraint maps in estimating future growth patterns has already been discussed (see Figure 5). A water-resources project depends upon whether or not these future uses and demands are satisifed. For example, estimating future water-supply needs can be used to indicate future-storage requirements of a proposed lake.

In addition to estimating future land use, predicitons of urbanization are used to calculate anticipated runoff values. If growth and population trends indicate an increase of urbanization from 20% to 40% over a project's economic life, the increased runoff due to urbanization can be incorporated into the project plans. Thus, social considerations are directly related to the evaluation of project and/or alternative feasibilities.

Sources of basic data responsible for economic considerations include the U. S. Census Bureau, numerous city and state planning reports, and other publications containing production figures. Presentation of social factors is more qualitative. Potential data sources (similar to economic contributors) include the U. S. Census Bureau and city planning reports. Appropriate personal questionnaires, when available, provide another data source. Studies of other areas affected by projects similar to the proposed project and/or alternative may also be useful. Maps showing the distributions of various social factors such as ethnic or income concentrations offer an effective method of data presentation.

CHAPTER VI

EFFECTS ASSESSMENT OF PROJECT AND ALTERNATIVES

Introduction

A discussion of the effects (impact) assessment of each project and viable alternative follows the evaluation of project and alternative feasibility. This is consistent with the intent of NEPA, the regulations of the Flood Control Act of 1970, and the U. S. Army Corps of Engineers Guidelines for environmental impact statement preparation. The results of the effects assessment are presented in matrix form (Figure 25), and can be assigned weighted values. These values are used to recommend the most favorable project or alternative and to prepare the final environmental impact statement.

Guidelines for Impact Assessment

The first aspect to consider in the Effects Assessment centers upon conditions expected without the project. This aspect is based on the information presented in the environmental inventory and provides pertinent data about future environmental conditions, needs, and problems of the proposed-project area without the project. These conditions are also incorporated into the "no action" alternative. The environmental factor maps (Figures 22, 23, and 24) are used to assess this aspect of the effects assessment (see Figure 5).

The significant effects caused by the proposed project and alternatives on the environment are identified by comparing project and alternative actions with the environmental aspects identified without the project or alternatives. Significant effects are those which would be likely to have a socio-economic impact on the decision-making process. Early identification of significant effects can allow adjustments in alternative project plans, and thus avoid or reduce identified adverse effects.

A discussion and display of all significant effects follows their identification. The effects are assessed qualitatively and designated as adverse or beneficial. This information is based on an understanding of the environmental factors requested in the environmental inventory. It is therefore imperative that the physical factor maps be used to determine as much as possible the cause and effect relationships which exist among all physical-environmental aspects. "Corps" guidelines require the display of significant effects in a manner that is easily understood, interpreted, and evaluated. Differences among the effects are to be made clearly visible.

Once adverse and beneficial effects have been described and displayed (see Figure 25), they must be quantitatively evaluated. Where applicable, values placed on effects are in monetary terms. Quantitative values are preferred, but, when not practical, qualitative terms will be accepted. A description of the criteria and assumptions used to evaluate significant effects in Figure 25 is included in Table IV.

Significant adverse effects are considered as a basis for project modifications. This process of "scoping" (modifying a project after identification of adverse effects) provides an opportunity to either eliminate the effect or reduce the effect to a level of magnitude which will place the project alternative in a more favorable level of acceptance.

Assessment "feedback" is sought by the Corps during the period of the environmental impact assessment process. Public hearings serve as a check to ensure that effects have not been overlooked. The response from the public, states, and other federal agencies can also be helpful in judging the adequacy of the environmental effects assessment.

Matrix Presentation

The use of a matrix is an ideal method of assessing environmental effects and is consistent with the ideas expressed in Leopold et al. (1971) and the Corps of Engineers Guidelines. In order to demonstrate the potential contributions of geology to an environmental impact statement, a matrix is proposed for a hypothetical water-resources project (Figure 25). The section presented includes only the physical and hydrological factors of the natural environment. Major categories comprising the environmental quality elements along the abscissa include natural elements (including physical and hydrologic factors), human social environments, and economic environment. The basic elements evaluated represent severe modifications (including additions and deletions) of the matrix proposed by Leopold et al. (1971). These modifications reflect adaptations tailored to water resource and the geographic location.

Beneficial, no effect, and adverse effects are assigned +, 0, and - values, respectively. Magnitude of the effect is described with a 1 to 5 rating system with five signifying the greatest effect. Values of 1, 3, and 5 are most generally used, but two and four are assigned when

ALTERNATIVE	VI. PHYSICAL AND HYDROLOGIC FACTORS A. LAND 1. MINERAL RESOURCES	2. CONSTRUCTION MATERIAL RESOURCES	3. UNIQUE PHYSICAL FEATURES	4. SOILS	B. SURFACE WATER 1. QUANTITY	2. QUALITY	C. GROUND WATER 1. QUANTITY	2. QUALITY	D. EARTH PROCESSES 1. FLOODS	2. EROSION a. UPSTREAM	b. DOWNSTREAM	3. SEDIMENT DEPOSITION a. UPSTREAM	b. DOWNSTREAM	4. SLOPE STABILITY a. UPSTREAM	b. DOWNSTREAM	5. PHYSIOGRAPHICAL CHANGES	6. COMPACTION AND SUBSIDENCE
	ENVIRONMENT QUALITY ELEMENTS — NATURAL RESOURCES																
PROJECT ELEMENTS																	
I. LAND ACQUISITION				A		+2 B		+1 C	D								
II. RELOCATION																	
A. UTILITIES AND PIPELINES																	
B. CEMETERIES																	
C. CULTURAL SITES																	
D. TRANSPORTATION																	
1. ROADS																	
2. HIGHWAYS																	
3. RAILS																	
E. BUILDINGS AND COMMUNITIES																	
III. ALTERATION OF REGIME																	
A. EXCAVATION, FILLING, DRILLING, AND DRAINAGE				-1 E						-1 F				G			
B. CONST. OF STRUCTURES																	
1. DAM	|—	—	—	—	—	— H —	—	—	—	—	—	—	—|	G	|—	H	—|
2. ACCESSESS	|—	—	—	—	—	— H —	—	—	—	—	—	—	—	—	—	—	—|
3. PROJECT HEADQUARTERS	|—	—	—	—	—	— H —	—	—	—	—	—	—	—	—	—	—	—|
4. LEVEES	|—	—	—	—	—	— H —	—	—	—	—	—	—	—	—	—	—	—|
5. RECREATION STRUCTURES	|—	—	—	—	—	— H —	—	—	—	—	—	—	—	—	—	—	—|
C. IMPOUNDMENT OF WATER	-1 J				+4 K	+3 M	+1 L	-1 N	O	+3 P	+5 Q	P	Q				
D. GROUND-WATER EXTRACTION																	
IV. OPERATION AND MAINT.																	
A. LIGHTS, MACHINERY																	
B. SOLID WASTES								-1 R									
C. PEST CONTROL (PLANT AND ANIMALS)						-1 S		-1 T									
D. WATER RELEASES AND SURFACE FLUCTUATION		-1 U		-1 V	+3 W				X	-2 Z	Y				-2 AA		
E. FERTILIZERS						-1 BB		-1 CC									
F. ACCESS MAINTENANCE																	
TOTAL																	

Figure 25. Sample matrix examining physical and hydrological factors

completeness of the data-base permits such a distinction.

A letter in the upper right-hand corner of each box refers to an explanation of the criteria or assumptions responsible for a beneficial or adverse rating. The reasons for assigning magnitude are also discussed. The assignment of magnitude to the physical and hydrologic factors in the matrix is based on the criteria and assumptions listed in Table IV. All the magnitudes and associated significance for a given environmental element are algebraically summed. The significance of each sum is reflected by weighting factors assigned to each environmental quality element by the Corps of Engineers. The sum of each environmental element is multiplied by the corresponding weighting factor. The resulting products are summed algebraically. This final summation is used to rank the proposed project and each alternative.

Impact Statement Epilogue

The draft project or alternative is recommended by the Corps of Engineers following the ranking process. The final draft Environmental Impact Statement pertaining only to the recommended project is then written. Pertinent elements of the environmental inventory, and the complete sections describing feasibility or project and effects assessment are included in the impact statement. Correspondence with other agencies and individuals is also enclosed.

The Environmental Impact Statement for the recommended project is presented to the Council on Environmental Quality. The statement is then reviewed by the Council for a period of thirty days. During this period no contract for construction of the recommended project can be let. If, within the thirty days, someone files an objection to the project, the

TABLE IV

CRITERIA AND ASSUMPTIONS USED IN MATRIX EVALUATION

Referral Letter	Criteria and Assumptions for Evaluation
A	Crop production potential is decreased, but effect is counted under the economic section. Potential data sources: Physical Properties and Detailed Current Land Use Maps.
B	A benefit to surface and ground-water quality is envisioned because of the removal of potential pollutant sources such as fertilizers, grazing (NO_3), and local solid waste disposal. Potential data source: Hydrogeology of the Shallow Aquifer System Map.
C	See B.
D	Removal of potentially damaged crops and farm facilities will create a beneficial effect, and is therefore counted under the economic section. Potential data source: Current Land Use Map.
E	Detrimental effect will result because of alteration of existing soil structures due to back-fill, removal, and compaction peripheral to impoundment. Potential data source: Physical Properties Map.
F	A detrimental effect will result because erosion and subsequent removal of topsoil will be increased by disturbance of soils. Potential data sources: Physical Properties and General Land Slope - "A" Horizon Permeability Maps.
G	Detrimental effect may occur near the dam site because of a potential landslide hazard due to the enhancement of fractures (caused by construction activities such as overloading, vibrating, and undercutting) in sandstones and overlying shales. This problem can be eliminated by using proper precautionary measures in construction practices. Potential data sources: Physical Properties Map and Field Investigations (see Figure 21).

TABLE IV (Continued)

Referral Letter	Criteria and Assumptions for Evaluation
H	Use of structures constructed will have a negligible effect because potential problems will be eliminated by employing standard precautionary measures during construction at the dam site.
I	Ground-water extraction will have a negligible effect on ground-water quantity because of the small area involved. Potential data sources: Groundwater Availability and Hydrogeology of the Shallow Aquifer System Maps.
J	Detrimental effect will result because impoundment will prohibit development of petroleum reserves. Magnitude is slight because of the limited extent of resources in the immediate project area. There will be a negligible effect on sand and gravel deposits within the impounded area because of the limited extent of extractable sand and gravel deposits. Potential data sources: Economic Resources and Physical Geology Maps.
K,L	Beneficial effect will result because of an increase in storage. Potential data source: Hydrogeology of the Shallow Aquifer System Map.
M	A beneficial effect on surface water quality will result in the upper part of the reservoir because of dilution and associated sedimentation and precipitation of dissolved solids toward the bottom of the reservoir.
N	A slight adverse effect on the ground-water quality will result because of percolation and infiltration in the lower part of the reservoir. Effect is judged to be slight because of dilution with good quality ground-water. Potential data source: Hydrogeology of Shallow Aquifer System Map.
O	A decrease in downstream flood potential may be considered as a beneficial effect because of the decrease in the amount of erosion. Therefore this effect is counted under "downstream erosion" (Q). Potential data sources: Land Use and Soil Associations Maps.

TABLE IV (Continued)

Referral Letter	Criteria and Assumptions for Evaluation
P	Raising local base level (due to impounded water) will have a beneficial effect by reducing upstream erosion. The rate of sediment deposition will corresponding increase and is therefore not counted as a separate effect. Potential data source: General Land Slope - "A" Horizon Permeability Map.
Q	Although the potential of downstream erosion is increased by decreasing the sediment load, this effect is offset by the reduction of flood-induced extensive erosion. The rate of sediment deposition will be negligible and is therefore not counted as a separate effect.
R	Only a slight adverse effect is expected because percolation and infiltration are primarily limited to the peripheral zone around the impounded water. Potential data source: Constraint Map for Area and Trench-type Sanitary Landfills.
S	A slight negative effect will result from surface runoff containing pesticides. Slight because of limited areal extent. Potential data sources: Current Land Use and General Soil Associations Maps.
T	A slight adverse effect is expected due to infiltration of pesticide-rich waters. Slight because of limited areal extent of lands under pest-control programs. Potential data sources: General Land Slope - "A" Horizon Permeability and Physical Properties Maps.
U	Water release and surface fluctuations will have a minor detrimental effect on construction material resources downstream because the supply of sand for sand and gravel quarrying operation downstream may be reduced. This reduction will be caused by sand settling to the bottom of the reservoir. Potential data source: The Natural Physical Economic Resources Map.

TABLE IV (Continued)

Referral Letter	Criteria and Assumptions for Evaluation
V	A detrimental effect will result because the alternative wetting and drying events cause destruction of soil structure and erosion. Effect is slight because only soils peripheral to the reservoir are affected. Potential data sources: General Soils Association and Physical Properties Maps.
W	A moderate beneficial effect on downstream surface-water quantity will result because of regulated gate releases and subsequent low-flow augmentation.
X	Already discussed in O.
Y	Already discussed in Q.
Z	Temporary lowering of base levels caused by surface fluctuations may have an adverse effect on upstream erosion. Effect is slight because areal extent affected is slight and because soil properties in this area are not conducive to extensive erosion. Potential data source: Physical Properties Map.
AA	A detrimental effect on slope stability (and enhancement of rock slides adjacent to impoundment) may result from fluctuating water levels with subsequent wetting and drying of fractured sandstones overlying shales on bluffs. Mechanical weathering, fracturing, and overloading by saturation may be enhanced by this process. Potential data source: General Land Slope - "A" Horizon Permeability Map.
BB	Surface runoff containing fertilizers will have a slight detrimental effect on surface water quality. Effect is slight because of limited areal extent of fertilized land.
CC	Percolation of fertilizer-rich water will have a slight adverse effect. Slight rating is due to the small quantity contributed. Potential data sources: General Land Slope - "A" Horizon Permeability and Ground-water Availability Maps.

Corps is granted thirty additional days for a rebuttal and preparation of the revised Environmental Impact Statement. If, in the opinion of the Council on Environmental Quality, the objections raised were answered, the project is recommended to Congress. Then barring court injunction, and if Congress approves funds for the project, the project is referred to the Office of Management and Budget for funds allocation and project implementation.

CHAPTER VII

SUMMARY AND CONCLUSIONS

Following a discussion of the history and theory of environmental impact statements, a conceptual approach is introduced in which a series of factor maps are used to present conditions for the environmental inventory to select viable alternatives, to evaluate project and alternative feasibility, and to decide upon effects assessment. A sample matrix is used to present the results of an impact assessment for the physical and hydrological factors of a hypothetical project (see Figure 5). The following maps were prepared:

(1) Physical Geology;

(2) General Soil Associations;

(3) Ground-water Availability;

(4) Natural Physical Economic Resources;

(5) General Land Slope - "A" Horizon Permeability;

(6) Physical Soil Properties;

(7) Distribution of Alluvial Thickness;

(8) Hydrogeology of the Shallow Aquifer System;

(9) Detailed Current Land Use; and

(10) Soil-interpretative Constraints.

Factor maps used in the environmental inventory feasibility, and effects assessment provide a more quantitative means of preparing the environmental assessment. Preparation of the basic factor maps includes selection, compilation and interpretation of basic data. In addition to constructing maps, the role of a geologist in the selection of the elements discussed in the physical and hydrological factors section of the matrix is demonstrated.

The approach presented is not intended to be an absolute, inflexible panacea. Consideration, emphasis, and magnitude of physical and hydrologic factors as well as other parameters will vary with the geographic location and type of the proposed water-resource project. Additions and deletions will be common. The general concept, however, of using maps and geologic skills to supplement an interdisciplinary team effort preparing an environmental impact statement can be very successful.

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APPENDIX A

COMPUTER OUTPUT AND RESULTS OF PERMEABILITY ANALYSIS OF ALLUVIAL SAMPLES

```
$JOB ****************,TIME#30,PAGES#75,KP#26    CASE, LEE
C-----J# SAMPLE NUMBER
C-----HR# WATER HEIGHT IN TANK FOR REVERSE FALLING HEAD
C-----HC# WATER HEIGHT IN TANK FOR CONSTANT HEAD
C-----TR# TIME FOR REVERSE FALLING HEAD
C-----TC# TIME FOR CONSTANT HEAD
C-----M# TEMPERATURE CODE%1#16 DC, 2#17 DC, 3#18 DC, 4#19 DC, 5#20 DC,
C-----6#21 DC, 7#22 DC, 8#23 DC, 9#24 DC, 10#25 DC<
C-----WD# SATURATED WEIGHT AFTER DRAINING FOR SPECIFIC YIELD
C-----WOD# OVEN DRIED WEIGHT
C-----LK# LENGTH OF SPECIMEN FOR PERMEABILITY TEST
C-----LS# LENGTH OF SPECIMEN FOR SPECIFIC YIELD TEST
C-----Q# AMOUNT MEASURED FOR WATER FLOW IN CONSTANT HEAD TEST
C-----PSI# PRESSURE USED IN THREE TESTS
C-----BALL# BALL READING FOR FLOW TUBE
C-----ITEMP# TEMPERATURE CODE%1#20
C-----ITEMP# TEMPERATURE CODE%1#20 DC, 2#21 DC, 3#22 DC, 4#23 DC,
C-----5#24 DC, BELOW 20 DEG. C#1, ABOVE 24 DEG. C#5<
C-----IFTUBE# FLOW TUBE NUMBER %1,2,3<
C-----VISC# VISCOSITY
C-----GPD# FACTOR THAT CONVERTS DARCIES TO GALLONS/DAY/FOOT
C     SQUARED
C-----CMSQ# FACTOR THAT CONVERTS DARCIES TO CM/SEC
C-----CORR# CORRECTED INTRINSIC PERMEABILITY
C-----PGPD# PERMEABILITY IN GALL/DAY/FOOT SQUARED
C-----PCMSEC# PERMEABILITY IN CM/SEC
C-----AVGP# AVERAGE PERMEABILITY
      REAL LK,LS
      WRITE(6,4)
       WRITE(6,8)
    4 FORMAT(1H1,@ ID   REV HD--K   REV HD--K   FAL HD--K   FAL HD--K
     2  AVG--K      AVG--K      YIELD     YIELD     POROS     POROS     FLOW
     3TB--K@<
    8 FORMAT(1H ,@ NO     GPD 16C   DARCY 16C    GPD 16C   DARCY 16C
     4  GPD 16C    DARCY 16C    NO CORR     CORR   NO CORR     CORR         G
     7PD@/
     51X,@------------------------------------------------------------
     6--------------------------------------------------------@<
      A=(3.142/4.0)*2.8*2.8
      LINES=0
   10 READ(5,2)J,HR,HC,TR,TC,M,WD,WOD,LK,LS,Q,PSI,BALL,ITEMP,IFTUBE
    2 FORMAT(I3,2F4.1,2F5.1,I2,5F4.1,2F6.2,I3,I2<
      IF(J)9999,20,9999
 9999 GO TO (1,13,14,15,16,17,18,19,9,21),M
    1 V=111.11
      GO TO 93
   13 V=108.88
      GO TO 93
   14 V=105.59
      GO TO 93
   15 V=102.99
      GO TO 93
   16 V=100.5
      GO TO 93
   17 V=98.1
      GO TO 93
   18 V=95.79
      GO TO 93
   19 V=93.58
      GO TO 93
```

```
    9 V=91.4
      GO TO 93
   21 V=89.37
   93 VS=A*LS
      IF(VS) 6,5,6
    6 SPY=WD/0.998/VS
      WCO=WOD/0.998/VS
      ESPY=((WD/0.98)+(5.05-LS)*A)/(5.05*A)
      EWCO=((WOD/0.98)+(5.05-LS)*A)/(5.05*A)
      APSI=PSI*70.54
      HI=APSI+HR-32.8+LK/2.0
      HO=APSI+HR-24.8+LK/2.0
      IF(TR) 11,5,11
   11 RKT=(0.869*LK*ALOG10(HO/HI))/(A*TR)
      RK24=RKT*V/91.4
      RK24G=RK24*21200.0
      RK16G=RK24G*0.82
      H=APSI+HC-56.8+LK/2.0
      IF(TC) 7,5,7
    7 CKT=(Q*LK)/(A*H*TC)
      CK24=CKT*V/91.4
      CK24G=CK24*21200.0
      CK16G=CK24G*0.82
      RKD=RK16G/18.8
      CKD=CK16G/18.8
      AVEGPD=(RK16G+CK16G)/2.0
      AVED=(RKD+CKD)/2.0
      GO TO 1112
    5 WRITE(6,1111)J
 1111 FORMAT (1H0@SAMPLE NUMBER@,I3,@ LOST DURING LAB TESTING.@<
      GO TO 10
 1112 MEDIUM=1
      RAD=1.4
      IFTUBE=3
      N=1
      XLEN=LK
      IF(MEDIUM-1)30,60,30
   30 CONTINUE
  150 GO TO (155,160,165),IFTUBE
  155 CALL WCC1(BALL,N,QB)
      GO TO 350
  160 CALL WCC2(BALL,N,QB)
      GO TO 350
  165 CALL WCC3(BALL,N,QB)
  350 P2=1.0
  360 CONTINUE
  375 PDAR=0.0
      PM=0.0
      Q=0.0
      P1=1.0+(PSI+0.061)/14.7
      Q=((QB*0.0167)*P2)/(3.14*(RAD*RAD))
      PDIFF=P1*P1-P2*P2
      PDAR=(Q/PDIFF)*2.0*XLEN*VISC
      PMEAN=(P1+P2)/2.0
      PM=1.0/PMEAN
      PGPD=PDAR*18.8
      AVEGPD=(RK16G+CK16G+PGPD)/3.0
      AVED=(RKD+CKD+PDAR)/3.0
      WRITE(6,3)J,RK16G,RKD,CK16G,CKD,AVEGPD,AVED,SPY,ESPY,WCO,EWCO,PGPD
    3 FORMAT (1H0I3,6%2XE10.3<,4%4XF5.3<,3XE10.3<
```

```
      LINES=LINES+1
      IF(LINES.EQ.25) GO TO 99
   80 CONTINUE
      GO TO 10
   99 WRITE(6,43)
      WRITE(6,8)
   43 FORMAT (127H1SAMPLE--K  REVERSE--K  REVERSE--K  FALLING--K  FALLIN
     6G--K  AVERAGE--K  AVERAGE---YIELD-----YIELD---POROSITY--POROSITY--
     6-K  GPD<
      LINES=0
      GO TO 80
   60 GO TO  (62,64,66,68,70),ITEMP
   62 VISC=1.002
      GPD=20.75
      CMSQ=99300.
      GO TO 150
   64 VISC=0.9779
      GPD=21.25
      CMSQ=104100.
      GO TO 150
   66 VISC=0.9548
      GPD=21.75
      CMSQ=104100.
      GO TO 150
   68 VISC=0.9325
      GPD=22.25
      CMSQ=106600.
      GO TO 150
   70 VISC=0.9111
      GPD=22.75
      CMSQ=109000.
      GO TO 150
   20 CONTINUE
      WRITE(6,53)
   53 FORMAT(1H1<
      STOP
      END

      SUBROUTINE WCC3(BALL,N,QB)
      IF(BALL-4.4)24,24,20
   20 IF(BALL-12.4)26,26,22
   22 IF(BALL-26.5)28,28,30
   24 SLOPE=0.88
      XINTER=1.12
      GO TO 32
   26 SLOPE=1.87
      XINTER=-3.25
      GO TO 32
   28 SLOPE=2.84
      XINTER=-15.18
      GO TO 32
   30 SLOPE=3.43
      XINTER=-30.91
   32 QB=0.0
      QB=SLOPE*BALL+XINTER
      RETURN
      END

      SUBROUTINE WCC2(BALL,N,QB)
      IF(BALL-5.9)46,46,40
```

```
   40 IF(BALL-10.5)48,48,42
   42 IF(BALL-14.6)50,50,44
   44 IF(BALL-23.0)52,52,54
   46 SLOPE=0.12
      XINTER=0.28
      GO TO 56
   48 SLOPE=0.22
      XINTER=-0.28
      GO TO 56
   50 SLOPE=0.24
      XINTER=-0.56
      GO TO 56
   52 SLOPE=0.36
      XINTER=-2.21
      GO TO 56
   54 SLOPE=0.50
      XINTER=-5.72
   56 QB=0.0
      QB=SLOPE*BALL+XINTER
      RETURN
      END

      SUBROUTINE WCC1(BALL,N,QB)
      IF(BALL-13.0)70,70,60
   60 IF(BALL-19.0)72,72,62
   62 IF(BALL-26.5)74,74,64
   64 IF(BALL-30.0)76,76,66
   66 IF(BALL-45.7)78,78,68
   68 IF(BALL-58.0)80,80,82
   70 SLOPE=0.02
      XINTER=-0.08
      GO TO 84
   72 SLOPE=0.02
      XINTER=-0.12
      GO TO 84
   74 SLOPE=0.03
      XINTER=-0.13
      GO TO 84
   76 SLOPE=0.06
      XINTER=-1.11
      GO TO 84
   78 SLOPE=0.05
      XINTER=-1.04
      GO TO 84
   80 SLOPE=0.07
      XINTER=-2.04
      GO TO 84
   82 SLOPE=0.09
      XINTER=-3.29
   84 QB=0.0
      QB=SLOPE*BALL+XINTER
      RETURN
      END

$ENTRY
```

ID NO	REV HD--K GPD 16C	REV HD--K DARCY 16C	FAL HD--K GPD 16C	FAL HD--K DARCY 16C	AVG--K GPD 16C	AVG--K DARCY 16C	YIELD NO CORR	YIELD CORR	POROS NO CORR	POROS CORR	FLOW TB--K GPD
11	0.357E 02	0.190E 01	0.368E 02	0.196E 01	0.300E 02	0.160E 01	0.003	0.073	0.398	0.447	0.177E 02
12	0.195E 02	0.104E 01	0.193E 02	0.103E 01	0.180E 02	0.956E 00	0.003	0.053	0.454	0.489	0.151E 02
13	0.176E 02	0.938E 00	0.173E 02	0.922E 00	0.162E 02	0.859E 00	0.022	0.129	0.419	0.490	0.135E 02
21	0.351E 02	0.187E 01	0.301E 02	0.160E 01	0.327E 02	0.174E 01	0.022	0.129	0.416	0.486	0.330E 02
22	0.396E 02	0.211E 01	0.330E 02	0.175E 01	0.362E 02	0.193E 01	0.020	0.069	0.420	0.456	0.361E 02
23	0.740E 02	0.393E 01	0.568E 02	0.302E 01	0.614E 02	0.327E 01	0.010	0.079	0.429	0.476	0.535E 02
31	0.278E 02	0.148E 01	0.255E 02	0.136E 01	0.241E 02	0.128E 01	0.025	0.112	0.432	0.489	0.189E 02
32	0.371E 02	0.197E 01	0.282E 02	0.150E 01	0.316E 02	0.168E 01	0.017	0.261	0.420	0.569	0.296E 02
33	0.398E 02	0.212E 01	0.415E 02	0.221E 01	0.407E 02	0.217E 01	0.028	0.096	0.436	0.483	0.409E 02
41	0.670E 02	0.356E 01	0.658E 02	0.350E 01	0.621E 02	0.331E 01	0.014	0.102	0.393	0.453	0.536E 02
42	0.560E 02	0.298E 01	0.603E 02	0.321E 01	0.552E 02	0.294E 01	0.008	0.175	0.380	0.490	0.493E 02
43	0.867E 02	0.461E 01	0.775E 02	0.412E 01	0.772E 02	0.411E 01	0.012	0.218	0.415	0.543	0.675E 02
51	0.851E 02	0.453E 01	0.809E 02	0.431E 01	0.779E 02	0.414E 01	0.010	0.059	0.383	0.420	0.677E 02
52	0.601E 01	0.320E 00	0.471E 01	0.251E 00	0.511E 01	0.272E 00	0.017	0.086	0.454	0.499	0.460E 01
53	0.540E 02	0.287E 01	0.564E 02	0.300E 01	0.522E 02	0.278E 01	0.014	0.102	0.446	0.503	0.462E 02

APPENDIX B

METHODS AND TECHNIQUES OF WATER QUALITY ANALYSIS

Preparation

All water samples were filtered through Whatman #2 filter paper.

Sodium, Calcium, Magnesium, Manganese, Iron

The above were analyzed with a Perkin-Elmer Model 403 atomic adsorption unit. Analytical methods described in the Perkin-Elmer Handbook (1971) were followed.

Lead

Lead analyses were performed with a heated graphite furnace accessory on the atomic adsorption spectrophotometer (Perkin-Elmer HGA-70) because the concentration of lead in the water was below detection levels of conventional flame methods. A hydrogen continuum lamp was used to correct for adsorption by organic background in the samples.

Chloride, Carbonate, Bicarbonate

Chloride, carbonate, and bicarbonate were determined using the titrimetric methods and procedures listed in Agricultural Handbook No. 60 (U. S. Salinity Lab, 1954).

Nitrate

The nitrate was analyzed by using the Orion Meter with a Nitrate Ion Electrode.

Sulphate

Sulphate was analyzed by a turbidimetric procedure using barium chloride and a Bausch and Lomb (Spec 20) spectrophotometer.

Phosphate

Phosphate was determined by the colorimetric procedure outlined by Watanabe and Olsen (1965).

pH Determination

pH was tested colorimetrically in the field using a Hach Model 17-H Phenol Red pH Tester.

Sodium Adsorption Ratio

The following formula,

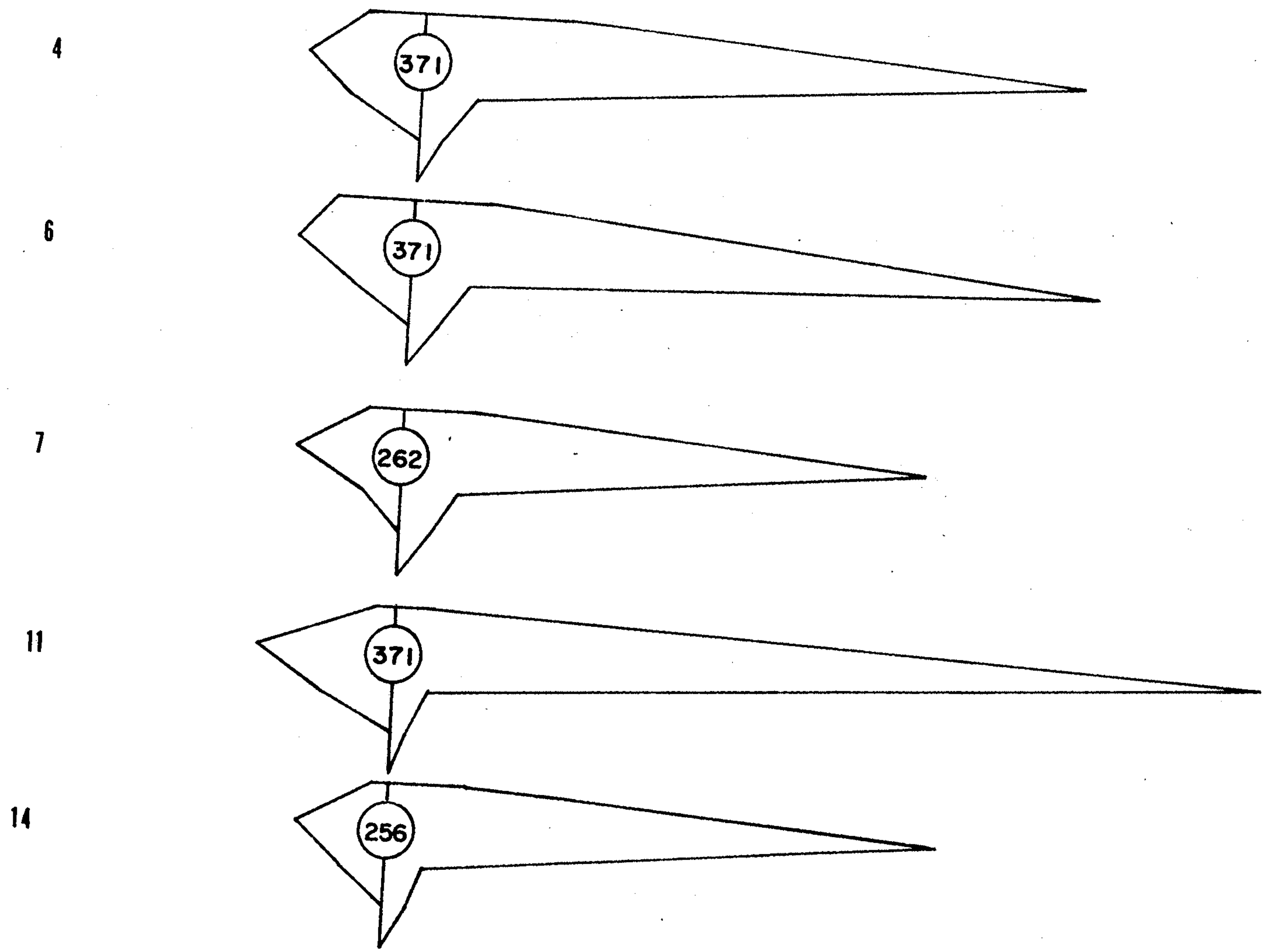
$$SAR = \frac{Na^{+}}{\sqrt{\frac{(Ca^{++} + Mg^{++})}{2}}}$$

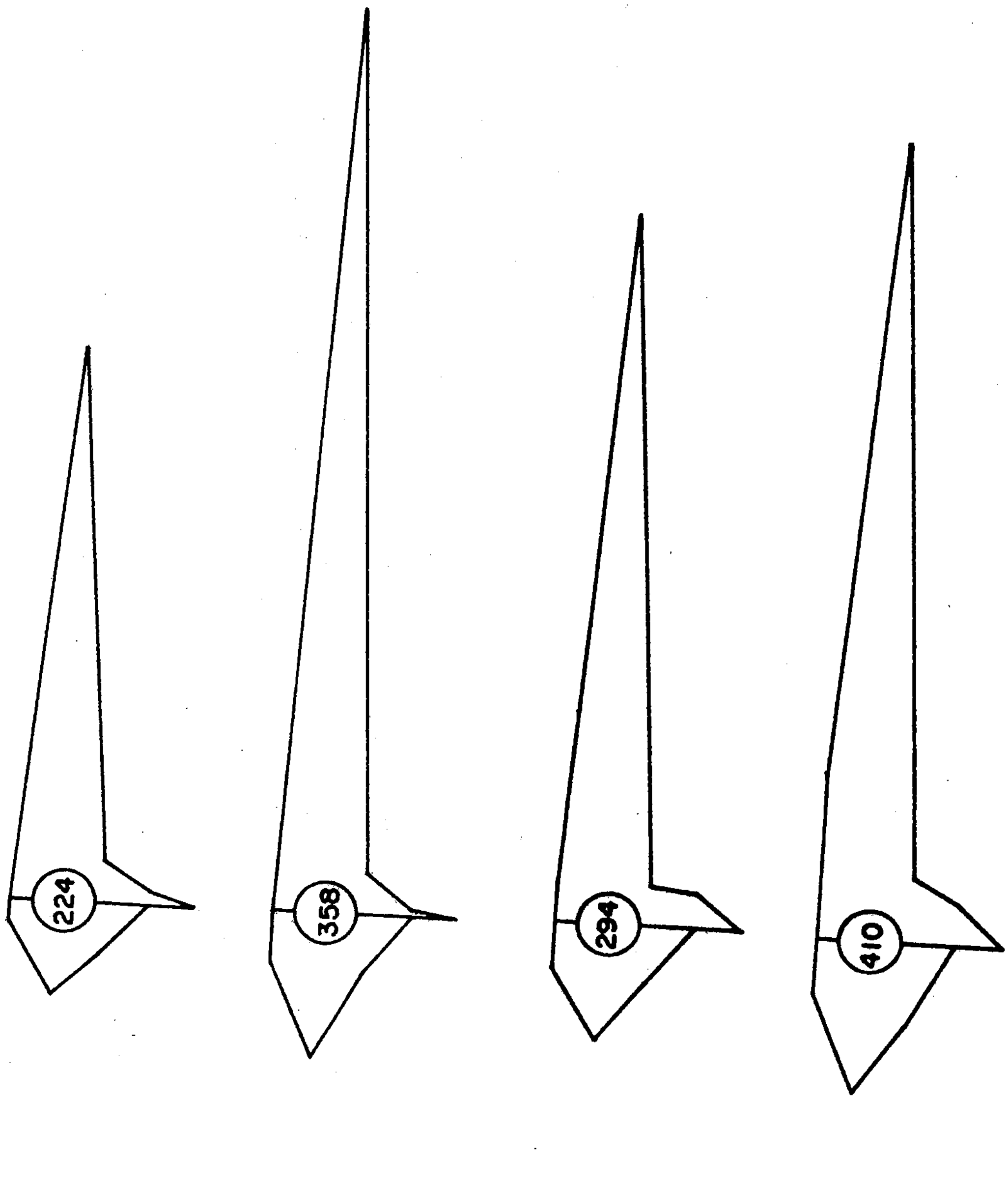
where Na^{+}, Ca^{++}, and Mg^{++} represent concentrations in milliequivalents per liter is from Agricultural Handbook No. 60 (U. S. Salinity Lab, 1954).

APPENDIX C

STIFF DIAGRAMS AT THE GROUND-WATER QUALITY LOCATIONS

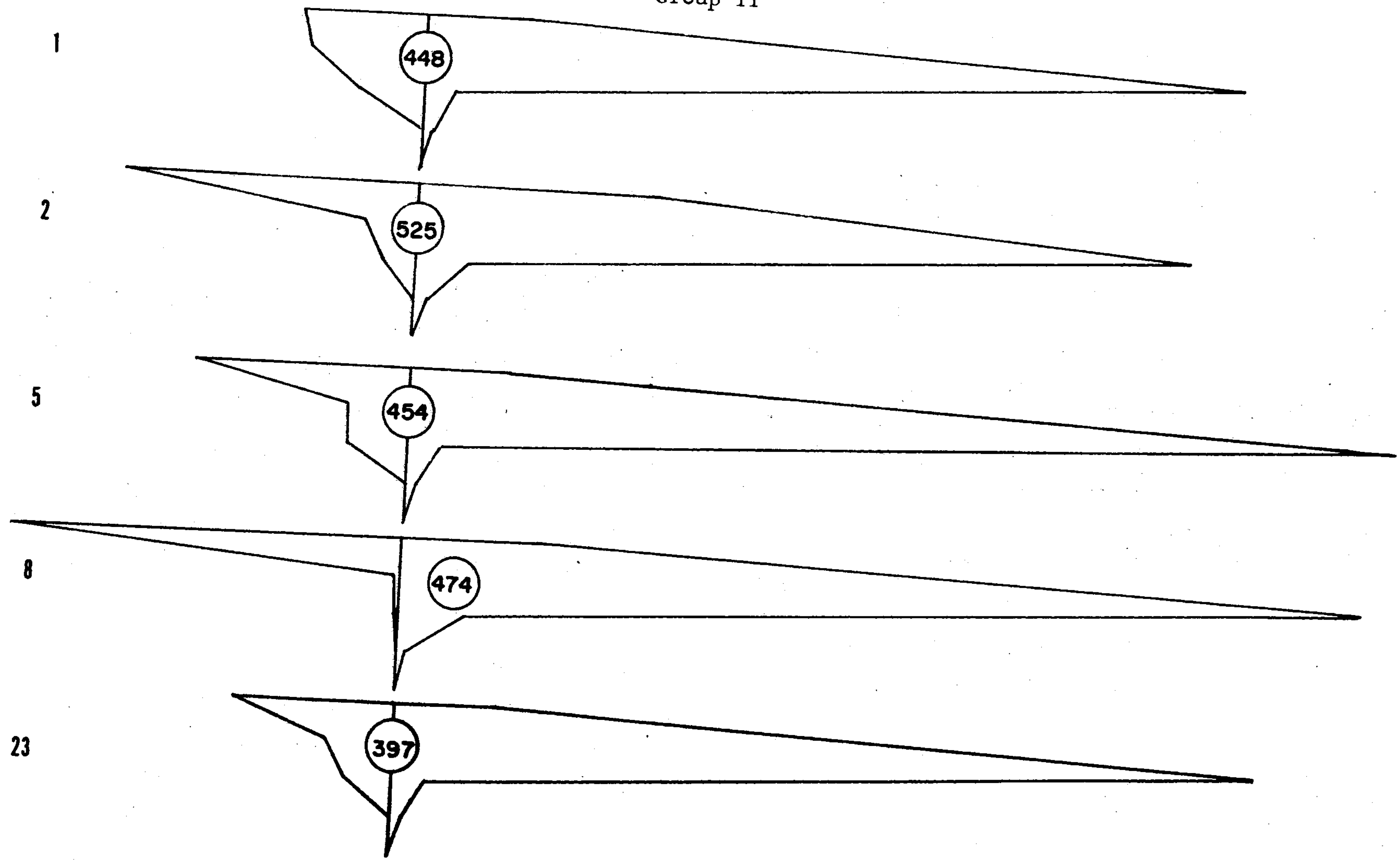
Group I

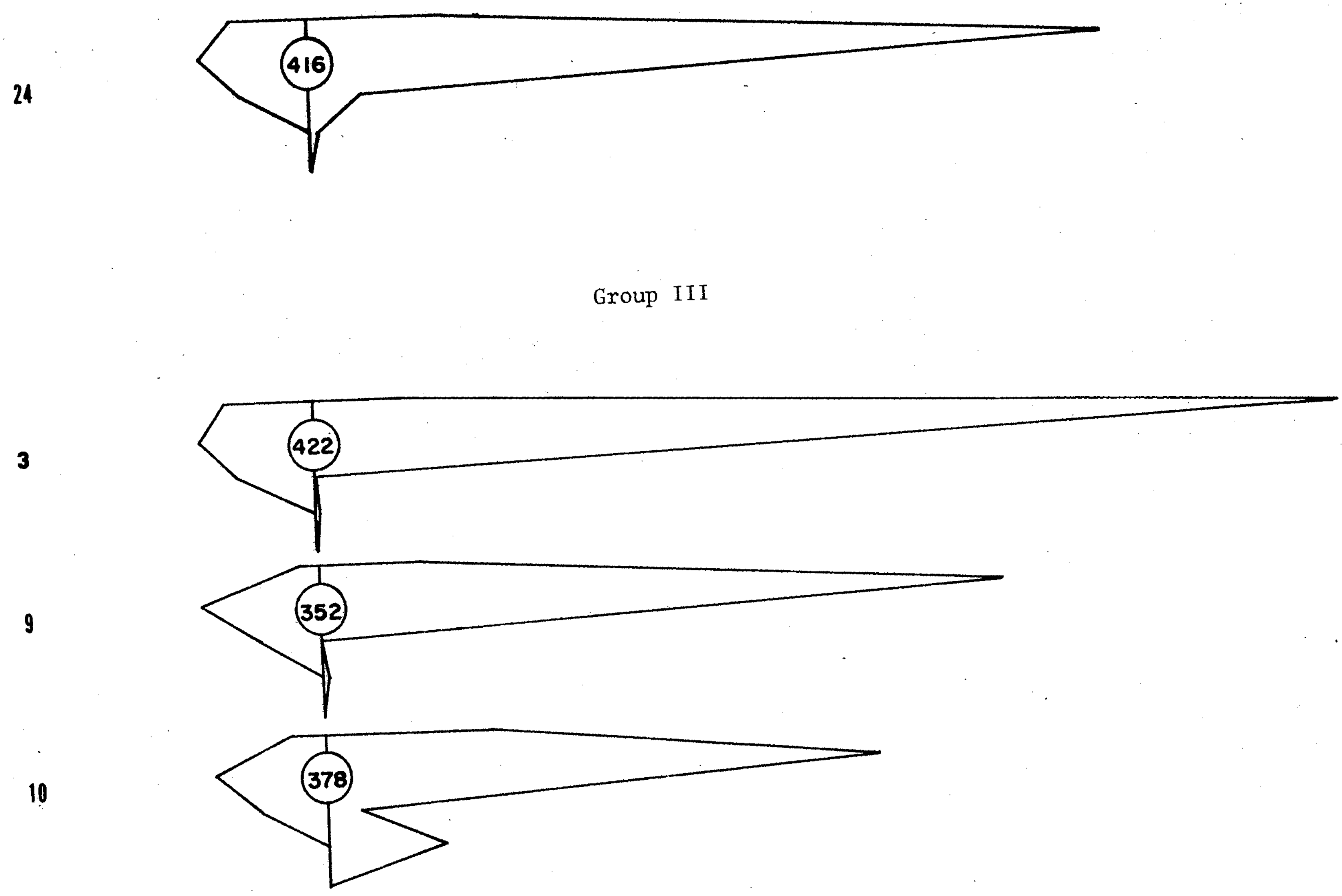


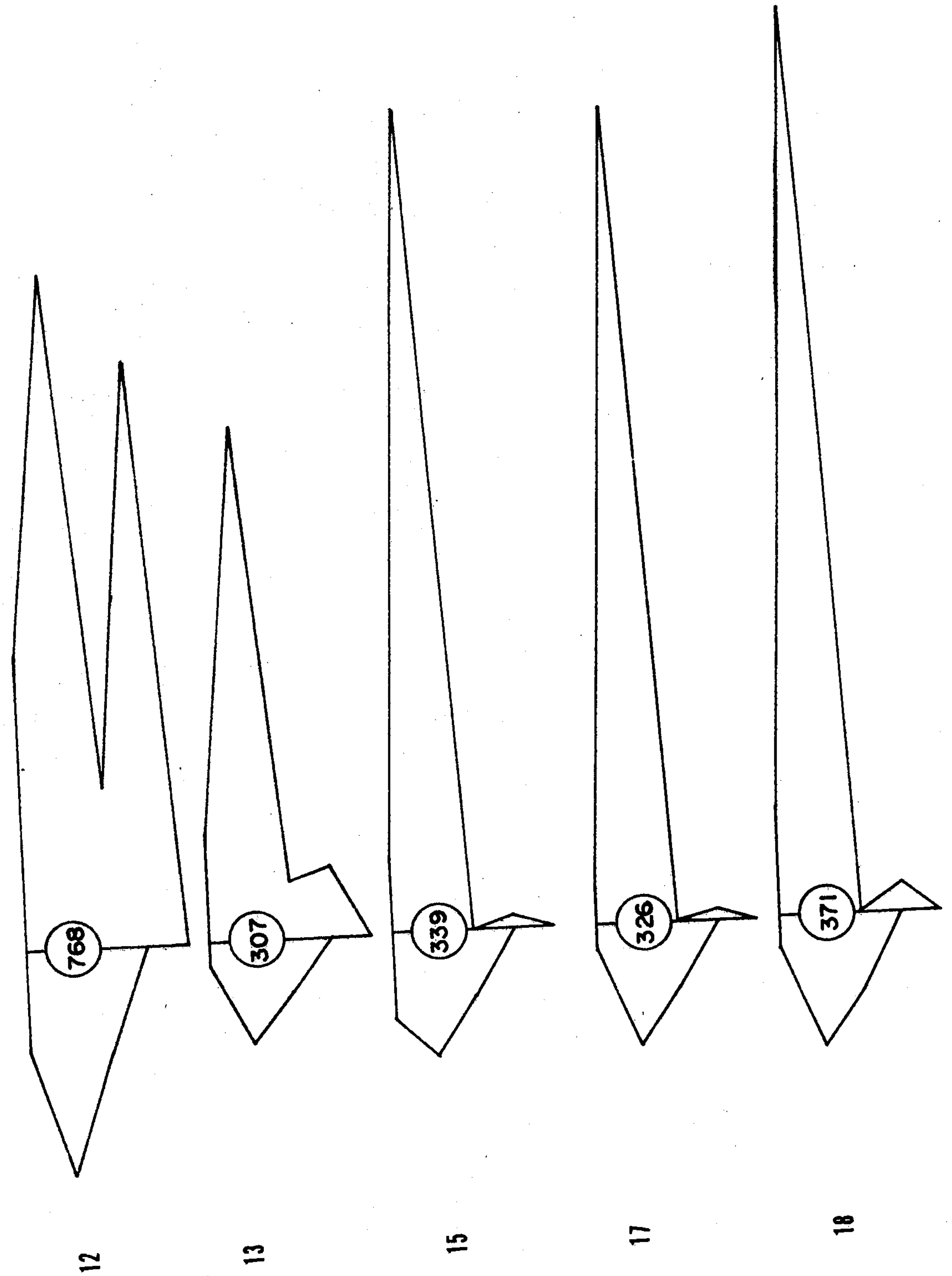


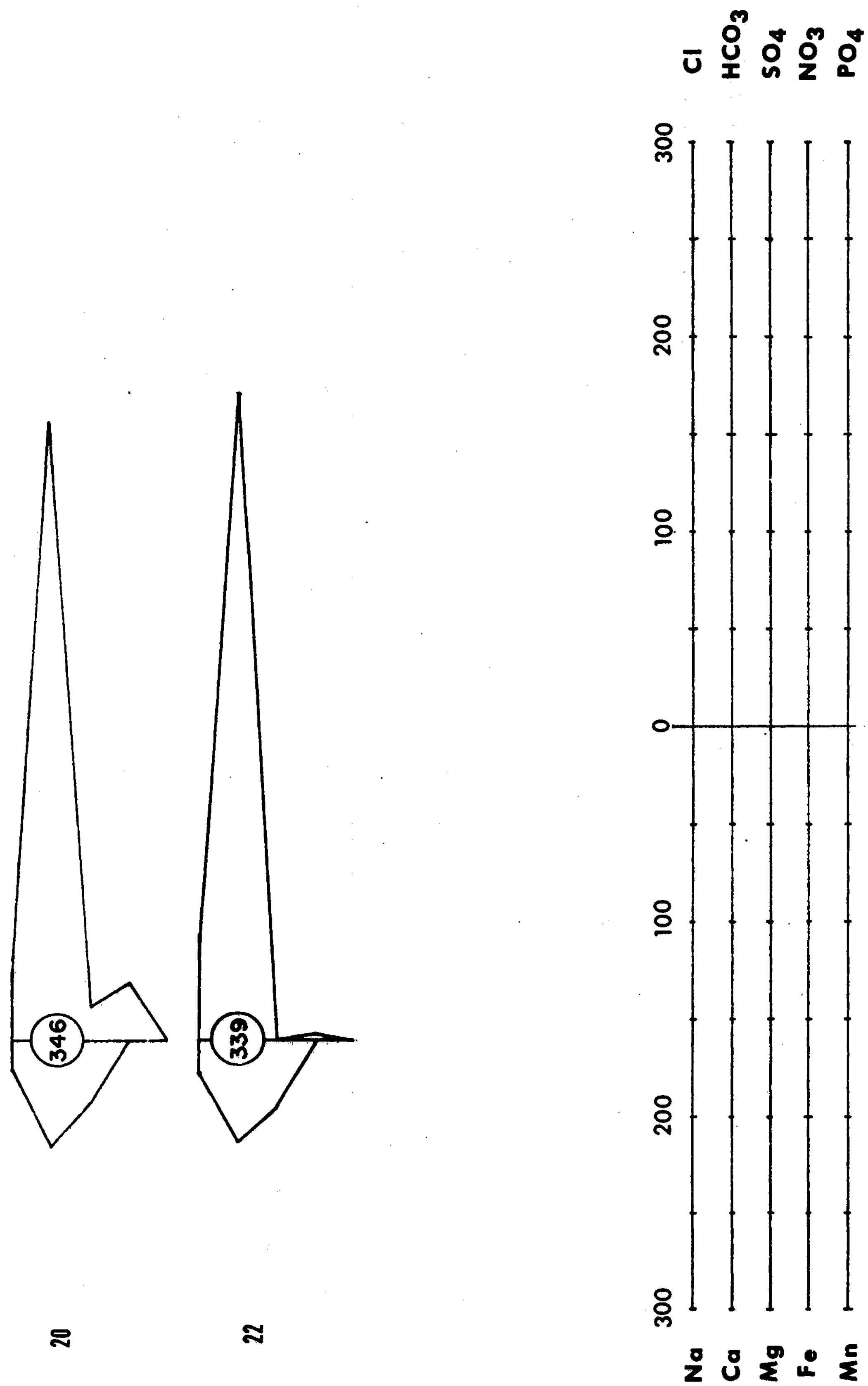
16 19 25 26

Group II




24
416
Group III
3
422
9
352
10
378


768
307
339
326
371
12
13
15
17
18



346
339
20
22
Na
Ca
Mg
Fe
Mn
Cl
HCO_3
SO_4
NO_3
PO_4
300
200
100
0
100
200
300

VITA

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Master of Science

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