The Maryland Power Plant Siting Project: An Application of the ORNL-Land Use Screening Procedure

Jerome E. Dobson

MASTER

Prepared for the U.S. Nuclear Regulatory Commission
Office of Standards Development
Under Interagency Agreement 40-543-75

OAK RIDGE NATIONAL LABORATORY

OPERATED BY UNION CARBIDE CORPORATION FOR THE ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

BLANK PAGE

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
Price: Printed Copy \$5.50; Microfiche \$3.00

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the Energy Research and Development Administration, United States Nuclear Regulatory Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.

Contract No. W-7405-eng-26

ENERGY DIVISION

THE MARYLAND POWER PLANT SITING PROJECT:
AN APPLICATION OF THE ORNL-LAND USE SCREENING PROCEDURE

Jerome E. Dobson

Manuscript Completed: October 3, 1976

Date Published: April 1977

Prepared for the
U.S. Nuclear Regulatory Commission
Office of Standards Development
Under Interagency Agreement 40-543-75

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

MASTER

MARYLAND POWER PLANT SITING PROJECT REPORTS

Title	Author(s)	Document ORNL/NUREG/TM-	Date
<i>The Maryland Power Plant Siting Project: An Application of the ORNL Land Use Screening Procedure</i>	J. E. Dobson	79	1977
<i>A Cell-Based Land Use Screening Procedure for Regional Siting Analysis</i>	J. S. Jalbert J. E. Dobson	80	1977
<i>Power Plant Siting: An Application of the Nominal Group Process Technique</i>	A. H. Voelker	81	1977
<i>A System for Regional Analysis of Water Availability</i>	J. S. Jalbert A. D. Shepherd	82	1977

CONTENTS

	<u>Page</u>
LIST OF FIGURES	vi
LIST OF TABLES	ix
ABSTRACT	xi
ACKNOWLEDGMENTS	xiii
 1. INTRODUCTION	 1
1.1 The Problem of Energy Facility Siting	1
1.1.1 National scale	3
1.1.2 Regional scale	3
1.1.3 Local scale	4
1.1.4 Site-specific analyses	4
1.2 Research Objectives	5
1.3 Background	6
1.3.1 Maryland Power Plant Siting Program	7
1.3.2 Maryland Automated Geographic Information System	7
1.3.3 Western Charles County study	8
1.4 The Study Area	8
 2. THE ORNL LAND USE SCREENING PROCEDURE	 11
2.1 The Maryland Data Base	12
2.1.1 The variables	12
2.2 Simulation of Alternatives in the Decision- making Process	15
2.2.1 User orientation	15
2.2.2 Screening algorithm	15
2.2.3 The problem of averaging ordinal numbers	17
2.2.4 Interpretation of cell suitability scores	18
 3. CRITERIA DEFINITION	 19
3.1 Multiobjective Siting Criteria	19
3.2 Methods of Obtaining Criteria Matrices	21
3.2.1 Staff determination of criteria matrices	21
3.2.2 Procedures for obtaining a group consensus	21
3.3 Ranking of Regional Siting Factors	23
3.3.1 Water availability	24
3.3.2 Seismicity	26
3.3.3 Presence of rare or endangered species	26
3.3.4 Population density and distribution	27
3.3.5 Flood hazard	27
3.3.6 Geologic structure	27
3.3.7 Soils	28

	<u>Page</u>
3.3.8 Man-made hazards	29
3.3.9 Water quality	29
3.3.10 Other regional screening factors	30
4. APPLICATION OF THE ORNL LAND USE SCREENING PROCEDURE TO NORTHERN MARYLAND	31
4.1 The Respondents	32
4.2 Comparisons of Criteria Matrices	33
4.2.1 Criteria for a fossil-fired power plant with a cooling tower: a comparison among siting objectives	33
4.2.2 Criteria for a nuclear power plant with cooling tower: a comparison among respondents	36
4.2.3 Criteria for a nuclear or fossil-fired power plant: a comparison between fuel options	38
4.2.4 Criteria for a fossil-fired plant with the objective of minimizing adverse ecologic impact: a comparison among cooling system options	40
4.3 The Utility of Multiple Matrices	42
5. ANALYSIS OF THE CELL SUITABILITY SCORES	43
5.1 Statistical Analysis	43
5.2 Spatial Analysis	44
5.2.1 Candidate areas for a fossil-fired power plant: a comparison among siting objectives	45
5.2.2 Candidate areas for a nuclear or fossil- fired power plant: a comparison between fuel types	50
5.2.3 Candidate areas for a fossil-fired power plant with the objective of minimizing adverse ecologic impact: a comparison of cooling system options	57
5.2.4 Candidate areas for a nuclear power plant with a composite siting objective: a comparison between respondents	57
5.3 Interpretation of Candidate Area Maps	64
5.3.1 Candidate areas consistently chosen for a nuclear power plant	65
5.3.2 Candidate areas consistently chosen for a fossil-fired power plant	66
5.3.3 Reliability of candidate-area maps	66
5.3.3.1 Accuracy of the Maryland Data Base	67
5.3.3.2 Missing factors	68

	<u>Page</u>
5.3.4 Sensitivity of the screening algorithm	69
5.3.5 The definition of candidate-areas	73
6. RESEARCH ACCOMPLISHMENTS	79
6.1 Application and Analysis of the ORNL LUSP	79
6.2 Criteria Definition	79
6.3 Expansion of the Maryland Data Base	80
7. CONCLUSIONS, RECOMMENDED APPLICATIONS, AND RESEARCH NEEDS	82
7.1 Recommended Applications	83
7.2 Functional Requirements for Future Applications	84
7.2.1 The geographic information system	84
7.2.2 The multiscale approach	85
7.3 Suggested Future Research	86
REFERENCES	88
Appendix A. COMPATIBILITY INDICES	91
Appendix B. CORRELATION MATRIX OF CELL SUITABILITY SCORES OBTAINED FROM CALCULATIONS OF VARIOUS SITING CRITERIA MATRICES	99

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1. The northern eight counties of Maryland	9
2. Stylized illustration of potential for an infinite number of sites within a region	11
3. Candidate areas for a fossil-fired power plant with cooling tower in northern Maryland, 1976. Siting objec- tive: minimization of construction and operating costs. Respondent: Maryland Power Plant Siting Program. Number of variables in calculation: 27	46
4. Candidate areas for a fossil-fired power plant with cooling tower in northern Maryland, 1976. Siting objective: minimization of adverse socioeconomic impact. Respondent: Maryland Power Plant Siting Program. Number of variables in calculation: 27	47
5. Candidate areas for a fossil-fired power plant with cooling tower in northern Maryland, 1976. Siting objective: minimization of adverse ecologic impact. Respondent: Maryland Power Plant Siting Program. Number of variables in calculation: 27	48
6. Candidate areas for a fossil-fired power plant with cooling tower in northern Maryland, 1976. Siting objective: composite of all objectives. Respondent: Maryland Power Plant Siting Program. Number of variables in calculation: 27	49
7. Candidate areas for a nuclear power plant with cooling tower in northern Maryland, 1976. Siting objective: minimization of construction and operating costs. Respondent: Maryland Power Plant Siting Program. Number of variables in calculation: 27	51
8. Candidate areas for a nuclear power plant with cooling tower in northern Maryland, 1976. Siting objective: minimization of adverse socioeconomic impact. Respondent: Maryland Power Plant Siting Program. Number of variables in calculation: 27	52
9. Candidate areas for a nuclear power plant with cooling tower in northern Maryland, 1976. Siting objective: minimization of adverse ecologic impact. Respondent: Maryland Power Plant Siting Program. Number of variables in calculation: 27	53

Figure**Page**

10. Candidate areas for a nuclear power plant with cooling tower in northern Maryland, 1976. Siting objective: composite of all objectives. Respondent: Maryland Power Plant Siting Program. Number of variables in calculation: 27 54
11. Candidate areas for a nuclear power plant with cooling tower in northern Maryland, 1976. Siting objective: minimization of adverse ecologic impact. Respondent: Oak Ridge National Laboratory. Number of variables in calculation: 20 55
12. Candidate areas for a fossil-fired power plant with cooling tower in northern Maryland, 1976. Siting objective: minimization of adverse ecologic impact. Respondent: Oak Ridge National Laboratory. Number of variables in calculation: 20 56
13. Candidate areas for a fossil-fired power plant with cooling pond in northern Maryland, 1976. Siting objective: minimization of adverse ecologic impact. Respondent: Oak Ridge National Laboratory. Number of variables in calculation: 20 58
14. Candidate areas for a fossil-fired power plant with once-through cooling technology in northern Maryland, 1976. Siting objective: minimization of adverse ecologic impact. Respondent: Oak Ridge National Laboratory. Number of variables in calculation: 20 59
15. Candidate areas for a nuclear power plant with cooling tower in northern Maryland, 1976. Siting objective: composite of all objectives. Respondent: first nominal group. Number of variables in calculation: 29 60
16. Candidate areas for a nuclear power plant with cooling tower in northern Maryland, 1976. Siting objective: composite of all objectives. Respondent: second nominal group. Number of variables in calculation: 29 61
17. Generalized candidate areas for a nuclear power plant with cooling tower 62
18. Generalized candidate areas for a fossil-fired power plant with cooling tower 63

Figure

Page

19. Coefficients of correlation between cell suitability scores calculated with all variables and scores calculated with successively fewer variables. The scores are those obtained from the first nominal group's criteria matrix for a nuclear power plant with cooling tower 71
20. Candidate areas for a nuclear power plant with cooling tower in northern Maryland, 1976. Siting objective: composite of all objectives. Respondent: first nominal group. Number of variables in calculation: 20 72
21. Candidate areas for a nuclear power plant with cooling tower in northern Maryland, 1976. Siting objective: composite of all objectives. Respondent: first nominal group. Number of variables in calculation: 13 74
22. Candidate areas for a nuclear power plant with cooling tower in northern Maryland, 1976. Siting objective: composite of all objectives. Respondent: first nominal group. Number of variables in calculation: 5 75
23. Candidate areas for a nuclear power plant with cooling tower in northern Maryland, 1976. Siting objective: composite of all objectives. Respondent: first nominal group. Number of variables in calculation: 4 76
24. Candidate areas for a nuclear power plant with cooling tower in northern Maryland, 1976. Siting objective: composite of all objectives. Respondent: Maryland Power Plant Siting Program. Number of variables in calculation: 27. Candidate areas are mean score or above 77
25. Candidate areas for a nuclear power plant with cooling tower in northern Maryland, 1976. Siting objective: composite of all objectives. Respondent: Maryland Power Plant Siting Program. Number of variables in calculation: 27. Candidate areas are one standard deviation below mean score or above 78

LIST OF TABLES

<u>Table</u>	<u>Page</u>
1. The Maryland Data Base	13
2. Criteria matrices determined in the Maryland Power Plant Siting Project by facility, objective, and respondent	32
3. Importance weights (on a scale of 0 to 10) assigned to variables in the Maryland data base for siting a 1000- to 1100-MWe fossil-fired power plant with cooling tower as determined by the Maryland Power Plant Siting Program	34
4. Categories and values of variables assigned exclusions for siting a 1000- to 1100-MWe fossil-fired power plant with cooling tower as determined by the Maryland Power Plant Siting Program for various objectives	35
5. Importance weights (on a scale of 0 to 10) assigned by respondents to variables in the Maryland data base for siting a 1000- to 1100-MWe nuclear power plant with cooling tower with a composite siting objective	37
6. Categories and values of variables assigned exclusions by respondents for siting a 1000- to 1100-MWe nuclear power plant with cooling tower with a composite siting objective	38
7. Importance weights (on a scale of 0 to 10) assigned to variables in the Maryland data base for siting a 1000- to 1100-MWe power plant with a composite siting objective as determined by the Maryland Power Plant Siting Program	39
8. Categories and values of variables assigned exclusions for siting a 1000- to 1100-MWe power plant with a composite siting objective as determined by the Maryland Power Plant Siting Program	40
9. Importance weights (on a scale of 0 to 10) assigned to variables in the Maryland data base for siting 1000- to 1100-MWe fossil-fired power plants with various types of cooling systems with the objective of minimizing adverse ecologic impact as determined by ORNL	41

Table

Page

10.	Categories and values of variables assigned exclusions for siting 1000- to 1100-MWe fossil- fired power plants with various types of cooling systems with the objective of minimizing adverse ecologic impact as determined by ORNL	42
11.	Undocumented or erroneous codes in the Maryland Automated Geographic Information System	67

ABSTRACT

Since 1974 the Resource Analysis Group in the Regional and Urban Studies Section of the Oak Ridge National Laboratory (ORNL) has been engaged in developing a procedure for regional and local siting analysis known as the ORNL Land Use Screening Procedure (LUSP). This document is the final report of the Maryland Power Plant Siting Project (MPPSP) in which the ORNL LUSP was used to identify candidate areas for power plant sites in northern Maryland.

Numerous candidate areas are identified on the basis of four different siting objectives: the minimization of adverse ecologic impact, the minimization of adverse socioeconomic impact, the minimization of construction and operating costs, and a composite of all siting objectives. Siting criteria have been defined for each of these objectives through group processing techniques administered to four different groups of siting specialists. The siting priorities and opinions of each group have been expressed quantitatively and applied to a geographic information system containing 52 variables for each 91.8-acre cell in the northern eight counties of Maryland.

Sensitivity analyses reveal that the spatial distribution of candidate cells is influenced considerably by variations in the criteria defined by different groups even for the same siting objective and type of facility. The distribution is highly sensitive to variations in siting objectives, and somewhat less sensitive to the facility type.

ACKNOWLEDGMENTS

The research presented in this report builds upon results of the Charles County siting study performed at ORNL in 1974. The project was directed by Steven L. Yaffee with research assistance by Curtis A. Miller and programming by Richard G. Mashburn and Peter A. Lesslie. Between March 1975 and March 1976, there was a gradual turnover of the project staff, and Yaffee remained as principal investigator until August 1975. No members of the original team remain on the MPPSP staff, but the transfer of research responsibilities was gradual enough to assure that their concepts are retained as integral parts of the current screening procedure. I wish to express my deepest appreciation to all of the project participants both past and present. I am especially grateful to Jeffrey S. Jalbert, who devoted his year of sabbatical leave from Denison University to this project. I thank him for his continual consultation and help during the formation of the screening procedure, for developing the Water Analysis System, for writing the thematic mapping and suitability calculation programs, and for managing the data systems during the most recent phase of the analysis.

The following individuals and organizations were instrumental in the development and implementation of this project, and I am most appreciative for their help.

The Computer Sciences Division of ORNL provided many of the programs and services necessary to implement this project. Peter A. Lesslie managed the data systems in 1974 and 1975 and wrote the proximity program. Barbara Lou Bishop assisted in the computer services necessary in the daily operation of the project. The graphic display and spatial analysis capabilities of the Oak Ridge Geographic Data Systems Group were essential. Phillip R. Coleman and Robert G. Edwards were responsible for the interpolation of population densities and calculation of site population factors, and Donald L. Wilson produced candidate-area maps for the final report.

The Maryland Power Plant Siting Program provided criteria matrices and insight into the siting process. Paul Massicott, William N. Jackson, and Kenneth E. Perkins were most helpful in reviewing our procedure.

BLANK PAGE

The Maryland Department of State Planning contributed 27 variables from their Maryland Automated Geographic Information System. John C. Antenucci and John P. Morgan were especially helpful.

My colleagues in the Energy Division have provided invaluable support and assistance. Alfred H. Voelker participated in numerous discussions that initiated and refined the concepts used in this analysis. He was also responsible for the nominal group exercises. Robert B. Honea reviewed the documents and facilitated the operation of the project administratively. Curtis A. Miller initiated the air diffusion impact analysis and provided siting criteria. Carey S. Rosemarin aided the criteria definition and participated in conceptual development of the procedure. Garvin J. Morris and Mary C. Ogle converted much of the data to digital form and contributed other technical services. Bonnie W. Brummitt typed the successive drafts of the reports and provided secretarial services with commendable patience and restraint.

Darrell C. West of the Environmental Sciences Division was responsible for identifying the habitats of endangered species.

Gary V. Downer, of the University of Tennessee Graduate School of Planning, performed numerous computer runs necessary in the analysis of candidate areas and facilitated the final production and assembly of the reports. Alf D. Shepherd of the Geography Department assisted in the application and documentation of the Water Analysis System.

Dale M. Honeycutt, of the Geography Department of Northern Arizona University, was responsible for checking the accuracy and documentation of all MAGI variables included in the Maryland Data Base.

Carl Cater, of the Allegheny Power Service Corporation, provided a utility's view of water availability for power plant siting.

We appreciate the effort and patience that went into the typing and assembling of this report. For this we thank Bonnie W. Brummitt, of the Energy Division, and members of the Technical Publications Department in the Information Division.

1. INTRODUCTION

Increasing local opposition to the impacts of proposed energy facilities and regulatory delays in licensing have pressed the need for a more comprehensive and objective means of selecting candidate sites. Many land use decision-makers and regulatory agencies would welcome a procedure capable of identifying the trade-offs between alternative sites and considering all viewpoints on any siting issue. It is unlikely that such a procedure will be developed, but significant gains have been made in recent years.

Since 1974 the Resource Analysis Group in the Regional and Urban Studies Section of the Oak Ridge National Laboratory (ORNL) has been engaged in developing and applying the ORNL Land Use Screening Procedure (LUSP), which is intended to aid in regional screening for power plant sites and in identifying potential conflicts before they become matters of public concern. This is the final report of the Maryland Power Plant Siting Project (MPPSP), in which the LUSP was applied to northern Maryland. The research was sponsored by the Nuclear Regulatory Commission and performed in cooperation with the Maryland Power Plant Siting Program. The State of Maryland was chosen because of its commitment to predesignation of power plant sites and its extensive cell-based geographic information system.

1.1 The Problem of Energy Facility Siting

Historically, energy-facility siting was a matter of local concern because environmental costs were usually borne by the same population as that benefiting from the production. Most early energy production facilities were located in or near their main centers of demand and utilized local resources. For example, during the 18th century, most European cities were surrounded by their main source of energy -- a zone of firewood production.¹ In the United States, many Eastern cities were established at the fall line, where streams descend from the Piedmont to

the coastal plain, producing abundant water power. Early coal-fired and hydroelectric generating plants were small facilities located in or near the cities that used their output.

The first substantial shift to regional energy networks resulted from large hydroelectric plants constructed during the 1930s and 1940s. The land requirements of these plants were great enough to discourage urban locations, and production capacities were too large to serve a single city. Thereafter, the continued development of regional utilities and greater economic efficiencies of large plants (including coal-fired and later nuclear plants) resulted in regional electric transmission grids with interregional ties. The wholesale distribution of power between communities and regions disassociated environmental costs from production in the perception of local populations while the expanded size of plants and scales of operation increased regional impacts.

At first, siting decisions were not greatly affected because public opinion generally favored industrial expansion, environmental awareness was not particularly acute, and contemporary legislation was not geared to environmental protection. By the 1960s, energy-facility siting was a regional rather than a local concern. Site selections, however, continued to be conducted as site-specific analyses throughout most of the 1960s.

The National Environmental Policy Act of 1969 (NEPA) requires that impact statements contain assessments of alternatives to each proposed Federally funded or regulated project [Sect. 102 (2)] and encourages planners and decision-makers to broaden their focuses from site-specific to regional analyses. Current siting practices usually involve almost an intuitive regional selection of a few candidate sites followed by rigorous analyses of their economic and environmental suitabilities.²

The consensus derived from our research experience at ORNL is that energy-facility siting must be viewed in the context of a spatial hierarchy of physical, social, and economic systems. For national energy planning, site selection should proceed from the national to the local scale with emphasis at each stage placed on siting criteria most meaningful and crucial for the areal units of observation. The suitability of a particular site is determined only after iterative screenings in a step-down procedure from the broadest to the most specific scale.

1.1.1 National scale

At the national scale, energy-facility siting analysis focuses on matters of general concern such as projections of energy demand and the availability of resources (particularly fuels) and capital. Most of the information for which national aggregate figures are meaningful are either ubiquitous or highly mobile. Aggregate capital, for example, is much more meaningful than aggregate coal supply, because of the former's high mobility in contrast to the lower mobility and considerable regional disparity of the latter. For most analytical purposes, it is necessary to consider data for areal units much smaller than the study area itself. For example, one can discuss the aggregate national supply of a commodity, but little can be said about its cost or availability without examining regional variations.

1.1.2 Regional scale

The second level of screening is the regional scale with boundaries defined according to the purpose of the analysis. The preferred regions often have to be modified because of data availability or other constraints, but an attempt is made to use political units, utility districts, or hydrologic basins depending upon whether emphasis is on water availability or institutional-social feasibility. Currently, analysis is being conducted with counties as the basic data cells, because they are the smallest areal units for which large amounts of digital data are available nationwide. Their small size in the eastern United States (usually about 300 square miles) provides a spatial resolution suitable for regional screening.

Regional siting factors which can be examined through a county-level analysis include distance to load demand, seismicity, accessibility to major transportation and transmission corridors, and proximity to major population centers. In general, these regional factors are continuous variables which do not vary greatly over distances of less than 20 miles (e.g., seismic activity) or they are discrete variables with categories covering contiguous areas of county size or larger (e.g., aquifer recharge zones).

A goal of the regional siting analysis is to identify areas that appear to be well situated for energy-facility development pending the availability of suitable specific sites. The counties or similar spatial units ranking highest in the regional screening are selected for more detailed analyses at the local level.

1.1.3 Local scale

An extensive geocoded data base generally is required for local-scale analyses because of the large volume of data involved in characterizing numerous areal units equal to or smaller than the size of a single site. The appropriate variables are those which form highly discontinuous data surfaces (i.e., those which vary considerably over small areas). Land surface slope, for example, varies so much over minute distances that an aggregate figure would be meaningless for facility siting if each areal unit were larger than a single site. The ultimate goal at this scale is to identify candidate siting areas of 25 to 100 square miles from which specific candidate sites can be selected. A high degree of spatial resolution and great variety of information should give considerable credence to the results of a screening procedure of this type.

1.1.4 Site-specific analyses

The final step is the analysis of specific candidate sites which have been identified by the local-scale analysis. Usually this involves a detailed environmental investigation for each of four or five candidate sites followed by a thorough impact assessment of the most promising site. Because the number of potential sites is small and the exact locations are known, it is possible to create a tremendous store of information for each location and to apply extensive models to simulate social, economic, and ecologic impacts. The goal is to identify a final site which best serves the political and economic interests of the region with a minimum of adverse environmental impact. In practice, site-specific analyses are the investigations most familiar to siting specialists today.

In the application of the multiscale screening procedure, all factors operating at broader scales must be considered at each of the more specific levels. A site-specific analysis, therefore, can contain all of the factors of importance at the national, regional, and local scales along with additional variables. The Maryland Power Plant Siting Project combines regional and local siting factors in a cell-based analysis at the local scale.

1.2 Research Objectives

The major purpose of this research is to develop an automated procedure for identifying the land use suitability of every land parcel within a candidate siting region. Although the current project involves power plant siting, it is intended that the procedure itself should have general capabilities of application to other land uses or facilities. Moreover, it is intended that suitability for any particular land use can be examined from the standpoint of various independent siting objectives. These requirements suggest that the procedure should operate with easily alterable, user-specified criteria and with geographic data of various resolutions (cell sizes).

An equally important purpose is the definition of multiobjective criteria for power plant siting in a regional context. This further implies the need for understanding the means by which regional-siting criteria can be expressed as measurable data representing each geographic unit. Thus, a parallel objective is to determine the specific data items which should be included in a geographic base file for power plant siting.

In its broadest context, the screening procedure is designed to be used in developing spatial scenarios of future energy production and in identifying critical areas where physical, economic, and social resources appear to be inadequate for or incompatible with production of projected energy requirements. Current research focuses on developing these general capabilities.

The more immediate objective of this project is to aid the Maryland Power Plant Siting Program in predesignating sites for future power plant development. The state has enacted legislation empowering that office

to select and purchase such sites. The power companies can recommend new sites to the state, but they can only develop those which have been approved by the Public Service Commission upon the recommendation of the Power Plant Siting Program.

It should be noted that ORNL's function in this process is to develop tools for siting rather than to choose sites. The latter is the responsibility of the Maryland Power Plant Siting Program. Hence, the final decision will be made by Maryland as to what criteria are employed in the user-oriented siting procedure developed by ORNL. The advantage of using the automated procedure is that all criteria can be stated objectively and applied to every land parcel within the state. Moreover, there will be greater assurance that every alternative site is considered.

Additional purposes are to test the applicability of the Maryland Automated Geographical Information System (MAGI) to actual siting problems and to determine additional data needs. Specifically, the geographic base file is to be evaluated in regard to the format of the data, the categorization of key variables, the completeness of the data set, and the accuracy and spatial resolution of the data.

1.3 Background

The National Environmental Policy Act of 1969 (NEPA) marks the beginning of most truly regional siting approaches. In the same year, long-standing geographic techniques of regional analysis were popularized with the publication of Ian McHarg's *Design with Nature*.³ The fervor with which many planners adopted McHarg's overlay-map technique is evidence of their need for workable regional-screening tools.

By 1971, many planners were using computers to store cellular data and print composite maps in an automated procedure similar to the manual application of overlay maps.⁴ A major advantage of automated screening techniques is that they offer the option of assigning varying weights to indicate the relative importance of each variable in the data base. Current state-of-the-art research focuses on methods of assigning these weights as expressions of siting criteria. The MPPSP, which began in 1974, is an analysis of siting criteria for fossil-fired and nuclear

power plants with an emphasis on adapting these criteria to regional land-use suitability screening of automated geographic information systems.

1.3.1 Maryland Power Plant Siting Program

An interdepartmental program of the State of Maryland, the Maryland Power Plant Siting Program was established in 1971 to deal specifically with power plant siting. It was given broad responsibility in environmental impact assessment and an annual budget currently approximating \$7,000,000 with which to evaluate proposed power plant sites, assess the impact of existing power plants, and identify and purchase prospective power plant sites. The enabling legislation provided the funds through a surcharge on electricity generated within the state.

The Power Plant Siting Program is well suited to a regional screening project like the MPPSP because it is responsible for choosing suitable sites throughout the State of Maryland. Moreover, its primary obligation is an unbiased collection and appraisal of information regarding the costs and benefits (including nonmonetary environmental costs and benefits) of potential sites. It represents the consumer, the utility, and any other interest groups with equal concern, and one of its major functions is to assure that a sufficient number of sites are predesignated for development.

1.3.2 Maryland Automated Geographic Information System

Automated regional screening procedures depend upon the availability of extensive geographic information systems which are time-consuming and expensive to build. It is unlikely that any single application such as power plant siting would justify the expense of developing a dedicated system of this type. The MPPSP was considerably expedited by the existence of the Maryland Automated Geographic Information System (MAGI).⁵ This geographic base file was developed in 1974 by the Maryland Department of State Planning (DSP) with technical assistance from the Environmental Systems Research Institute. It is designed to serve a variety of

planning needs with a high spatial resolution (91.8 acres per cell). The data are not structured specifically for power plant siting.

Data for all cells in the northern eight counties of the state were transferred to ORNL in 1975.

1.3.3 Western Charles County study

The initial application of the ORNL screening procedure was to a study area of approximately 240 square miles in western Charles County, Maryland.⁶ It was learned that candidate areas can be identified by applying siting criteria to the geographic information system through a mathematical screening algorithm. It was apparent, however, that certain improvements would be necessary if the results were to be accepted by decision-makers. Problems were identified in regard to the completeness of data coverage and the credibility of the siting criteria employed. It was concluded that no single set of criteria would be accepted by the diverse groups involved in power plant siting issues. The comparative approach to criteria definition and the extended data base in this project are in response to the recommendations derived from the western Charles County study.

1.4 The Study Area

The current research focuses on an eight-county study area in northern Maryland (Fig. 1). The counties Cecil, Harford, Baltimore, Carroll, Frederick, Washington, Allegany, and Garrett form an east-west transect 195 miles in length varying in width from 5 to 35 miles. This configuration has the advantage of sampling a broad spectrum of physiographic and cultural phenomena. The terrain, for example, varies from coastal plain to rolling Piedmont, to the intermittent escarpments of the Ridge and Valley Province, and the rugged slopes of the Allegheny Mountains. The settlement pattern ranges from the dense megalopolis of the east to the sparse rural clusters and individual farms of the west. Similarly, land use intensity and transportation network density decrease from east to west. Its selection was based primarily on the desire of the Maryland Power Plant Siting Program to predesignate a power plant site in western Maryland.

Fig. 1. The northern eight counties of Maryland.

Unfortunately, this sample strip is accompanied by the distinct disadvantage of a long border (approximately 430 miles) through areas for which extensive data bases like MAGI are not available. Because of the long, narrow shape, many cells are adjacent to these areas, and it is impossible to consider adjacent resources and land uses in the evaluation of the cells. This shape, coupled with the high resolution of the data and the large areal extent, has complicated the map presentation of research results. The long, narrow form is highly compatible with line printer output but requires a disproportionate amount of reduction for most other forms of visual presentation.

2. THE ORNL LAND USE SCREENING PROCEDURE

The requirements of a regional or local screening procedure are determined by the large number of areal units involved. In theory the number of potential sites within a given region is infinite regardless of the region's total area. This can be demonstrated by visualizing the site as a disk of area A with point O at its center (Fig. 2). If complete freedom of movement over the region is permitted, point O may become coincident with all of the infinite number of points on the surface. Each point defines a discrete potential site, and the total number of sites is infinite. If the morphologic constraint is dropped and the value of A is allowed to vary, each new configuration may be considered an individual site, and the number of potential sites is infinite even if point O remains stationary.

The first step in a regional or local screening analysis is to reduce the potential sites to a finite workable number of discrete areal units. This usually is done by placing a geometric grid over the area and considering each of the blocks or cells as a potential site. A

ORNL-DWG 76-16368

Fig. 2. Stylized illustration of potential for an infinite number of sites within a region.

hexagonal grid would produce the least distortion in characterizing the data surface, but a rectangular form usually is employed because of the ease with which it can be constructed. Both offer the advantages of regular shape and uniform size for all cells.

It is sometimes necessary to use irregular areal units because of the availability of data. In regional screening analysis, county units often serve best in the United States because of the extensive data bases available from the U.S. Census and other Federal sources.

When a regular grid is employed, the size of the cells affects the number of potential sites under consideration. If the cell size is equal to the area required for a single site, only one potential site is formed by each cell. However, numerous configurations are possible if smaller cells must be combined to form the final site. Cell sizes considerably larger than a single site are inappropriate for analyses in which discrete candidate sites are to be identified.

2.1 The Maryland Data Base

The MPPSP utilizes 91.8-acre cells with 52 items of information digitized for each.⁷ The term variable is used throughout this text in referring to the data items. The cells were determined by the Maryland Department of State Planning in the MAGI system and are defined by a rectangular grid with orthogonal intersections at 2000-ft intervals. Each cell is identified by a row number indicating its location on a north-south line and a column number indicating its east-west position. The eight counties of the study area lie within rows 1 through 110 and columns 1 through 530. Maryland State Plane Coordinates for the centroid of each cell can be obtained by the following conversion formulae:

$$\text{Eastings (in feet)} = [2000 \times (\text{column number} - 1)] + 90,000$$

$$\text{Northings (in feet)} = 700,000 - [2000 \times (\text{row number} - 1)]$$

2.1.1 The variables

The variables in the geographic base file (Table 1) are discussed fully in *A Cell-Based Land Use Screening Procedure for Regional Siting Analysis*.⁷ In summary it can be stated that they cover a broad range of

Table 1. The Maryland Data Base

Variable No.	Variable name
04	Surface water quality
05	Engineering geology (primary)
06	Engineering geology (secondary)
07	Transportation and transmission (primary)
08	Transportation and transmission (secondary)
09	State and Federal lands (primary)
10	State and Federal lands (secondary)
11	Mineral resources
12	Water and sewer facilities
13	Forest type
21	Watersheds
22	Electoral district number
14	Soil group (primary)
15	Soil group (secondary)
16	Soil group (tertiary)
17	Natural features (primary)
18	Natural features (secondary)
19	Land surface slope (primary)
20	Land surface slope (secondary)
23	Historic sites (first in cell)
24	Historic sites (second in cell)
25	Historic sites (third in cell)
26	Land use and land cover (primary)
27	Land use and land cover (secondary)
28	Land use and land cover (tertiary)
29	Planned land use and land cover (primary)
30	Planned land use and land cover (secondary)
31	Planned land use and land cover (tertiary)
32	Highways and proposed highways
33	Seismicity
34	Fish spawning and nursing areas in Chesapeake Bay
35	Thirty-mile SPF
36	Endangered species
37	Excavation requirements
38	Overburden thickness
39	Aquifer recharge zones
40	Five-mile SPF
41	Stream flow
42	Population density
43	Proximity to highways
44	Proximity to railroads
45	Proximity to stream flow
46	Proximity to residential land use
47	Proximity to agricultural land use
48	Proximity to transmission lines
49	Proximity to fish spawning and nursing areas in Chesapeake Bay
50	Proximity to airports and airport property
51	Proximity to endangered species
52	Proximity to natural features

social, economic, and physical phenomena. Physical characteristics, transportation facilities, and population densities are particularly well represented in the data set because such variables are more readily available. The structure of the data base is such that each variable is allotted one segment of the storage medium (usually magnetic tape). Within that segment is entered a code indicating the characteristic of that variable occurring within the cell. These characteristics are referred to as "categories" if the variable contains discrete classes and as "values" or "ranges of values" if the variable can assume a continuous spectrum of information. Thus, "scrub oak" is a category within the "forest type" variable, and "30-40 people per square mile" is a range of values within the "population density" variable. Only one code may be entered for each cell.

Variables 4 through 41 are referred to as raw variables to distinguish them from the proximity and suitability variables calculated at ORNL. The term is used somewhat loosely since several of the "raw" variables have undergone considerable calculation. For example, at ORNL the site population factor (SPF) (a weighted density value often employed by the Nuclear Regulatory Commission in evaluating sites) is derived from U.S. Census Enumeration District population totals which are distributed by an interpolation algorithm. The density is then calculated for a circular area of 5- or 30-mile radius with progressively higher weights assigned to the population within concentric rings nearer to the center. The SPF values then are assigned to cells using another interpolation algorithm. Most of the variables in this set, however, are "raw" in the sense that they have not been manipulated to form factors or indices through combination with other variables.

Variables 43 through 52 are proximity calculations indicating the distance between a cell and its nearest cell containing a specified category of a raw variable. Proximity variables near the border are inaccurate because of a lack of information regarding cells outside the study area. One solution is that all raw variables which are assumed to affect site selection in adjacent cells should be collected for an extended band around the study area. The correction would require additional manpower and could pose problems of data availability and compara-

bility when jurisdictional boundaries are crossed, but it is not difficult from a theoretical viewpoint. In the MPPSP the extraneous cells are treated as if they do not exist. No information regarding these cells is entered into the calculation of cell suitability scores.

2.2 Simulation of Alternatives in the Decision-making Process

The purpose of a regional siting exercise can be to simulate real-world site selections or to influence and improve the site selection process. In either case it is necessary to consider the values and priorities of the decision-makers and interest groups involved. The approach described in this report is designed to aid the Maryland Power Plant Siting Program in applying its own criteria to the data base and in considering a variety of siting objectives which might be espoused by different interest groups.

2.2.1 User orientation

Most site-screening procedures incorporate the siting priorities and opinions of the specialists who designed them. In contrast the ORNL Land Use Screening Procedure (LUSP) is a user-oriented system, and the users may incorporate their own opinions and as many different viewpoints as are felt to be necessary. Divergent views can be applied to the data base, and the resulting candidate areas can be displayed cartographically for consideration in the final site selection.

The user orientation is seen as an advantage because it involves the planner or decision-maker in the development of each calculation and assures that the values under consideration are those of the user. The results thus are more credible to the user because they are his own. Alternatively he can use the method to simulate the siting patterns which would result from employing the values and objectives of other interest groups. In fact, other interest groups can be asked to submit their own criteria to be used in trial runs, and the results can aid in anticipating their acceptance or rejection of sites before final selection.

2.2.2 Screening algorithm

The user is presented with a description of the facility to be sited and is asked to consider the importance each variable would have

in his siting decision. Each variable in the data base is ranked on an ordinal scale of 0 through 10; the rank is referred to as its importance weight.

The user is then asked to consider each category or value of a variable in regard to the positive or negative influence it would have on his decision if it occurred in a cell. If the category or value is highly compatible with the facility, it is assigned a value of 10 on an ordinal scale of 0 through 10. An incompatible characteristic is given a low index on the same scale, and neutral aspects are assigned a value of 5. These numbers are called compatibility indices. In cases where the variable is of great importance and the category or value is highly repulsive, a negative compatibility index may be assigned to indicate that cells possessing this characteristic must be excluded from the final selection regardless of how attractive their other characteristics may appear. The matrix of importance weights and compatibility indices forms an abstracted, quantitative set of criteria representing the siting priorities and opinions of the user.

The criteria are applied to the geographic data base in a cell-by-cell calculation of the form:

$$S_i = \frac{\sum_{V=1}^N C_{Vi} I_V}{\sum_{V=1}^N I_V} ,$$

where

S_i = suitability score for cell i ,

V = variable (e.g., land use, proximity to stream flow),

N = total number of variables,

C_{Vi} = compatibility index for value of variable V occurring in cell i ,

I_V = importance weight of variable V .

The final suitability score ranging from 1 to 10 is interpreted as an indication of the relative ability of a cell to support the proposed facility in accordance with the objectives of the respondent and subject to the limitation of the data.

2.2.3 The problem of averaging ordinal numbers

Quantitative screening algorithms of the type described above are employed in several state-of-the-art siting procedures currently under development.^{8,9} However, there is a theoretical fallacy inherent in the multiplication of importance weights and compatibility indices and in the normalization of indices to obtain a final suitability score. The fundamental problem is that ordinal numbers (numbers indicating order or succession rather than absolute values) may not be linear and, thus, cannot be multiplied, divided, added, or subtracted. The potential for error derives from the arbitrary manner in which the weights and indices were originally assigned. An importance weight of 6, for instance, indicates that the variable is more important than a variable which has been assigned a weight of 3, but there is no basis for assuming that 6 is twice as important as 3. Neither can it be stated that the difference in importance between 3 and 6 is the same as that between 6 and 9. Similarly, a compatibility index of 5 indicates greater compatibility than 4, but no indication of the proportional difference is implied. Furthermore, there is no assurance that the compatibility index range of 0 to 10 represents the same scale on all variables. In other words, it may be that an index of 10 is twice as compatible as an index of 9 on one variable and 20 times as compatible on another. The application of importance weights is intended to remedy this discrepancy, but, in fact, the actual values represented by the multiple scale cannot be determined from the two sets of ordinals obtained in the usual ranking procedure.

The problem and solutions to the ordinal dilemma are discussed fully in *Analytical Power Plant Siting Methodologies: A Theoretical Discussion and Survey of Current Practice*.¹⁰ For the purpose of this document it will suffice to say that some researchers have treated the indices as ordinal numbers, in which case no conclusion can be reached regarding the trade-offs between the combined characteristics of one cell and those of another. In contrast, other researchers have devised methods for assuring that the indices are real numbers which can be entered into quantitative algorithms of the type employed in ORNL LUSP. The Churchman-Ackhoff method, for example, iteratively requires respondents to compare between variables and state the proportional value of importance weights

and compatibility indices. Conceptual purity can be attained at a sizable cost in time and inconvenience to the users and respondents. Such an approach is impractical when it is desirable to incorporate numerous sets of criteria from various respondents, particularly if the respondents have no vested interest in the outcome of the screening exercise.

2.2.4 Interpretation of cell suitability scores

Regional and local screening analyses require conclusions in regard to trade-offs between cells, and in the MPPSP it was considered desirable to employ numerous sets of criteria. Hence, it was decided that the rankings would have to be treated as real numbers although it would be impractical to assure that they truly were on a uniform interval scale. The inherent potential for error was avoided by interpreting only gross differences in final scores as indications of relative suitability, so that the class intervals were significantly larger than the accumulated error. The end result is four classes of cell suitability scores:

1. Exclusion (-1)
2. Low suitability (0 to one standard deviation below the mean)
3. Indeterminate scores (one standard deviation below the mean to one standard deviation above the mean)
4. High suitability (one standard deviation above the mean to 10).

Candidate areas are identified as clusters of cells considerably larger than a single site in which all cells score in the highest class. Trade-offs do not pose an acute conceptual problem because no actual comparison is made between the upper and middle classes or middle and lower classes. It is reasonable to assume that cells in the high suitability class are superior to those in the low suitability class because the latter have poor scores on numerous variables while the former have high scores on all or almost all variables.

3. CRITERIA DEFINITION

The most crucial aspect of the screening procedure is the matrix of importance weights and compatibility indices which determine the spatial and statistical distributions of the cell suitability scores. If the criteria are obtained in a rigorous and objective manner, they can lend credibility to the candidate area selection. On the other hand, biased or haphazardly conceived sets of criteria can destroy public confidence in the entire procedure. The criteria can be made highly specific to fit a particular type of facility characterized by fuel type, cooling technology, and size of plant, or they can be quite general. While this report is limited to power plant siting, there is no reason LUSP cannot be adapted to another land use merely by changing the criteria matrix and perhaps adding variables to the data base.

3.1 Multiobjective Siting Criteria

For a utility company there is no alternative but to consider economic and technical feasibility as primary siting objectives. However, there is no justification for excluding other siting objectives from consideration, particularly since these, too, may be expressed in terms of monetary costs of delays or of mitigation requirements.

It can be argued that consideration of various siting objectives has become a necessary part of power plant siting. Most utilities now perceive an advantage in anticipating environmental impacts before final site selection. For some this represents a pragmatic desire to avoid the delays that can result from hearings, litigations, and detailed impact investigations. For others it represents a genuine concern for the environment and heightened awareness of detrimental impacts. In either case, it is important that the decision-maker be able to cast aside his own biases and apply the criteria of other interest groups even if he is philosophically opposed to their views. Moreover, the interests of other groups are best served if their opinions are considered before the utility has committed large sums of money to a specific site.

A mathematical algorithm of the type used in LUSP cannot be highly sensitive to individual factors with low importance weights. Hence, it is possible for a minor siting objective to have little effect on the final cell score even though it may have a profound effect on the site's acceptance or rejection by a particular interest group. In order to ascertain that all appropriate siting objectives have been given full consideration, it is suggested that a separate run be devoted to each. The user or other respondent is asked to create a criteria matrix in which the chosen objective is held paramount and all others are ignored. Ultimately the scores obtained from each should be compared with those resulting from the composite matrix. Additional refinement of individual objectives can be attained by choosing at least one respondent with specific expertise in the area of consideration (e.g., a group of ecologists, biologists, and physical geographers might be asked to create a set of siting criteria focusing on the minimization of adverse ecologic impact).

In the MPPSP, siting criteria were obtained for the following siting objectives (no ranking of importance is implied):

- a. the minimization of adverse ecologic impact,
- b. the minimization of adverse socioeconomic impact,
- c. the minimization of construction and operating costs,
- d. a composite of all siting objectives in the perspective of the respondent.

If properly constructed, these four sets of criteria can cover most of the issues which have caused general concern among the utilities and other interest groups in recent siting decisions. This list of objectives could be subdivided even further. For example, aesthetic impact or detrimental effects on aquatic biota could be chosen for special emphasis within the ecologic objective, and separate criteria matrices could be constructed. The general cost objective could be replaced by more specific ones dealing individually with land acquisition costs, land preparation costs, and the continuing costs of hazard abatement. The initial list is not exhaustive. It would be helpful, for instance, to create a fifth matrix dealing with the maximization of energy efficiency.

It is advisable to provide at least one cross-check for the scores obtained for each siting objective. The anticipated application is for the user to define a criteria matrix for each siting objective and to ask groups of topical specialists to focus on criteria for each according to their fields of expertise. The resulting scores then can be compared in regard to their statistical and spatial distributions.

3.2 Methods of Obtaining Criteria Matrices

In LUSP the user supplies his own criteria; ORNL cannot control the quality. It is suggested, however, that the user should make every effort to assure that each matrix is determined as rigorously as possible and validly represents the criteria of the user or respondent. This section discusses various methods of obtaining the criteria and emphasizes the Nominal Group Process (NGP) as a means of assessing expert opinion.

3.2.1 Staff determination of criteria matrices

In current siting practice, regional screening is performed solely with the criteria defined by the decision-maker. His perceptions of the constraints which will be placed by regulatory agencies and intervening groups are incorporated, but the operational criteria clearly are his own. Even the most enlightened organization could not be expected to substitute the criteria of another group, however well respected, for its own. Thus, it is anticipated that the responsible utility company or regulatory authority will always wish to have its siting specialists prepare a criteria matrix as the Maryland Power Plant Siting Program has done in this study.

3.2.2 Procedures for obtaining a group consensus

Whether the user organization is formulating a criteria matrix from numerous siting specialists within the organization or is attempting to assess the opinions of other interest groups or topical specialists, it is often necessary to condense the opinions of several participants into a single matrix representing the group consensus. It is extremely

important that this should be done as rigorously as possible because of the important role that the matrix plays in the screening procedure.

Three methods of assessing the judgmental consensus of a group were considered in this study. The Delphi Method is a well-established approach in which questionnaires are administered to a selected group of individuals, herein called respondents, in a series of iterative rounds.¹¹ After each round, the results are summarized and presented as feedback for the next. The process continues until the researcher is satisfied that the results validly represent the group consensus. The NGP is one of several task group approaches which require the participants to convene in a panel discussion under highly structured conditions.¹² The third method, gaming, is an even more highly structured process, in which each participant plays an assigned role in a well-defined decision-making situation. Certain rules and assumptions are dictated in an attempt to simulate real-world policies and constraints, and the game is carried out just as a child's game is played. The judgments derived from the interplay are assumed to represent the group consensus or a policy compromise which might be obtained in a real-world situation.¹³

A comparison of the three methods reveals differences in the degree of interaction between participants. In the Delphi Method, participants are not required to face each other; their only intercourse is through written correspondence at the beginning of each round with intervals of several weeks or months. Hence, true interaction is minimal. In contrast, NGP participants are forced to think and speak as a group, and full interaction between group members is encouraged. Gaming is perhaps even more interactive because the game design requires that players must argue among themselves over every contestable issue, with the judgmental outcome deriving directly from these confrontations.

Considerable disparity in the amount of time required to obtain useful results is apparent also. Each of the methods requires from one to two months to select the participants and obtain their cooperation in the exercise. Preparation for both Delphi and NGP involves careful formulation of specific questions and issues to put before the participants. Generally this can be performed simultaneously with the selection of

participants and does not greatly affect overall time requirements. The construction of a game, however, is an expensive activity which requires several months of development and usually is not perfected for several years.¹⁴

After initial preparation, both the NGP and gaming proceed rapidly once the participants have convened, and results can be obtained in a matter of days. In contrast, the Delphi Method entails several months of intermittent correspondence, with the total span dependent upon the number of iterations required.

Experience at ORNL has shown that participant attrition poses a serious problem in application of the Delphi Method. Presumably the protracted nature of the process causes participants to reconsider their commitments of time and effort. Furthermore, many respondents are intimidated by the complexity and bulk of the survey materials.¹⁵ Reaction to the NGP has been just the opposite; most participants have been highly enthusiastic and have felt that they learned enough from the experience to justify their expenditure of time. Often the participants value the insights exchanged in interactive group discussions as much as the user values the weightings obtained from the process. These exchanges of insights are totally lacking from the Delphi process, so there is little to compensate a busy executive or other siting specialist for his time.

The NGP seems best suited to the needs of regional screening. The time requirement, including preparation and execution, is considerably less than that of the Delphi Method or gaming. This is a significant factor due to the numerous runs involved in LUSP and the need for expedition in most real-world siting analyses. Moreover, the participants, except those employed by the user organization, usually have no vested interest in the results. The process must use their time efficiently and make them feel that the imposition is recompensed.

3.3 Ranking of Regional Siting Factors

The application and results of two NGP exercises are described in *Power Plant Siting: An Application of the Nominal Group Process*

Technique, by A. H. Voelker. Siting specialists from OKNL, the Tennessee Valley Authority (TVA), Maryland Power Plant Siting Program, Allegheny Power Service Corporation (the utility providing electric service to western Maryland), and the University of Illinois were asked to name, define, and rank the siting factors which would influence their decisions in designating candidate areas for a 1000- to 1100-MWe nuclear power plant with cooling tower. The rankings obtained from each group were used as importance weights in two separate applications of LUSP which will serve as examples in the remaining chapters of this report. The purpose of this section is to introduce the siting factors as an aid to understanding the criteria matrices to be encountered in Chap. 4. They will be discussed in approximately descending order of importance for a composite siting objective. There is, of course, variation among the different matrices.

3.3.1 Water availability

The availability of sufficient quantities of water within a reasonable distance of the plant lies at or near the top of the priority list of factors ranked by all respondents, including those determined by the Maryland Power Plant Siting Program. In this context, availability is defined in terms of low-flow characteristics of the stream from which water is to be withdrawn. The ability to obtain the legal right to use a portion of a stream's flow is viewed separately by the respondents and generally ranks much lower as an importance factor. Groundwater sources, oceans, bays, and the Great Lakes are treated in still another context because of the stringent environmental protection of critical natural areas and the costs associated with drilling for groundwater or counter-acting the corrosive effects of salt water.

The amount of water available usually is expressed as a percentage of the ten-year, seven-day low flow. Most siting specialists and many river basin authorities prefer this measure because of its relation to extreme hydrologic events. The possibility of environmental damage exists, however, if numerous users are promised allocations whose sum represents an over-commitment of a stream's low flow. In order to

prevent this situation, several states require users to decrease or cease withdrawals when established standards for required minimum low flow are reached. Minimum low flow standards for a stream are generally specified as a fixed required rate of runoff or sometimes are based on a minimum low flow per unit of drainage area. The Allegheny Power Service Corporation, for example, requires that its plants should at no time reduce streamflow below 0.15 cfs per square mile of drainage area. Usually, the latter method leads to larger minimum standards for streams serving large drainage areas and lower standards for smaller basins. In considering these required minimum standards, utilities are most concerned with the number of days that production likely will have to be curtailed. As an alternative to dependence on natural flows, water may be stored in utility-owned reservoirs to augment the stream during periods of low flow to a level where consumptive withdrawal can continue.

The water availability factor was incorporated into the Maryland Data Base through a modeling effort described in *A System for Regional Analysis of Water Availability* by J. S. Jalbert and A. D. Shepherd.¹⁶ The Water Analysis System (WAS) allows the user to identify a geographic area by state, county, or latitude-longitude frame and recall data on streamflow from the USGS water tapes for all stream gaging stations within the area. Stations may be screened further on the basis of drainage area size if it is desirable to reduce the amount of data or if only basins of a certain size are considered relevant to the study. A calculation of the probability of recurrence of low-flow phenomena is made for all selected stations.

In the Maryland Data Base, streams whose flows are sufficient to support an additional 1000- to 1100-MWe power plant and still meet minimum standard low flows have been indicated. Stations unable to support such a facility dependably and meet minimum flow standards are subjected to a reservoir model analysis. The reservoir model predicts the drawdown capacity required to support a given consumptive withdrawal, including estimated evaporative losses from the reservoir surface, while maintaining a specified minimum low flow. Daily flow values for the entire period of record drive the model. Streams which will support a

power plant upon construction of a reasonable-size reservoir form a second category, and those which would require a reservoir of extraordinarily large drawdown capacity form a third. Proximities to all streams in the first and second categories are calculated.

3.3.2 Seismicity

Respondents invariably are highly concerned with the seismic risk at a prospective nuclear site; this is a chief differentiation between criteria matrices for nuclear and fossil-fired plants. Most respondents combine regional levels of seismic activity and the susceptibility of local geologic structures to form this factor. In practice, regional levels of seismic risk are readily available from the Nuclear Regulatory Commission,¹⁷ but the susceptibility of local geologic structures depends upon land surface slope, climate, overburden thickness, and subsurface characteristics that are measured separately. A comprehensive factor model could be constructed from the raw variables in the Maryland Data Base, but as of now, seismic activity and each of the structural variables are handled individually in the matrix.

3.3.3 Presence of rare or endangered species

Registered habitats of rare or endangered species are viewed as totally unacceptable for power plant sites because of their current legal status. Most respondents assume that the plant will disrupt the habitat and that litigation will prohibit or delay its construction. It is noteworthy that, coincident with the NGP session, the TVA was embroiled in litigation which threatened to halt construction of the Tellico Dam because of its possible impact on the snail darter, a rare species of fish. Group participants from TVA were sensitive to this factor, and other group members endorsed their high ranking. All respondents indicated that the species must be legally defined as rare or endangered in order to warrant the high importance weight. Pertinent data were obtained from the U.S. Army Corps of Engineers.¹⁸ The habitats of other species of concern but not legally registered as rare or endangered are considered in two separate factors dealing with impacts on aquatic and terrestrial biota. These rank somewhat lower in importance.

3.3.4 Population density and distribution

Population density is considered to be of great importance, particularly in regard to nuclear plants. Some respondents choose to list population distribution as a separate, though related, factor because of variations in potential radiation dosage with distance from the plant or position relative to wind patterns. Others included distribution in their concepts of density. In either case there was a tendency to defer to "NRC guidelines." In point of fact, the NRC has several measures of population density and distribution, and none is intended as a strict guideline. Variations in emergency evacuation plans and physiographic barriers must be considered in reaching a final decision on acceptable levels of population density. Nevertheless, the site population factor (SPF) defined by NRC often is used by utilities as a quasi guideline in regional screening.¹⁹

LUSP uses three measures of population density and distribution. A simple density is calculated from U.S. Census Enumeration District population totals. In addition, 5-mile and 30-mile SPF weighted density values (described in Sect. 2.1.1) serve as indicators of population distribution around each potential site.

3.3.5 Flood hazard

The likelihood of flooding is cited consistently among the most important factors in nuclear power plant location. At the individual scale of site-specific analysis, calculations of the probability of recurrence of various high rates of streamflow are required. However, most respondents do not feel that such detailed analyses are necessary at the regional scale. Generally the presence of a floodplain is taken as an indication of potential flooding, and no estimate of the magnitude is made. In the Maryland Data Base, floodplains are identified by the presence of periodically inundated soils in the soils (primary) variable.

3.3.6 Geologic structure

The importance of a cell's geologic foundation can be linked to construction and engineering characteristics as well as to its suitability

for the continued stability of a built facility. Fault zones, karst topography, and areas with a high potential for landslide obviously must be considered in evaluating natural hazards. Other structural characteristics can be interpreted in terms of engineering traits which affect building costs. Bedrock hardness, for example, can be included in a variable on blasting and grading requirements.

In practice the stability characteristics often are exclusionary, and the construction characteristics are of considerable importance though not exclusionary.

Six variables have been devoted to geology in the Maryland Data Base. The first three list geologic formations in descending order of areal extent within the cell. These have been interpreted further as variables on overburden thickness and blasting, grading, or dredging requirements.

The sixth geology variable relates to aquifer productivity (the capacity of permeable layers of sand, gravel, or porous rock to hold or transmit groundwater). Most respondents rate this factor much lower than other geologic traits, but environmental impact statements for proposed facilities invariably contain an investigation of aquifers and aquicludes (impermeable layers preventing seepage to an aquifer). This is especially important for nuclear plants because of the potential for underground contamination of water supplies in the event of radiation leakage.

3.3.7 Soils

The soils factor is ranked highly by most respondents, sometimes in combination with geology and sometimes standing alone. Wherever the geologic foundation is judged to be of sufficient supportive strength, soils are viewed primarily in terms of construction characteristics. Soils which can be graded and packed easily, which drain rapidly, and which do not become plastic under moist conditions are ideal for almost any type of building activity.

Of all those in the data base, the soils variable is, perhaps, the least understood by most respondents. Confusion arises in distinguishing

soil depth from overburden thickness, which includes soils as well as weathered and crumbling bedrock. Furthermore, many respondents have difficulty in interpreting soil characteristics in terms of their impacts on construction costs.

In addition to inherent engineering qualities, soil type is often used as a proxy for other cell characteristics such as the presence of marsh, swamps, rock outcrops, floodplains, or beaches.

3.3.8 Man-made hazards

Proximity to airports and industrial hazards such as munitions plants, refineries, and fuel storage tank farms is considered a significant factor in calculating the likelihood of accidental release of radiation from a nuclear reactor. Environmental impact statements contain a statistical analysis of the recurrence intervals for major disasters. The characteristics of both the reactor and the hazardous facility and the position of the plant relative to the facility enter into the calculation.

Such detailed calculations would be impractical in regional screening because of the large number of cells containing potential hazards which would have to be paired with cells representing potential sites. Moreover, the data base cannot contain meticulous information on each hazardous facility. Hence, proximity to broadly defined hazardous installations in itself serves as an indication of a potential risk. Usually cells adjacent to airports and other identifiable hazards are excluded from candidate areas.

3.3.9 Water quality

Existing water quality is viewed as a determinant of costs associated with plant design and operation because of the corrosiveness of some pollutants and the precipitate-producing tendency of others. Pure water can be recirculated through the cooling system over and over, but highly polluted water quickly becomes too concentrated because of evaporative losses. Herbicides must be added to all incoming water to prevent algal growth. All discharges must meet certain standards. Thus,

operating costs are increased by the additional treatment required for the greater intake and discharge of water from streams of poor quality. An alternative is to purify the intake water, but this increases plant design as well as operating costs.

The existing quality of the stream relative to pollution control standards is of further interest because of possible impacts on aquatic biota. If current effluents are at or near the maximum levels permitted by the Environmental Protection Agency or state and local implementation standards, the power plant must be designed to release almost no additional pollution. This is regarded as especially crucial if discharges must be released into known fish spawning areas or water with high concentrations of juvenile fish and benthic macroinvertebrates. Trout streams, both stocked and natural, are deemed critical regardless of existing water quality.

3.3.10 Other regional screening factors

Each nominal group listed more than 30 factors applicable to cells of the size used in the MPPSP, and it would be impractical to discuss them all in detail at this point. In summary it can be said that they display remarkable insight and a concern for a broad spectrum of conceivable impacts resulting from a power plant. No doubt many would be placed much higher on the importance scale if the same respondents or other interest groups were asked to emphasize other, more specific siting objectives.

4. APPLICATION OF THE ORNL LAND USE SCREENING PROCEDURE TO NORTHERN MARYLAND

The ORNL Land Use Screening Procedure (LUSP) was applied to the northern Maryland study area to identify candidate siting areas for nuclear and fossil-fired power plants, 1000 to 1100 MWe in size, each with three cooling options: cooling towers, cooling ponds, or once-through cooling systems. The six combinations of fuel and cooling technologies were treated as separate facilities with separate siting criteria entered into the screening procedure. Hence, siting criteria were determined for each of the following facilities:

1. a 1000- to 1100-MWe nuclear power plant with cooling tower,
2. a 1000- to 1100-MWe nuclear power plant with cooling pond,
3. a 1000- to 1100-MWe nuclear power plant with once-through cooling,
4. a 1000- to 1100-MWe fossil-fired power plant with cooling tower,
5. a 1000- to 1100-MWe fossil-fired power plant with cooling pond, and
6. a 1000- to 1100-MWe fossil-fired power plant with once-through cooling.

Each matrix of siting criteria has been applied to 31,234 cells of the Maryland Data Base for the northern eight counties. The record for each cell contains 52 variables; however, none of the siting specialists in the nominal group session felt that all 52 were relevant to siting considerations. The matrices utilized thus far have contained 29 or fewer variables.

The siting analysis for each facility type employs multiple criteria matrices as discussed in Chap. 3. Four respondent groups were asked to define these matrices for each of the four siting objectives. It was impractical to apply the entire procedure to each of the six facilities for all possible criteria matrices because this would require analysis of 96 separate sets of criteria. The final output consists of 22 criteria matrices distributed among the six facility types as appropriate to the siting analysis.

4.1 The Respondents

Resource analysts in the Maryland Power Plant Siting Program are the users of this procedure in its application to northern Maryland. Eight of the twenty-two criteria matrices have been determined by that office for the purposes of this study. For either nuclear or fossil-fired plants with cooling towers, the criteria deal with all four siting objectives: (1) minimization of construction and operating costs, (2) minimization of adverse socioeconomic impact, (3) minimization of adverse ecologic impact, and (4) a composite of all siting objectives (see Table 2). ORNL staff members have prepared 14 additional matrices covering the six facility types for the ecologic and composite siting objectives.

Table 2. Criteria matrices determined in the Maryland Power Plant Siting Project by facility, objective, and respondent

Objective	Minimization of construction and operating costs	Minimization of adverse ecologic impact	Minimization of adverse socioeconomic impact	Composite of all objectives
Nuclear with cooling tower	PPSP ^a	PPSP ORNL ^b	PPSP	PPSP ORNL 1st Nominal Group ^c 2nd Nominal Group ^c
Nuclear with cooling pond		ORNL		ORNL
Nuclear with once-through cooling		ORNL		ORNL
Fossil-fired with cooling tower	PPSP	PPSP ORNL	PPSP	PPSP ORNL
Fossil-fired with cooling pond		ORNL		ORNL
Fossil-fired with once-through cooling		ORNL		ORNL

^aPPSP - Maryland Power Plant Siting Program.

^bORNL - Oak Ridge National Laboratory.

^cImportance weights were determined by the Nominal Group Process. Compatibility indices were determined by ORNL staff.

Two separate groups of siting specialists were asked to determine siting criteria in an application of the Nominal Group Process. The precise makeup and operation of these panels are discussed in *Power Plant Siting: An Application of the Nominal Group Process Technique* by A. H. Voelker.¹² Each was asked to focus on nuclear power plants with cooling towers for a composite of all siting objectives. The first group contained representatives from ORNL, TVA, and the Maryland Power Plant Siting Program. The second consisted of different representatives of these same organizations plus one member from the Allegheny Power Service Corporation and one from the University of Illinois.

Because of time constraints and the desire not to inconvenience participants, the two groups were asked to provide importance weights only. To complete the necessary matrix, ORNL personnel produced compatibility indices to be used in suitability calculations for both nominal groups.

4.2 Comparisons of Criteria Matrices

The purpose of providing multiple matrices is to allow comparisons and cross-checks between various facilities, respondents, and objectives. The following types of comparisons are useful in analyzing the input data for each matrix:

- a. comparisons between different objectives for a given facility,
- b. comparisons between different respondents for a given facility and objective,
- c. comparisons between different facilities for a given objective.

To avoid the confusion of describing all 22 matrices, certain sets will be selected for comparison. The remaining portions of this chapter discuss such comparisons using the representative criteria matrices as illustrative examples.

4.2.1 Criteria for a fossil-fired power plant with cooling tower: a comparison among siting objectives

Importance weights obtained for four different siting objectives are displayed in Table 3. Each set is distinctively different from all

Table 3 Importance weights (on a scale of 0 to 10) assigned to variables in the Maryland Data Base for siting a 1000- to 1100-MWe fossil fired power plant with cooling tower as determined by the Maryland Power Plant Siting Program

Importance weights assigned to variables					
No	Variable Name	Minimization of construction and operating costs	Minimization of adverse ecological impact	Minimization of adverse socioeconomic impact	A composite of all siting objectives
45	Proximity to stream flow	10	2	0	10
36	Endangered species	0	10	0	10
23	Historic sites	0	0	8	8
48	Proximity to transmission lines	4	4	0	8
49	Proximity to fish spawning and nursing areas	0	8	0	8
26	Land use and land cover	0	0	6	6
19	Land surface slope	4	2	0	6
33	Seismicity	6	0	0	6
44	Proximity to railroads	4	2	0	6
4	Surface water quality	0	4	0	4
9	State and Federal lands	0	4	4	4
29	Planned land use and land cover	0	0	4	4
43	Proximity to highways	2	2	0	4
50	Proximity to airports and airport property	0	0	4	4
51	Proximity to endangered species	0	4	0	4
14	Soil group	2	0	0	4
37	Excavation requirements	3	0	0	3
38	Overburden thickness	3	0	0	3
11	Mineral resources	0	0	2	2
32	Highways and proposed highways	0	0	2	2
39	Aquifer recharge zones	0	2	0	2
35	Thirty-mile SPF	0	0	3	1
40	Five-mile SPF	0	0	4	1
42	Population density	0	0	3	1
46	Proximity to residential	0	0	4	1

others, and the composite objective incorporates the weights assigned to the three individual objectives. As one might expect, physical factors such as proximity to streamflow and seismicity rank high in the cost minimization matrix, while historic sites, land use, and population factors rank high on the socioeconomic matrix. (The importance weight for the population factor is divided between three population variables whose total weight is 10.) Endangered species and designated natural areas head the list on the ecologic matrix.

For each highly incompatible category or value of a highly important variable a decision must be made by the respondent either to assign an exclusion index (-1) or a minimum compatibility index (0). This decision can have a dramatic effect on the final scores because the assignment of numerous exclusions reduces the number of potential sites while increasing the average score of the cells remaining in the calcu-

lation. Excluded categories and values serve well as a means of comparing the compatibility components of various criteria matrices. The entire set of compatibility indices presented in Appendix A is too cumbersome for a detailed comparison.

Table 4 displays the exclusion factors prepared by Maryland personnel for four different criteria matrices. It is evident that the respondents were distinguishing between the three individual objectives, since no two matrices contain the same exclusions. The composite matrix contains the accumulated exclusions of all other matrices; however, it is quite possible for a category to be perceived as exclusionary for a specific objective and merely of low compatibility in the composite matrix. This results from the implicit importance ascribed to the objective itself in preparing the composite matrix. The accumulation of exclusions from all objectives, as in this example, demonstrates a willingness to consider all objectives equally.

Table 4. Categories and values of variables assigned exclusions for siting a 1000- to 1100-MWe fossil-fired power plant with cooling tower as determined by the Maryland Power Plant Siting Program for various objectives

No	Variable Name	Category or range of values	Minimization of construction and operating costs	Minimization of adverse ecologic impact	Minimization of adverse socioeconomic impact	A composite of all siting objectives
9	State and Federal lands	Department of the Interior, Fish and Wildlife, and Forests and Parks			X	X
19	Land surface slope	>20% slope	X	X		X
26	Land use and land cover	Urban activity, water cover, barren land			X	X
29	Planned land use and land cover	Urban activity, water cover, barren land			X	X
32	Highways and proposed highways	Existing two- and four-lane and interstate and major intersections			X	X
45	Proximity to stream flow	Proximity greater than 16.6 km	X			X
51	Proximity to endangered species	Proximity of 0-0.6 km		X		X

4.2.2 Criteria for a nuclear power plant with cooling tower: a comparison among respondents

A fundamental reason for requiring numerous criteria matrices is the expected variation between the values and judgments of different groups. Table 5 indicates that great differences can be obtained from different respondents even for the same facility and objective. Three of the four respondent groups rated seismicity, proximity to water, and presence of endangered species at 10. Surprisingly, the fourth group felt that potential subsidence associated with deep mining of mineral resources was a more important consideration than any of those listed above.

For any given variable the weight can vary considerably among the four respondents. In fact, no variable received exactly the same weight from all respondents, only a few were perceived by all respondents to be of approximately the same importance, and some variables ranged as much as eight or nine points between their maximum and minimum assignments. These wide variations could bring into question the validity of the quantification if it were not for the probability that such variations actually do exist among siting specialists. Certainly disagreement exists among "experts" in any field. The advantage here is that their values are stated explicitly so that comparisons can be made.

Table 6 reveals further variation in the respondents' attitudes toward assigning exclusions. The three respondents were able to agree only on exclusions for certain land-use and land-cover categories, including urban uses and water bodies.

Table 5. Importance weights (on a scale of 0 to 10) assigned by respondents to variables in the Maryland Data Base for siting a 1000- to 1100-MWe nuclear power plant with cooling tower with a composite siting objective

No.	Variable	PPSP ^a	First	Second	ORNL ^b
	Name		Nominal Group	Nominal Group	
33	Seismicity	10	10	7	10
45	Proximity to stream flow	10	10	9	10
36	Endangered species	10	10	7	10
17	Natural features	10	7	5	10
23	Historic sites	8	5	8	6
48	Proximity to transmission lines	8	7	4	2
49	Proximity to fish spawning and nursing areas	8	8	9	0
52	Proximity to natural features	8	7	3	2
26	Land use and land cover	6	6	9	10
19	Land surface slope	6	4	8	8
4	Surface water quality	4	8	9	8
9	State and Federal lands	4	4	7	8
29	Planned land use and land cover	4	0	0	0
37	Excavation requirements	4	5	5	0
38	Overburden thickness	4	2	3	0
40	Five-mile SPF	4	4	3	0
43	Proximity to highways	4	6	3	6
44	Proximity to railroads	4	6	4	8
46	Proximity to residential	4	6	2	10
50	Proximity to airports and airport property	4	8	8	8
51	Proximity to endangered species	4	10	2	6
42	Population density	3	9	7	10
35	Thirty-mile SPF	3	4	2	0
11	Mineral resources	2	8	10	4
14	Soil group	2	2	5	6
32	Highways and proposed highways	2	6	3	4
39	Aquifer recharge zones	2	3	4	0
7	Transportation and transmission	0	6	3	4
34	Fish spawning and nursing areas	0	8	9	0
47	Proximity to agricultural land use	0	6	0	4
12	Water and sewer facilities	0	0	0	2

^aPPSP - Maryland Power Plant Siting Program.

^bORNL - Oak Ridge National Laboratory.

Table 6. Categories and values of variables assigned exclusions by respondents for siting a 1000- to 1100-MWe nuclear power plant with cooling tower with a composite siting objective

No.	Name	Variable	Category or range of values	PPSP ^a	J. E. Dobson and J. S. Jalbert (used in matrices for First and Second Nominal Groups)	ORNL ^b
4	Surface water quality	Class II, III, and IV waters and clam beds				X ^c
7	Transportation and transmission	Airports and airport property				X
9	State and Federal lands	Departments of the Interior, Fish and Wildlife, and Forests and Parks		X		X
11	Mineral resources	Gas field used for storage		X		
14	Soil group	Tidal marshes and swamps			X	
17	Natural features	Presence of natural feature				X
19	Land surface slope	<20% slope		X		
26	Land use and land cover	Urban activity, water cover, barren land		X	X	X
29	Planned land use and land cover	Urban activity, water cover, barren land		X		
32	Highways and proposed highways	Existing two- and four-lane and interstate and major intersections		X		X
35	Thirty mile SPF	SPF factor < 0.5		X	X	
36	Endangered species	Observed range of Indiana bat			X	X
40	Five mile SPF	SPF factor < 0.5			X	
42	Population density	512-2999 persons sq mile			X	
		>2999 persons sq mile			X	X
43	Proximity to highways	Proximity greater than 6 km				X
45	Proximity to stream flow	Proximity greater than 10 km			X	
		Proximity greater than 16.6 km		X		
46	Proximity to residential	Proximity of 0-0.6 km		X		X
47	Proximity to agricultural	Proximity of 0.6-1.8 km				X
49	Proximity to fish spawning and nursing areas	Proximity of 0-0.6 km			X	
50	Proximity to airports and airport property	Proximity of 0-1.2 km			X	X
		Proximity of 1.2-4.2 km				X
51	Proximity to endangered species	Proximity of 0-0.6 km		X		X
		Proximity of 0.6-1.8 km				X
52	Proximity to natural features	Proximity of 0.6-1.8 km				X

^aPPSP - Maryland Power Plant Siting Program

^bORNL - Oak Ridge National Laboratory

X - Indicates exclusionary index

4.2.3 Criteria for a nuclear or fossil-fired power plant: a comparison between fuel options

The considerations which influence a utility company's decision regarding the choice of fuel types for a given facility are too complex to be solved in a screening algorithm of the type used in LUSP. They include questions of fuel cost, reliability, and public acceptance which generally are not suited to inclusion in an extensive geocoded data base either because the information can be collected only through strenuous site-specific analyses or because it would require continuous updating.

Presumably many land parcels would be suited to either a nuclear or fossil-fired facility in terms of their capability to support it physically and to bear the social, ecologic, and economic impacts. Tables 7 and 8 show that the same importance weights and exclusions are assigned for most variables. There are basic distinctions between the matrices where population densities and seismic risk are concerned. For all

Table 7. Importance weights (on a scale of 0 to 10) assigned to variables in the Maryland Data Base for siting a 1000- to 1100-MWe power plant with a composite siting objective as determined by the Maryland Power Plant Siting Program

No.	Variable	Nuclear power plant with cooling tower	Fossil-fired power plant with cooling tower
	Name		
33	Seismicity	10	6
45	Proximity to stream flow	10	10
36	Endangered species	10	10
17	Natural resources	10	10
23	Historic sites	8	8
48	Proximity to transmission lines	8	8
49	Proximity to fish spawning and nursing areas	8	8
52	Proximity to natural features	8	8
26	Land use and land cover	6	6
19	Land surface slope	6	6
4	Surface water quality	4	4
9	State and Federal lands	4	4
29	Planned land uses and land cover	4	4
37	Excavation requirements	4	3
38	Overburden thickness	4	3
40	Five-mile SPF	4	1
43	Proximity to highways	4	4
44	Proximity to railroads	4	6
46	Proximity to residential	4	1
50	Proximity to airports and airport property	4	4
51	Proximity to endangered species	4	4
42	Population density	3	1
35	Thirty-mile SPF	3	1
11	Mineral resources	2	2
14	Soil group	2	4
32	Highways and proposed highways	2	2
39	Aquifer recharge zone	2	2

Table 8. Categories and values of variables assigned exclusions for siting a 1000- to 1100-MWe plant with a composite siting objective as determined by the Maryland Power Plant Siting Program

No.	Name	Variable Category or range of values	Nuclear power plant with cooling tower	Fossil-fired power plant with cooling tower
9	State and Federal lands	Departments of the Interior, Fish and Wildlife, and Forests and Parks	X ^a	X
11	Mineral resources	Gas field used for storage	X	
14	Soil group	Tidal marshes and swamps	X	
19	Land surface slope	>20% slope	X	X
20	Land use and land cover	Urban activity, water cover, barren land	X	X
29	Planned land use and land cover	Urban activity, water cover, barren land	X	X
32	Highways and proposed highways	Existing two- and four-lane and interstate and major intersections	X	X
35	Thirty-mile SPF	SPF factor >0.5	X	
36	Endangered species	Observed range of Indiana bat	X	X
45	Proximity to stream flow	Proximity greater than 16.6 km	X	X
46	Proximity to residential	Proximity of 0-0.6 km	X	
50	Proximity to airports and airport property	Proximity of 0-1.2 km	X	

^aX - Indicates exclusionary index.

variables dealing with these factors the standards for nuclear plants are much more stringent. It should be noted, however, that air pollution standards for fossil-fired plants often have the same effect of forcing the facilities away from large urban settlements.²⁰

The respondent also indicated a difference in transportation and accessibility factors between the two fuel types. Proximity to railroads was viewed as slightly more important for fossil-fired plants because of the need for frequent shipments of fuel (most respondents anticipated that fossil-fired plants would use coal). On the other hand, barge access was considered to be somewhat more desirable for nuclear plants because of the difficulty of transporting the reactor pressure vessel overland during the initial construction phase. Airports were felt to be particularly hazardous for nuclear plants.

4.2.4 Criteria for a fossil-fired plant with the objective of minimizing adverse ecologic impact: a comparison among cooling system options

Most respondents express difficulty in distinguishing between the criteria for various cooling system options at the regional and local screening levels. Table 9 reveals only slight differences in the

Table 9. Importance weights (on a scale of 0 to 10) assigned to variables in the Maryland Data Base for siting 1000- to 1100-MWe fossil-fired power plants with various types of cooling systems with the objective of minimizing adverse ecologic impact as determined by ORNL.

Variable		Cooling tower	Cooling pond	Once-through
No.	Name			
17	Natural features	10	10	10
36	Endangered species	10	10	10
39	Aquifer recharge zones	10	10	9
4	Surface water quality	9	9	10
51	Proximity to endangered species	9	9	9
52	Proximity to natural features	9	9	9
9	State and Federal lands	8	8	8
26	Land use and land cover	8	8	8
14	Soil group	7	7	5
49	Proximity to fish spawning and nursing areas	7	7	8
19	Land surface slope	6	6	5
29	Planned land use and land cover	6	6	6
42	Population density	6	6	6
13	Forest type	5	7	5
45	Proximity to stream flow	4	4	4
11	Mineral resources	3	3	3
23	Historic sites	2	1	1
43	Proximity to highways	1	1	1
44	Proximity to railroads	1	1	1
48	Proximity to transmission lines	1	1	1

importance weights assigned in each matrix. The majority of variables receive precisely the same weight for all three cooling systems, and in no case do the weights differ by more than 2 points. Table 10 shows even less distinction in the exclusions granted to the three facilities. The only difference is in the categories indicating polluted trout streams, where the respondent feels that fish should not be subjected to the greater intake of once-through cooling systems regardless of the condition of the stream.

Table 10. Categories and values of variables assigned exclusions for siting 1000- to 1100-MWe fossil-fired power plants with various types of cooling systems with the objective of minimizing adverse ecologic impact as determined by ORNL.

Variable			Cooling tower	Cooling pond	Once-through
No.	Name	Category or range of values			
4	Surface water quality	Class III and IV waters Class III and IV waters not meeting standards	X ^a	X	X X
9	State and Federal lands	Departments of the Interior, Agriculture, Fish and Wildlife, and Forests and Parks	X	X	X
13	Forest type	Southern cypress	X	X	X
14	Soil group	Wet sandy, poorly drained - dense subsoils, flood plains, tidal marshes and swamps, and very rocky	X	X	X
17	Natural features	Presence of natural features	X	X	X
19	Land surface slope	>20% slope	X	X	X
26	Land use and land cover	Water cover and wetlands	X	X	X
29	Planned land use and land cover	Water cover and wetlands	X	X	X
36	Endangered species	Generalized cave region and observed location of Indiana bat	X	X	X
39	Aquifer recharge zones	Hydrologic unit I of Piedmont and Appalachian provinces and sandy aquifer of coastal plains	X	X	X
42	Population density	0-35 persons/sq mile	X	X	X
51	Proximity to endangered species	Proximity of 0-0.6 km	X	X	X
52	Proximity to natural features	Proximity of 0-1.2 km	X	X	X

^aX - Indicates exclusionary index.

4.3 The Utility of Multiple Matrices

The examples discussed in this chapter and other criteria matrices examined at ORNL support the conclusion that at the regional and local screening levels, most respondents can distinguish clearly between different siting objectives. The distinction between criteria for different fuel types also is great enough to warrant the application of separate matrices. However, the ability of most respondents to distinguish between various cooling options with the current data coverage is doubtful. Additional refinement of the streamflow and soil type variables is required.

Perhaps the most important conclusion is that differences among respondents are sizable even when the type of facility and siting objective are the same. This suggests that it is essential to consult numerous interest groups in establishing criteria for regional and local screening. A further test of this conclusion is the analysis of the spatial distributions of candidate areas obtained from different matrices, and these are discussed in Chap. 5.

5. ANALYSIS OF THE CELL SUITABILITY SCORES

The criteria matrices are applied to the data base according to the formula described in Sect. 2.2.2, and suitability scores are obtained for each cell. The suitability calculation program automatically produces histograms and calculates statistical moments describing the frequencies of cell suitability scores. An additional program is available to map the spatial distribution of scores obtained from each matrix.⁷ This chapter focuses on statistical and spatial analyses of cell suitability scores and the interpretation of candidate-area maps.

5.1 Statistical Analysis

The primary purpose of the statistical information is to serve as a guide in deciding which ranges of scores form meaningful classes for candidate-area selection. Usually it is necessary to know the frequency and central tendency of the scores to determine which ranges should be mapped.

The histogram provides a quick check on the operation of the screening algorithm. At a glance the user can detect certain types of errors evident in the range and skewness of the distribution. For example, a range of scores from 0 to 5 on the histogram might indicate that the user had substituted a 0 to 5 scale in one of the matrices for the usual compatibility range of 0 to 10. This would alert the user that one set of scores was not precisely comparable with others employing the usual range.

More important, the histogram creates a visual impression of the strictness with which respondents have assigned compatibility indices. In a comparison of the scores obtained from different respondents for the same facility (and objective), a distribution abnormally skewed toward the upper range indicates that the respondent has been willing to grant higher compatibility indices in the original matrix. Whether this results from a genuinely more lenient siting policy or from a different understanding of the data or screening procedure should be taken into account in mapping candidate areas.

The user can define candidate areas by any range of scores he chooses, but it is recommended that the choice should take the overall distribution and the value of the mean into consideration. In the MPPSP, candidate areas consist of cells whose scores are one or more standard deviations above the mean. This compensates for any variation in the strictness with which the compatibility indices were assigned because the mean is influenced by the skewness of the overall distribution. Furthermore, it assures that a constant proportion of the total distribution will be defined in each set of suitability scores. Cells receiving exclusions are not included in the calculation of the mean and standard deviation. From the 22 sets of scores obtained thus far it is apparent that the histogram usually approximates a normal distribution of scores around the mean.

5.2 Spatial Analysis

The thematic mapping program designed to accompany the LUSP produces line-printer maps with typed titles and legends in a standardized format. Programming instructions and illustrations can be found in *A Cell-Based Land Use Screening Procedure for Regional Siting Analysis*.⁷ This particular form of graphic output was chosen because the resultant maps are sufficient for analytical purposes and can be run cheaply on relatively small computer systems. It was anticipated that many potential users would not possess highly sophisticated graphic capabilities.

The line-printer maps are not well suited for display in published reports. Hence the maps contained in this document were produced on a Calcomp plotter by the Computer Sciences Division of ORNL. Both types of maps can be used to display raw variables, proximity variables, or suitability scores with up to 30 symbols representing different categories defined in the legend.

Maps displaying ranges of suitability scores are essential in the spatial analysis of the scores obtained from the various criteria matrices. The remainder of this section is organized for ease of comparison between the scores obtained from different respondents for differing objectives and facilities.

5.2.1 Candidate areas for a fossil-fired power plant: a comparison among siting objectives

The role of various siting objectives in selecting candidate areas is illustrated in the maps obtained from matrices developed by the Maryland Power Plant Siting Program. When cost minimization is the overriding objective, most of the coastal and riverine areas in the study region are defined as candidate areas (Fig. 3). Considering that most of the electrical demand is in the eastern megalopolis including Baltimore and Washington, D.C., locations on Chesapeake Bay seem especially attractive. The Monocacy and Potomac Rivers in Frederick County form extensive candidate areas within 65 km (40 miles) of Baltimore. These, too, would be near the electrical load center and would be within a reasonable commuting distance of the heavy construction labor forces in Baltimore and Washington, D.C. Scattered sites can be seen also along the upper reaches of the Potomac in Washington, Allegany, and Garrett Counties, with heaviest concentrations near Cumberland, Maryland. However, these must be viewed with suspicion because of the lack of geographic data beyond the state boundary.

The distribution of suitable candidate areas for a socioeconomic objective is substantially different from that discussed above (Fig. 4). Almost the entire eastern one-third of the study region is eliminated because of characteristics associated with its high population concentration. The extent of the candidate areas increases to the west as population densities decline, with noticeable gaps near the cities of Frederick, Hagerstown, and Cumberland.

Ecologic considerations, on the other hand, cause the distribution of candidate areas to shift away from the sparsely populated, more natural and scenic areas of the west (Fig. 5). Similarly, most of the land near Chesapeake Bay is eliminated because of natural and scenic qualities. The resulting candidate areas are concentrated in areas of intermediate population in the central and eastern counties, with a few scattered cells near the urban areas of the west.

The distribution of candidate areas obtained for a composite of all siting objectives appears to be a compromise of the three individual objectives (Fig. 6). The largest concentration is in the center of the

Fig. 3. Candidate areas for a fossil-fired power plant with cooling tower in northern Maryland, 1976. Siting objective: minimization of construction and operating costs. Respondent: Maryland Power Plant Siting Program. Number of variables in calculation: 27.

Fig. 4. Candidate areas for a fossil-fired power plant with cooling tower in northern Maryland, 1976. Siting objective: minimization of adverse socioeconomic impact. Respondent: Maryland Power Plant Siting Program. Number of variables in calculation: 27.

PRODUCED BY DAN RIDGE
GEOGRAPHIC DATA SYSTEMS

Fig. 5. Candidate areas for a fossil-fired power plant with cooling tower in northern Maryland, 1976. Siting objective: minimization of adverse ecologic impact. Respondent: Maryland Power Plant Siting Program. Number of variables in calculation: 27.

PRODUCED BY ORNL RIDGE
GEOGRAPHIC DATA SYSTEMS

Fig. 6. Candidate areas for a fossil-fired power plant with cooling tower in northern Maryland, 1976. Siting objective: composite of all objectives. Respondent: Maryland Power Plant Siting Program. Number of variables in calculation: 27.

study region, where all three previous maps have shown candidate areas. Except for those near the Monacacy River and the upper Potomac near Cumberland, most of the high-scoring cells form clusters too small to be utilized as actual sites. In the east only one cluster on the Susquehanna River appears to be large enough to constitute a viable candidate site without acquiring adjacent lower-scoring cells.

5.2.2 Candidate areas for a nuclear or fossil-fired power plant: a comparison between fuel types

A comparison between the candidate areas obtained for nuclear vs fossil-fired plants by the Power Plant Siting Program for each siting objective shows that their spatial distributions are almost identical (Figs. 3-10). Although several distinctions between fuel types were noted in the criteria matrices, the more stringent standards for nuclear plants have had almost no effect on the overall distribution of high-scoring cells.

In going from the candidate areas for fossil-fired plants to those for nuclear plants, it appears that a few scattered cells are eliminated in the east, while concentrations have become slightly heavier in the west. In addition, a few cells near urban centers have been dropped. In other words, some of the socioeconomic impacts anticipated for nuclear plants have forced the user to risk slightly greater ecologic impact by opting for more remote areas. In this particular example it is doubtful that the distinction is great enough to justify the additional effort involved in treating them as separate facilities. It is possible, however, that the spatial distributions might differ substantially in other parts of the United States, especially in locations where seismic risk varies considerably within the region.

Much greater distinction between fuel types is apparent in the maps prepared at ORNL with the objective of minimizing adverse ecologic impact (Figs. 11 and 12). While the candidate areas for a fossil-fired plant are not unlike those produced by the Power Plant Siting Program for the same facility and objective (Fig. 5), the ecologic criteria for a nuclear plant are so stringent that only a few candidate areas remain.

Fig. 7. Candidate areas for a nuclear power plant with cooling tower in northern Maryland, 1976. Siting objective: minimization of construction and operating costs. Respondent: Maryland Power Plant Siting Program. Number of variables in calculation: 27.

Fig. 8. Candidate areas for a nuclear power plant with cooling tower in northern Maryland, 1976. Siting objective: minimization of adverse socioeconomic impact. Respondent: Maryland Power Plant Siting Program. Number of variables in calculation: 27.

Fig. 9. Candidate areas for a nuclear power plant with cooling tower in northern Maryland, 1976. Siting objective: minimization of adverse ecologic impact. Respondent: Maryland Power Plant Siting Program. Number of variables in calculation: 27.

PRODUCED BY ORNL R1002
GEOGRAPHIC DATA SYSTEMS

Fig. 10. Candidate areas for a nuclear power plant with cooling tower in northern Maryland, 1976. Siting objective: composite of all objectives. Respondent: Maryland Power Plant Siting Program. Number of variables in calculation: 27.

Fig. 11. Candidate areas for a nuclear power plant with cooling tower in northern Maryland, 1976. Siting objective: minimization of adverse ecologic impact. Respondent: Oak Ridge National Laboratory. Number of variables in calculation: 20.

Fig. 12. Candidate areas for a fossil-fired power plant with cooling tower in northern Maryland, 1976. Siting objective: minimization of adverse ecologic impact. Respondent: Oak Ridge National Laboratory. Number of variables in calculation: 20.

5.2.3 Candidate areas for a fossil-fired power plant with the objective of minimizing adverse ecologic impact: a comparison of cooling system options

The spatial distributions of suitability scores obtained for three different cooling systems for the same objective and from the same respondent are almost precisely identical (Figs. 12-18). This supports the conclusion reached in the discussion of criteria matrices that most respondents are unable to distinguish between them without more precise information regarding streamflow and soil type. It is recommended, therefore, that they should not be treated as separate types of facilities in interpreting the results of this analysis.

5.2.4 Candidate areas for a nuclear power plant with a composite siting objective: a comparison among respondents

Figures 10, 15, and 16 offer a comparison of the candidate areas for a nuclear power plant obtained from three different respondents. The overall distributions are similar though far from identical. The Power Plant Siting Program map has fewer candidate-area cells because more exclusions have been granted in this matrix than in the compatibility indices used jointly for the two nominal group matrices. For the most part the candidate areas in Fig. 10 are smaller concentrations in the same general pattern as those produced by the nominal groups. In the east the difference in size is enough to eliminate most clusters large enough to support a large nuclear facility. A few concentrations remain along the upper Potomac, but most of the clusters in Washington County are eliminated by the Power Plant Siting Program criteria matrix.

The prominent concentration of high scores along the Monocacy and near its junction with the Potomac is evident on all three maps, but there are subtle differences in its configuration. Criteria specified by the nominal groups have brought about tighter clusters with a broader opening for the urban influence of Frederick. A narrow strip of lower-scoring cells occurs on the upper portion of the Monocacy River on maps produced from input of the first nominal group and from personnel in the Maryland Power Plant Siting Program but not on those maps based on input

Fig. 13. Candidate areas for a fossil-fired power plant with cooling pond in northern Maryland, 1976. Siting objective: minimization of adverse ecologic impact. Respondent: Oak Ridge National Laboratory. Number of variables in calculation: 20.

Fig. 14. Candidate areas for a fossil-fired power plant with once-through cooling technology in northern Maryland, 1976. Siting objective: minimization of adverse ecologic impact. Respondent: Oak Ridge National Laboratory. Number of variables in calculation: 20.

Fig. 15. Candidate areas for a nuclear power plant with cooling tower in northern Maryland, 1976. Siting objective: composite of all objectives. Respondent: first nominal group. Number of variables in calculation: 29.

Fig. 16. Candidate areas for a nuclear power plant with cooling tower in northern Maryland, 1976. Siting objective: composite of all objectives. Respondent: second nominal group. Number of variables in calculation: 29.

Fig. 17. Generalized candidate areas for a nuclear power plant with cooling tower.

Fig. 18. Generalized candidate areas for a fossil-fired power plant with cooling tower.

from the second nominal group. Apparently this results from different treatment of the transportation variable.

5.3 Interpretation of Candidate-Area Maps

It should be apparent from the material presented in this report that a given region has not one set but many sets of candidate areas depending upon the perspectives of the respondents. This accounts for the difficulty in gaining public and corporate acceptance of most regional-screening packages which operate with a single built-in set of criteria. Yet, regional planners, utility executives, and regulatory officials often are faced with the necessity of defining a rigid set of candidate areas from which candidate sites will be chosen. If the LUSP is to be of any use, it must serve as a tool in selecting a final slate of candidate areas representing the best compromise between all interest groups. The user, therefore, should thoroughly understand the meaning and limitations of the candidate-area maps.

The user should be aware that the maps are not intended as a substitute for the knowledge or judgment of an experienced siting specialist. They are simply a means of examining alternative policies and simulating different viewpoints or priorities in site selection. LUSP is not intended to perform the judgmental decisions involved in choosing the final set of candidate areas. The judgment of the user is essential to make the decision as to which criteria will dominate the final selection.

From a technical standpoint the LUSP programs allow the user to create a set of compromised suitability scores by treating the previously obtained scores as if they are raw variables. Importance weights can be assigned to indicate the influence the user wishes a particular set of criteria to have in the final selection. Exclusions can be assigned to low ranges of the scores obtained from all or a few of the respondents. From a theoretical standpoint, however, it is extremely difficult to represent the power of various interest groups by a simple importance weight, and an optimal solution can only be defined as a site in which high scores are obtained from all matrices.¹⁰ Of course, very few cells in the entire study region score well on all matrices.

Perhaps, the best way for the user to employ the candidate-area maps is to examine and compare them as we have done, looking especially for cells which score highly on numerous matrices. If a concentration of cells appears in almost all candidate-area maps but scores poorly on one or two maps, the user can decide objectively whether or not to allow the minority opinion to influence the final selection. If the user decides other interests should prevail, at least he will be aware of the potential for opposition, and opponents are assured that their views were considered in the selection process. In some cases, users may be inclined to go against the majority opinion, and here again they are forewarned of the potential for strong opposition.

5.3.1 Candidate areas consistently chosen for a nuclear power plant

The following example illustrates a possible compromise between the candidate-area maps displayed in this report.

From a comparison of all candidate areas for a nuclear plant (Figs. 7-11, 15, and 16), it can be seen that no clusters of cells large enough to form a candidate site score highly on all matrices. The ecological matrix assigned at ORNL is so stringent that only a few scattered cells have scored highly (Fig. 11), and these are mostly in the eastern portion, which is eliminated by the socioeconomic matrix (Fig. 8). If the user has been charged with the responsibility for locating a nuclear plant, he will not be able to dismiss all sites so easily. Most likely it will be necessary to set the most stringent matrix aside and examine those which allow some possibility of defining a site.

The remaining maps show that a sizable concentration of cells in the vicinity of the Monocacy River in Frederick County scores highly on all other matrices. Thus, it is possible to define a large candidate area northeast of Frederick (Fig. 17) with the foreknowledge that it may require detailed ecologic impact analysis before specific sites can be chosen with confidence. Another large concentration south of Frederick appears on all maps except those produced by the Power Plant Siting Program. This can be defined as a candidate area with an even greater warning of the potential for ecologic impact.

Similarly, a few small clusters of cells appear along the Potomac east of Cumberland on all matrices except those emphasizing ecologic concerns. These, too, can be defined as candidate areas with a caveat regarding the need for ecologic impact analysis.

Three generalized candidate areas for a nuclear power plant can be defined as a compromise between all previously obtained candidate-area maps. If the user feels that more are necessary, he can form a second set of generalized candidate areas which score highly on fewer matrices than those shown in Fig. 17. For this set he knows that the chances of opposition are even greater.

5.3.2 Candidate areas consistently chosen for a fossil-fired power plant

A comparison of all candidate-area maps for a fossil-fired power plant with cooling tower (Figs. 3-6 and 12) reveals that no clusters of cells score highly on all matrices. The distributions obtained from the socioeconomic and ecologic matrices completed by the Power Plant Siting Program are almost precisely the inverse of each other, and this precludes the possibility of cells scoring uniformly high on all maps. Most of the upper-Monocacy candidate area and portions of the lower-Monocacy candidate area appear on four of the five maps (Fig. 18). Of the cells included in the generalized candidate area, half must be accompanied with reservations regarding socioeconomic impacts and half with ecologic reservations. A few scattered cells near Cumberland also appear on four of the five candidate-area maps, and these bear similar reservations of potential impacts.

5.3.3 Reliability of candidate-area maps

In interpreting candidate-area maps, the user should remember that they represent only those variables included in the data base and the criteria assigned by the respondent. In any case, when the user has firsthand knowledge of contradictory information or of extenuating circumstances, that knowledge necessarily must be permitted to overrule the results of the screening procedure. In addition, reliability of the candidate-area maps is affected by the accuracy of the data, the

respondents' understanding of the data, the completeness with which siting factors are covered, and the sensitivity of the screening algorithm to the number of variables included in each calculation.

5.3.3.1 Accuracy of the Maryland Data Base. The accuracy of all variables obtained from the Maryland Automated Geographic Information System (MAGI) was checked against independent sources wherever possible. If other sources were not available, the data were checked for internal consistency between categories of different variables containing approximately the same information. For example, cross tabulations were made between the forest type variable and the forest cover category of the land use and land cover variable. In other cases, simple visual checks of the mapped variables were sufficient, as with the county number variable, where errors are easily detected as noncontiguous cells.

The data appear to be extremely accurate, especially when the size and areal extent of the base file are taken into account. The discrepancies between MAGI and other sources were less than 1% on several variables and did not exceed 6% on any of the variables so checked. Cross tabulations within the MAGI variables indicate enough congruence of similar categories to suggest that the accuracy and precision of the geocoded data are well within acceptable bounds.

A more significant problem with the MAGI variables results from incomplete documentation of the codes used in storing the data. A total of 22 codes appear in the data files but not in the accompanying documentation (Table 11). Some of these, no doubt, result from typographical

Table 11. Undocumented or erroneous codes in the Maryland Automated Geographic Information System

Variable	Number of undocumented or erroneous codes	Number of cells affected
Surface water quality	1	1
Transportation and transmission	8	13
State and Federal lands	1	1
Mineral resources	2	56
Forest type	6	61
Soil group	3	39
Land surface slope ^a	1 ^a	2025 ^a
Total	22	2196

^aIn MAGI this variable is named "Topography." The undocumented code is zero (0), which apparently represents water surfaces.

errors in digitizing, while some are accurate codes for which no key has been provided. If this were the only problem with the documentation, the degree of error still would be acceptable, for these affect a maximum of 7% of all cells. Since the meaning of the undocumented "land surface slope" code can be deduced by examining the mapped variable, no more than 171 cells (0.5%) remain truly undocumented.

A much larger number of cells have insufficient documentation. It is often difficult to understand precisely what is meant by the variable and category descriptions. For example, the geologic formation variable contains a description of overburden thickness, but the terms "thin," "medium," and "thick" are never defined numerically. Often categories are combined awkwardly, as in the case of water and sewer facilities, where two independent variables are coded as a single variable. Some variables contain categories which are not mutually exclusive. For instance, transportation and transmission facilities are combined, and there is no indication as to which facilities are involved when they occur in the same cell.

The effect of insufficient, confusing, or misleading documentation is difficult to assess because it varies from one respondent to another. Through prolonged contact with the system an individual may eventually understand the meaning of all but a few codes; however, it is sometimes necessary to obtain expert opinion from specialists, who can hardly be expected to spend weeks or months learning the data base. Hence, understanding of the data varies from respondent to respondent and occasionally may influence the spatial distribution of candidate areas.

5.3.3.2 Missing factors. As a test of the completeness of data coverage in the Maryland Data Base, both nominal groups were asked to name regional and local siting factors without reference to the list of variables already available. Their lists of factors were then compared with the list of variables in the data file. Roughly equivalent information was found to be available for most of the factors named. Moreover, all of the missing factors were those which ranked relatively low among the siting factors. In descending order of importance the missing factors as defined by the first nominal group are (1) the existence of regional and local planning agencies to manage anticipated social and economic

changes, (2) the local perception of plant desirability, (3) the availability of water and land in terms of ownership, (4) meteorological hazards, (5) background radiation, and (6) visual compatibility. The second nominal group added proximity to load demand — a factor which probably should be handled at a broader scale of analysis.

A comparison of the two lists also underscores the need for development of factor indices rather than simple measured variables. A case in point is the transportation accessibility factor named by the two nominal groups. It is intended to measure the relative ease of transporting workers and materials to and from urban areas. Yet, the data base contains only a listing of the transportation facilities available within each cell. Unless the raw variable is entered into an accessibility model along with road and rail distance to nearest distribution centers and labor sources, it is at best an expedient surrogate for the information requested by the nominal groups. The calculation of proximities to roads and railroads is a simple first step toward the type of factor models needed for adapting the data file to serve site screening purposes fully.

Each factor model in itself would require extensive analysis and considerable research time. Priority was given to those factors which rank highly on most matrices, with the greatest effort devoted to estimating the availability of sufficient water for cooling.¹⁶ Considerable effort also was expended in adapting and applying existing population models to the data base. Additional work needs to be done on these and other variables.

5.3.4 Sensitivity of the screening algorithm

The number of variables included in each suitability calculation is a matter of concern in interpreting the candidate-area maps. It must be ascertained that the coverage is sufficient to produce patterns more discriminating, for example, than a simple replication of the stream courses. On the other hand, the incremental cost of adding new variables to the data base is a considerable expense in time and money which must be balanced against the potential influence of the variable on the suitability scores. The sensitivity of the screening algorithm (the degree to which the final scores are altered by changes in one or more

variables) is a major consideration in justifying the collection of additional variables of low importance.

To test the influence of variables at each level of importance, suitability scores were calculated and candidate-area maps were produced from each matrix, first including all variables and then successively deleting the least important ones. The results obtained from the first nominal group's composite matrix for a nuclear power plant are offered as an example of the sensitivity analysis. All variables in the criteria matrix were grouped according to their importance weights. The first calculation (Fig. 15) included all variables, the next deleted those with an importance weight of 1, and so on until only those with an importance weight of 10 remained. The score distributions were then compared statistically and spatially to determine at which points significant changes occurred.

Coefficients of correlation (r values) were computed between the scores obtained from all 29 variables and those obtained at each step in the deletion, and the r values were graphed (Fig. 19). It can be seen that the scores are only slightly affected by removal of the least important variables (represented by an importance weight of 2, since no variables were assigned weights of 1). In fact, the r value is still extremely high when all variables weighted 2 through 5 are dropped, indicating that this particular calculation is not very sensitive to variables of low importance. However, a marked break in the curve suggests that the distribution of cell scores changes significantly when variables with a weight of 6 are deleted. Thereafter, the correlation decreases consistently.

An examination of the suitability maps reveals little change in the overall pattern of candidate areas between those obtained from the full matrix and those with variables of low importance deleted. Again the first significant alteration appears when importance weight 6 is dropped, and variables of higher weights exhibit a considerable influence on the spatial distribution.

It is apparent from a comparison of Figs. 15 and 20 that the same concentrations of high-scoring cells would have been obtained with or without the nine variables of lowest importance. Their inclusion in this matrix, therefore, is somewhat superfluous, and they neither help

ORNL DWG 76-14694

Fig. 19. Coefficients of correlation between cell suitability scores calculated with all variables and scores calculated with successively fewer variables. The scores are those obtained from the first nominal group's criteria matrix for a nuclear power plant with cooling tower.

Fig. 20. Candidate areas for a nuclear power plant with cooling tower in northern Maryland, 1976. Siting objective: composite of all objectives. Respondent: first nominal group. Number of variables in calculation: 20.

nor hinder the accuracy of the candidate-area maps. Thus it can be anticipated that the cost of obtaining the missing variables identified by the nominal groups will not be justified for those with importance weights of 5 or less.

At the opposite extreme, when only proximity to water, seismicity, and proximity to endangered species are included, the distribution is similar to the stream pattern (Fig. 21). Population density has been considered in Fig. 22. and the resulting pattern is one which could have been reached intuitively without the aid of screening algorithms and extensive data bases. Only when variables of importance weight 7 or greater are included (Fig. 23) do we begin to see the emergence of candidate areas which have been identified consistently by other respondents. The calculations seem to become more and more discriminating as more variables are added through importance weight 6 (Fig. 20).

It can be concluded that the reliability of this particular criteria matrix is greatest when 20 or more variables are included. However, the number will vary for other matrices obtained from different respondents or for different facilities and siting objectives. In practice it would be advisable to perform this type of sensitivity analysis for each matrix and to collect additional data for all missing factors ranking within the importance ranges found to affect final scores.

5.3.5 The definition of candidate areas

The decision as to which scores will be included in the candidate-area definition is an arbitrary one. As discussed in Sect. 2.2.4, in this analysis all cells with scores one or more standard deviations above the mean have been considered as potential candidate-area cells. If the user is willing to accept lower scores or is forced to do so because of an insufficient number of potential sites at the higher level, he may alter the definition to suit his needs.

Figures 24 and 25 illustrate the effect of successively lowering the definition. In this case the candidate areas have broadened to offer more choices for site selection, but the general pattern has not changed greatly. This result is obtained because the excluded areas are still excluded regardless of which positive scores are included. The effect on siting is that less optimal sites may be chosen, but the really critical areas are still avoided.

Fig. 21. Candidate areas for a nuclear power plant with cooling tower in northern Maryland, 1976. Siting objective: composite of all objectives. Respondent: first nominal group. Number of variables in calculation: 13.

Fig. 22. . Candidate areas for a nuclear power plant with cooling tower in northern Maryland, 1976. Siting objective: composite of all objectives. Respondent: first nominal group. Number of variables in calculation: 5.

Fig. 23. Candidate areas for a nuclear power plant with cooling tower in northern Maryland, 1976. Siting objective: composite of all objectives. Respondent: first nominal group. Number of variables in calculation: 4.

PRODUCED BY GDM AIDCE
GEOGRAPHIC DATA SYSTEMS

Fig. 24. Candidate areas for a nuclear power plant with cooling tower in northern Maryland, 1976. Siting objective: composite of all objectives. Respondent: Maryland Power Plant Siting Program. Number of variables in calculation: 27. Candidate areas are mean score or above.

PRODUCED BY OAK RIDGE
GEOGRAPHIC DATA SYSTEMS

Fig. 25. Candidate areas for a nuclear power plant with cooling tower in northern Maryland, 1976. Siting objective: composite of all objectives. Respondent: Maryland Power Plant Siting Program. Number of variables in calculation: 27. Candidate areas are one standard deviation below mean score or above.

6. RESEARCH ACCOMPLISHMENTS

6.1 Application and Analysis of the ORNL LUSP

A major accomplishment of the MPPSP is that every land parcel in northern Maryland has been evaluated in regard to its suitability for power plant siting. Numerous sets of criteria representing the views of different siting specialists for various siting objectives have been applied to the Maryland Data Base, and candidate areas have been identified according to each. ORNL does not have the responsibility of choosing a final slate of candidate areas, but it can be noted that concentrations of high-scoring cells in the vicinity of the Monocacy River northeast and south of Frederick and on the Potomac River east of Cumberland appear on almost all candidate-area maps for fossil-fired and nuclear power plants. Caveats regarding ecologic impact have been noted for all generalized candidate areas.

The significance of this exercise is that automated regional screening techniques have been taken beyond mere development to the stages of application and analysis. Criteria matrices can vary substantially among respondents, and the differences are reflected in the spatial distributions of high-scoring cells. Furthermore, most respondents are able to distinguish between facilities based on fuel types but not on cooling systems. The distributions of candidate areas for nuclear power plants are somewhat different from those for fossil-fired plants for a composite siting objective and dramatically different for an ecologic objective.

In order to accomplish the regional screening and to implement the analysis, three programs for thematic mapping, proximity calculation, and computation of cell suitability scores were developed and documented.⁷

6.2 Criteria Definition

The criteria matrices constitute a contribution to power plant siting methodology. Some were obtained under highly structured group techniques,¹² and others were determined administratively just as criteria are defined in most utility-siting applications. The criteria

matrices illustrate emphatically that there is no "right" set of criteria or "best" candidate area. "Expert" opinion is as diverse as the individuals involved, and the resultant candidate areas should be viewed as spatial expressions of those opinions. Thus, the validity of any screening procedure, automated or manual, which utilizes a single, rigid set of criteria defined by "experts" can be questioned.

6.3 Expansion of the Maryland Data Base

An attempt was made to incorporate into the data base all of the important factors which were identified in the criteria definition phase. In the course of the project the Maryland Data Base was expanded from the 27 MAGI variables to 52 variables. Most of these were obtained by adapting available digital information, such as U.S. Census Tapes and USGS Water Tapes, to a format and spatial resolution compatible with MAGI.

Special attention was given to the modeling of water availability.¹⁶ The result is a computer package which enables the user (1) to delimit any region of the United States by state, county, drainage area, or latitude-longitude frame; (2) to recall daily flow values from the USGS Water Tapes for all gaging stations within the study region; (3) to compute estimates of the recurrence frequency of low flows; and (4) to calculate the reservoir drawdown capacity which would be necessary to maintain a given rate of flow at any specified rate of consumptive use.

Population density and two weighted population density values (5-mile and 30-mile site population factors) were calculated for all cells in the study area. Emphasis was placed on developing factors applicable to site screening at the regional and local scales of analysis, and the resulting values were entered into the Maryland Data Base.

The analysis of air diffusion, a factor which must be considered in siting fossil-fired power plants, was performed as an example of the types of analyses which must follow regional screening to select specific candidate sites from candidate areas.⁴ Two alternative models of air diffusion from a point source have been applied to two candidate

sites in Washington and Frederick Counties, and a measure of population density has been added to evaluate air pollution impacts on populated areas. Since the information has been generated for only two points, it cannot serve as an air diffusion index in the Maryland Data Base.

7. CONCLUSIONS, RECOMMENDED APPLICATIONS, AND RESEARCH NEEDS

The primary purpose of this report is to explore the usefulness and functional requirements of cell-based land use screening procedures. Hence, the conclusions will emphasize the utility of the ORNL LUSP, its advantages and disadvantages in regional and local siting analyses, and recommendations for future applications and research.

The results of the MPPSP suggest the following conclusions:

1. The ORNL LUSP is a useful tool for regional screening of geographic information systems even when the systems are not designed for the specific problem of power plant siting.
2. The ORNL LUSP can serve as a means of simulating alternative siting policies in order to anticipate potential conflicts before they become matters of public concern.
3. Since the construction of a geographic information system is the greatest potential constraint to the development of an automated screening procedure, the data base should be designed to serve diverse uses. The shared cost can be minimized by considering the needs of potential users during system development and by including only those variables which receive high importance weights on numerous criteria matrices.
4. Siting factors must be viewed in the context of a spatial hierarchy of physical, economic, and social phenomena. Each factor should be examined at the appropriate level of spatial resolution and stored in a multiscale data base.
5. The greatest limitation to the interpretation of the candidate-area maps in this study is that most siting factors are represented by raw variables rather than by indices derived from factor models.

These findings are discussed in greater detail in the following sections.

7.1 Recommended Applications

The ORNL-LUSP places a quantitative screening algorithm properly within a comprehensive site selection process. Most published reports on automated screening techniques imply that a definitive selection of candidate areas can be made by the computer and that a single set of criteria is sufficient for regional screening.^{8,9} In contrast, our work leads us to recognize that an automated screening procedure is one tool among many which may be useful in candidate-area selection. Furthermore, many sets of candidate areas can be identified depending upon the values of different interest groups, and the ORNL-LUSP can be used for identifying and resolving potential conflicts.

The ORNL-LUSP is designed as a tool for simulating the effects of alternative siting policies. It is particularly useful early in the selection process when the study area is being screened to identify candidate areas capable of hosting a generating facility. The early application of the screening procedure can help incorporate the views of diverse groups while it is still possible to accommodate those views. The users can create criteria matrices which anticipate the requirements of other interest groups, or they can ask representatives of known interest groups to create their own matrices. For example, the views of a recognized conservation society might be entered into a suitability calculation for the objective of minimizing adverse ecologic impact. The power of the ORNL-LUSP is that it is designed to identify and weight site selection criteria for a hierarchy of geographic scales -- national, regional, and local.

This report has been written as if the users are utility-siting specialists or regional planners, but the features of the ORNL-LUSP also make it well suited for use by regulatory agencies in evaluating alternative sites. In fact, a strict interpretation of the NEPA requirements for consideration of alternative sites could demand regional screening to determine the most feasible site with the least adverse impact. Even under present regulatory practice a regional screening procedure could aid in alerting regulatory officials to potential conflicts before they become issues of public concern. The Nuclear Regulatory Commission and

many state agencies with responsibilities varying from evaluation to predesignation of energy facility sites might benefit from such an approach. The ORNL LUSP is particularly well suited to agencies like the Tennessee Valley Authority and the Maryland Power Plant Siting Program which are charged with the responsibility of selecting facility sites and simultaneously protecting public interests.

A third possible use for the ORNL LUSP is in modeling future scenarios of energy supply. Most projections of energy production have been at the national scale and have not been concerned with the spatial distribution of production facilities. However, there is some impetus to create projections with a higher degree of spatial resolution. The Water Resources Council, for example, is attempting to project water requirements for energy production to the year 2000 for multicounty units called aggregated subareas (ASAs).

While energy production for multistate regions may be determined by economic considerations of supply and demand, the actual placement of facilities at a county level of resolution will be determined by the ability of the areas to support the facility physically and economically and to bear its social, economic, and ecologic impacts. A regional screening procedure could be used to build spatial scenarios of energy production just as economic models have been used to project aggregate supplies. Furthermore, it should be recognized that the aggregate supply may ultimately be constrained by the availability of a sufficient number of feasible sites, and the spatial scenarios should serve as checks against aggregate supply scenarios. It may be possible, for example, to determine approximately how much additional electrical generating capacity can be sited before it is necessary to resort to locations unacceptable in regard to ecologic impact or economic feasibility.

7.2 Functional Requirements for Future Applications

7.2.1 The geographic information system

The development of a geographic information system is a major consideration in establishing an automated screening procedure like the

ORNL LUSP. The cost, which varies according to the number and types of data items, is excessive for most single applications. The greatest portion of the expense is for computer hardware and software to handle the storage and retrieval of data and for the capture of key data items -- a one-time expense which could serve many applications equally well. Whenever possible, it is advisable to develop a single information system for a region and to incorporate general capabilities for access by numerous users. It is unlikely that the initial data coverage will be sufficient for power plant siting or most other specific applications, but during system development an attempt should be made to identify potential users and consider their needs.

Whether the user is establishing an information system dedicated to a single application or is adding supplemental data items to a pre-existing system, siting criteria should be defined early enough to serve as guides in determining data requirements. Too often, data collection is preceded by insufficient forethought and analysis. Most geographic information systems constructed in such an a priori manner contain numerous variables which are expensive to obtain and yet are relevant only to a few specific applications. On the other hand, a clear definition of siting criteria, including the importance of each variable and indicating critical categories, can lead to efficient collection of useful information in the proper form for the intended application.

The operation of the MPPSP suggests that the Nominal Group Process is a fast, convenient means of obtaining siting criteria. It could be especially helpful in incorporating expert opinion on the necessary data items to be included in a system under development. In fact, the NGP and similar task group techniques work best when the participants are not constrained by a rigid list of the variables already available.

7.2.2 The multiscale approach

A second major consideration is the development of a conceptual framework for dealing with the numerous factors affecting site suitability. The experience in this and other studies at ORNL is that these factors must be viewed in a spatial context and examined at the scale of analysis appropriate to each. In a geographic information system the

scale is determined by the cell size employed in capturing and storing data, and care must be taken to assure that the cell size does not greatly exceed the spatial resolution of each data item. Often it is impractical to establish a small-cell data base for the entire region, as has been done in the MPPSP study area. A more efficient approach is to build a multiscale data base and to screen for suitability according to the dominant factors at each scale. In going from the national to the local scale it is necessary to establish complete data coverage only in those areas which survive each successive screening.

For each factor there is a "natural" scale of operation which depends upon its functional interaction with other factors and its potential for interaction with the proposed facility. Indeed, some factors operate at more than one level. Transportation accessibility, for example, should be treated at the local scale to determine how much construction will be required to link the cell with a local transportation network and at the regional scale to evaluate the interconnectivity between the local network and sources of labor, construction materials, or fuels.

7.3 Suggested Future Research

The most pressing need for future research is in the development of regional and local siting factor models. Numerous models have been developed for use with a known specific site, but the more difficult problem of dealing with thousands of potential sites has received far too little attention in siting methodology. Air quality impact and transportation accessibility are factors which deserve special attention in future research. In fact, it would be desirable for each of the major siting factors identified by the nominal groups to serve as the focus of a sophisticated modeling effort at the regional or local scale.

A second matter of concern is the role of citizen input in regional or local screening. The use of various sets of siting criteria defined by groups of experts and representatives of utilities and special interest groups is not intended to preclude consideration of the opinions of other citizens who will be affected by the siting decision. Indeed, the intent is to anticipate genuinely adverse impacts on local popula-

tion before the final decision is made. It is unlikely, however, that the screening procedure can detect opposition which results from local perceptions of, for example, the desirability of economic growth in general or the safety of a particular plant. The issues which determine such local perceptions are too complex to be examined at the regional scale. Even at the local scale it would be extremely difficult to consider this factor for every cell. A preliminary hypothesis would be that the proper stage for consideration is during the selection of candidate sites from candidate areas, since the candidate areas are large enough to contain several small towns or communities. This question requires additional research.

REFERENCES

1. R. H. Platt, *Interface of Law and Geography*, Resource Paper No. 75-1, American Association of Geographers, Washington, D.C., 1976, p. 6.
2. J. D. Calvert, Jr., W. L. Heilman, and H. L. Smith, *Nuclear Power Plant Siting: A Generalized Process*, Atomic Industrial Forum, Inc., New York, 1974, p. 9.
3. I. L. McHarg, *Design with Nature*, Natural History Press, New York, 1969.
4. G. T. Miller, Jr., *Living in the Environment, Concepts, Problems, and Alternatives*, Wadsworth Publishing Company, Inc., Belmont, California, 1975, pp. 196-197.
5. Maryland Department of State Planning, *Maryland Automated Geographic Information System*, Technical Series, Pub. No. 207, Baltimore, 1974.
6. S. L. Yaffee and C. A. Miller, *Toward a Regional Power Plant Siting Method: AEC-Maryland Regional Siting Factors Study*, FY 1974 Progress Report, ORNL/TM-4944 (1974).
7. J. S. Jalbert and J. E. Dobson, *A Cell-Based Land Use Screening Procedure for Regional Siting Analysis*, ORNL/NUREG/TM-80 (1977).
8. N. A. Frigerio, L. J. Habegger, R. F. King, L. J. Hoover, N. A. Clark, and J. M. Cobian, *Site: A Methodology for Energy Facility Site Screening and Regional Environmental Impact Assessment*, Energy and Environmental Systems Division, Argonne National Laboratory, Argonne, Illinois, 1975.
9. J. A. Halpern, D. M. O'Regan, and W. R. Miller, *Computerized Methods in Power Plant Siting Studies*, Second Annual University of Missouri-Missouri Energy Council Conference on Energy, October 7-9, 1975.
10. B. F. Hobbs and A. H. Voelker, *Analytical Power Plant Siting Methodologies: A Theoretical Discussion and Survey of Current Practice*, ORNL/TM-5749 (1977).
11. H. A. Linstone and M. Turoff, eds., *The Delphi Method: Techniques and Applications*, Addison-Wesley Publishing Company, London, 1975.
12. A. H. Voelker, *Power Plant Siting: An Application of the Nominal Group Process Technique*, ORNL/NUREG/TM-81 (1977).

13. R. D. Duke, "Toward a General Theory of Gaming," in *Simulation and Gaming: Proceedings of the 12th Annual Symposium of the National Gaming Council and the 4th Annual Conference of the International Simulation and Gaming Association*, Special Publication No. 395, National Bureau of Standards, 1974, pp. 18-19.
14. G. I. Gibbs, ed., *Handbook of Games and Simulation Exercises*, E. and F. N. Spon, Ltd., London, 1974.
15. O. L. Ervin, *An Application of the Delphi Method to Regional Land Use Forecasting*, ORNL/RUS-21, 1976, p. 15.
16. J. S. Jalbert and Alf D. Shepherd, *A System for Regional Analysis of Water Availability*, ORNL/NUREG/TM-82 (1977).
17. United States Nuclear Regulatory Commission, *Nuclear Energy Center Site Survey - 1975 (NECSS-75), Resource Availability and Site Screening*, NUREG-0001, Part V of V, Springfield, Va., 1976.
18. United States Army Corps of Engineers, *A User-Accessed Computer Information System for Environmentally Sensitive Wildlife*, Technical Report No. M-74-6, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss., (June 1974).
19. J. E. Kohler, A. P. Kenneke, and B. K. Grines, *A Technique for Consideration of Population in Site Comparison*, WASH-1235, Regulatory Staff Technical Report, Directorate of Licensing, U.S. Atomic Energy Commission, Washington, D.C., (October 1974).
20. C. A. Miller and R. B. Honea, *Evaluating Air Quality/Population Impacts of Fossil-Fueled Power Plants: A Case Study in Frederick County, Maryland*, Forthcoming.

Appendix A
COMPATIBILITY INDICES

Appendix A

COMPATIBILITY INDICES

Variable No.	Variable Name	Category or range of values	Composite PPSP	Fossil with cooling tower		Minimization of socioeconomic impact PPSP	Fossil with cooling pond, minimization of ecological impact ORNL	Fossil with cooling pond, minimization of ecological impact ORNL	Fossil with cooling pond, minimization of ecological impact ORNL
				Cost minimization, PPSP	Minimization of ecological impact PPSP ORNL				
4	Surface water quality	Class I waters	10	5	10	2	5	5	5
		Class I waters not meeting standards	10	5	10	10	5	10	10
		Class II waters	8	5	8	6	5	6	6
		Class II waters not meeting standards	8	5	8	1	5	1	1
		Class III waters	3	5	3	1	5	1	1
		Class III waters not meeting standards	3	5	3	3	5	3	3
		Class IV waters	5	5	5	3	5	3	3
		Class IV waters not meeting standards	5	5	5	10	5	10	10
		Oyster beds open to fishing	0	5	0	1	5	1	1
		Polluted oyster beds	5	5	5	1	5	1	1
		Clam beds open to fishing	0	5	0	10	5	10	10
		Polluted clam beds	5	5	5	10	5	10	10
7	Transportation and transmission	Railroad	2	2	2	2	2	2	2
		Channel spoils disposal site							
		Channels 27 to 42							
		Existing and proposed major intersections							
		Mass transit facilities							
		Utility lines							
9	State and Federal lands	State of Maryland (general)	0	5	5	5	0	5	5
		Health and Mental Hygiene	5	5	5	3	5	3	3
		Natural Resources	5	5	5	1	5	1	1
		Fish and Wildlife	1	5	0	1	1	1	1
		Forests and Parks	1	5	0	1	1	1	1
		State Police	5	5	5	5	5	5	5
		Department of Correction	5	5	5	3	5	3	3
		General Services (state)	5	5	5	5	5	5	5
		Aviation	5	5	5	5	5	5	5
		Mass Transit Administration	5	5	5	5	5	5	5
		Port Authority	5	5	5	5	5	5	5
		Motor Vehicles Administration	5	5	5	5	5	5	5
		State Highways Administration	5	5	5	5	5	5	5
		Military	5	5	5	5	5	5	5
		Education	5	5	5	3	5	3	3
		Agriculture and Industry Agency	5	5	5	5	5	5	5
		Board of Public Works	5	5	5	5	5	5	5
		Federal Government (general)	1	5	0	5	1	5	5
		Department of Agriculture	5	5	5	1	5	1	1
		Department of the Air Force	5	5	5	5	5	5	5
		Department of the Army	5	5	5	5	5	5	5
		Corps of Engineers	5	5	5	5	5	5	5
		Department of the Navy	5	5	5	5	5	5	5
		Department of Commerce	5	5	5	5	5	5	5
		Department of Health, Education, and Welfare	5	5	5	3	5	3	3
		National Institutes of Health	5	5	5	3	5	3	3
		Social Security Administration	5	5	5	5	5	5	5
		Department of Transportation	5	5	5	5	5	5	5
		Coast Board	5	5	5	5	5	5	5
		Atomic Energy Commission	5	5	5	5	5	5	5
		Federal Communications Commission	5	5	5	5	5	5	5
		General Services Administration	5	5	5	5	5	5	5
		NASA	5	5	5	5	5	5	5

Appendix A
COMPATIBILITY INDICES

Cooling tower		Fossil with cooling pond		Fossil with once-through		Nuclear with cooling tower							Nuclear with cooling pond		Nuclear with once-through		
Minimization of ecologic impact		Minimization of socioeconomic impact		Minimization of ecologic impact		Composite		Cost minimization		Minimization of ecologic impact		Minimization of socioeconomic impact		Minimization of ecologic impact		Minimization of ecologic impact	
PPSP	ORNL	PPSP	ORNL	PPSP	ORNL	PPSP	Nominal group 1	Nominal group 2	PPSP	PPSP	ORNL	PPSP	ORNL	ORNL	ORNL	ORNL	
10	8	5	8	4	10	10	10	5	10	7	5	7	3				
10	10	5	10	10	10	8	8	5	10	10	5	10	10				
8	6	5	6	8	8	3	3	5	8	6	5	6	8				
8	-1	5	-1	-1	8	3	3	5	8	-1	5	-1	-1				
3	-1	5	-1	-1	3	3	3	5	3	-1	5	-1	-1				
3	3	5	3	5	3	3	3	5	3	3	5	3	5				
5	3	5	3	5	5	3	3	5	5	3	5	3	5				
5	10	5	10	10	5	1	1	5	5	10	5	10	10				
0	1	5	1	-1	0	1	1	5	0	1	5	1	-1				
5	1	5	1	-1	5	1	1	5	5	1	5	1	-1				
0	10	5	10	8	0	1	1	5	0	10	5	10	8				
5	10	5	10	8	5	1	1	5	5	10	5	10	8				
2	2	2	2	2	2	10	10	2	2	2	2	2	2				
						5	5										
						10	10										
						2	2										
						0	0										
						4	4										
5	5	0	5	5	0	2	2	5	5	4	0	4	4				
5	3	5	3	3	5	0	0	5	5	1	5	1	1				
5	-1	5	-1	-1	5	0	0	5	5	-1	5	-1	-1				
0	-1	-1	-1	-1	-1	0	0	5	0	-1	-1	-1	-1				
0	-1	-1	-1	-1	-1	0	0	5	0	-1	-1	-1	-1				
5	5	5	5	5	5	5	5	5	5	4	5	4	4				
5	3	5	3	3	5	2	2	5	5	1	5	1	1				
5	5	5	5	5	5	0	0	5	5	4	5	4	4				
5	5	5	5	5	5	0	0	5	5	4	5	4	4				
5	5	5	5	5	5	0	0	5	5	4	5	4	4				
5	5	5	5	5	5	1	1	5	5	4	5	4	4				
5	5	5	5	5	5	0	0	5	5	4	5	4	4				
5	5	5	5	5	5	4	4	5	5	4	5	4	4				
5	5	5	5	5	5	5	5	5	5	4	5	4	4				
5	3	5	3	3	5	0	0	5	5	1	5	1	1				
5	5	5	5	5	5	8	8	5	5	4	5	4	4				
5	5	5	5	5	5	7	7	5	5	4	5	4	4				
0	5	-1	5	5	-1	0	0	5	0	4	-1	4	4				
5	-1	5	-1	-1	5	7	7	5	5	-1	5	-1	-1				
5	5	5	5	5	5	4	4	5	5	4	5	4	4				
5	5	5	5	5	5	6	6	5	5	4	5	4	4				
5	5	5	5	5	5	10	10	5	5	4	5	4	4				
5	5	5	5	5	5	8	8	5	5	4	5	4	4				
5	5	5	5	5	5	3	3	5	5	4	5	4	4				
8	3	5	3	3	5	3	3	5	5	1	5	1	1				
8	3	5	3	3	5	0	0	5	5	1	5	1	1				
5	5	5	5	5	5	0	0	5	5	4	5	4	4				
5	5	5	5	5	5	2	2	5	5	4	5	4	4				
5	5	5	5	5	5	7	7	5	5	4	5	4	4				
5	5	5	5	5	5	0	0	5	5	4	5	4	4				
5	5	5	5	5	5	0	0	5	5	4	5	4	4				
5	5	5	5	5	5	5	5	5	5	4	5	4	4				
5	5	5	5	5	5	0	0	5	5	4	5	4	4				

BLANK PAGE

Appendix A (continued)

Variable No. Name		Category or range of values	Fossil with cooling tower					Fossil with cooling pond, minimization of ecologic impact, ORNL	Fossil with once-through minimization of ecologic impact, ORNL	PP
			Composite, PPSP	Cost minimization, PPSP	Minimization of ecologic impact,		Minimization of socioeconomic impact, PPSP			
					PPSP	ORNL				
		Department of the Interior	-1	5	0	-1	-1	-1	-1	
		Fish and Wildlife Service	-1	5	0	-1	-1	-1	-1	
		Postal Service	5	5	5	5	5	5	5	
		Veterans Administration	5	5	5	5	5	5	5	
		Department of Justice	5	5	5	5	5	5	5	
		Department of the Treasury	5	5	5	5	5	5	5	
11	Mineral resources	Deep coal mine (active)	0	5	5	10	0	10	10	
		Deep coal mine (inactive)	0	5	5	10	0	10	10	
		Strip coal mine (active)	10	5	5	10	10	10	10	
		Strip coal mine (inactive)	3	5	5	10	1	10	10	
		Sand and/or gravel pit	3	5	5	10	3	10	10	
		Stone quarry	3	5	5	10	3	10	10	
		Clay and shale pit	3	5	5	10	3	10	10	
		Greensand area	3	5	5	10	3	10	10	
		Diatomite area	5	5	5	10	5	10	10	
		Gas field in operation	3	5	5	2	3	1	3	
		Gas field under development	0	5	5	2	0	1	3	
		Gas field used for storage	0	5	5	2	0	1	3	
		Peat pit	3	5	5	2	3	1	3	
		Copper deposits	3	5	5	2	3	1	3	
		Gold deposits	3	5	5	2	3	1	3	
13	Forest type	Aspen, pin cherry	2	2	2	10	2	10	10	
		Northern hardwoods, white pine				4		2	5	
		White pine, hardwoods				4		3	5	
		Oak, white pine				4		3	5	
		White pine				4		3	5	
		Hemlock				4		3	5	
		Northern hardwoods				4		3	5	
		Scrub oak				10		10	10	
		Chestnut oak				4		3	5	
		Hard pine				4		3	5	
		Hard pine, oak				4		3	5	
		Oak, hard pine				4		3	5	
		White oak				4		3	5	
		Red oak				4		3	5	
		Cove hardwoods				4		1	1	
		River birch, sycamore				1		1	1	
		Bottomland hardwoods				1		1	1	
		Loblolly pine				1		3	5	
		Loblolly pine, hardwoods				4		3	5	
		Hardwood, loblolly pine				4		3	5	
		Red gum, yellow poplar				4		3	5	
		Southern white cedar				1		1	1	
		Southern cypress				-1		-1	-1	

BLANK PAGE

Appendix A (continued)

Minimization of socioeconomic impact, PPSP	Fossil with cooling pond, minimization of ecologic impact, ORNL	Fossil with once-through minimization of ecologic impact, ORNL	Nuclear with cooling tower							Nuclear with cooling pond, minimization of ecologic impact, ORNL	Nuclear with once-through minimization of ecologic impact, ORNL
			Composite			Cost minimization, PPSP	Minimization of ecologic impact, PPSP		Minimization of socioeconomic impact, PPSP		
			PPSP	Nominal group 1	Nominal group 2		PPSP	ORNL			
-1	-1	-1	-1	0	0	5	0	-1	-1	-1	-1
-1	-1	-1	-1	0	0	5	0	-1	-1	-1	-1
5	5	5	5	0	0	5	5	4	5	4	4
5	5	5	5	0	0	5	5	4	5	4	4
5	5	5	5	0	0	5	5	4	5	4	4
5	5	5	5	0	0	5	5	4	5	4	4
5	5	5	5	6	6	5	5	4	5	4	4
0	10	10	0	1	1	5	5	5	0	5	5
0	10	10	0	0	0	5	5	5	0	5	5
10	10	10	10	10	10	5	5	5	10	5	5
3	10	10	3	6	6	5	5	5	3	5	5
3	10	10	3	4	4	5	5	10	3	10	10
3	10	10	3	4	4	5	5	10	3	10	10
3	10	10	3	4	4	5	5	10	3	10	10
3	10	10	3	4	4	5	5	10	3	10	10
5	10	10	5	4	4	5	5	10	5	10	10
3	1	3	3	0	0	5	5	2	3	1	3
0	1	3	0	0	0	5	5	2	0	1	3
0	1	3	-1	0	0	5	5	2	-1	1	3
3	1	3	3	4	4	5	5	2	3	1	3
3	1	3	3	4	4	5	5	2	3	1	3
3	1	3	3	4	4	5	5	2	3	1	3
•	10	10	•	•	•	•	•	10	•	10	10
	3	5						4		3	5
	3	5						4		3	5
	3	5						4		3	5
	3	5						4		3	5
	3	5						4		3	5
	3	5						4		3	5
	3	5						4		3	5
	3	5						4		3	5
	3	5						4		3	5
	1	1						1		1	1
	1	1						1		1	1
	1	1						1		1	1
	3	5						4		3	5
	3	5						4		3	5
	3	5						4		3	5
	3	5						4		3	5
	1	1						1		1	1
-1	-1	-1						-1		-1	-1

2

Appendix A (continued)

No.	Variable Name	Category or range of values	Fossil with cooling tower				Fossil with cooling pond, minimization of ecologic impact.	
			Composite, PPSP	Cost minimization, PPSP	Minimization of ecologic impact, PPSP ORNL		Minimization of socioeconomic impact, PPSP	ORNL
14	Soil group (primary)	Group G3*	0	0	5	-1	5	-1
		Group A2	0	0	5	3	5	3
		Group E3	0	0	5	3	5	3
		Group F3	0	0	5	-1	5	-1
		Group B3	3	3	5	3	5	3
		Group C2	3	3	5	3	5	3
		Groups G1 and G2	0	0	5	-1	5	-1
		Groups F1 and F2	0	0	5	-1	5	-1
		Groups E1 and E2	0	0	5	8	5	7
		Group A1	3	3	5	10	5	10
		Group B2	3	3	5	10	5	10
		Group B1	10	10	5	10	5	10
		Group C1	10	10	5	8	5	7
		Group D1	10	10	5	8	5	7
		Group H1	10	10	5	3	5	3
		Group H2	10	10	5	-1	5	-1
17	Natural features (primary)	No natural features in cell	5	5	5	5	5	5
		Natural feature in cell	0	5	0	-1	5	-1
19	Land surface slope (primary)	0 to 3% slope	5	5	5	10	5	10
		3 to 10% slope	10	10	10	9	5	8
		10 to 20% slope	0	0	0	7	5	3
		>20% slope	-1	-1	-1	-1	5	-1
23	Historic sites (first in cell)	No historic site in cell	5	5	5	5	5	5
		At least one registered historic site in cell	0	5	5	1	0	1
26	Land use and land cover (primary)	Residential	-1	5	5	1	-1	1
		Commercial and services	-1	5	5	6	-1	6
		Industrial	8	5	5	8	8	7
		Extractive	5	5	5	8	5	7
		Transportation, communications, utilities	-1	5	5	8	-1	7
		Institutional	-1	5	5	1	-1	1
		Strip and clustered settlement	-1	5	5	6	-1	6
		Mixed	0	5	5	6	0	6
		Open and other	8	5	5	6	8	6
		Cropland and pasture	8	5	5	1	8	1
		Orchards, groves, lush fruits, vineyards, horticultural areas	8	5	5	6	8	6
		Feeding operations	3	5	5	6	3	6
		Other agriculture	8	5	5	10	8	10
		Grass	5	5	5	10	5	10
		Savannas	5	5	5	10	5	10
		Chaparral	5	5	5	10	5	10
		Desert shrub	5	5	5	10	5	10
		Heavy crown cover forest	8	5	5	6	8	6
		Light crown cover forest	8	5	5	8	8	7
		Shrub growth	8	5	5	10	8	10
		Streams and waterways	-1	5	5	-1	-1	1
		Lakes	-1	5	5	-1	1	1
		Reservoirs	-1	5	5	-1	1	1

Appendix A (continued)

Minimization of bioeconomic impact, PPSP	Fossil with cooling pond, minimization of ecologic impact, ORNL	Fossil with once-through minimization of ecologic impact, ORNL	Nuclear with cooling tower							Nuclear with cooling pond, minimization of ecologic impact, ORNL	Nuclear with once-through minimization of ecologic impact, ORNL
			Composite			Cost minimization, PPSP	Minimization of ecologic impact, PPSP ORNL		Minimization of socioeconomic impact, PPSP		
			PPSP	Nominal group 1	Nominal group 2						
5	-1	-1	0	-1	-1	0	5	-1	5	-1	-1
5	3	4	0	0	0	0	5	3	5	3	4
5	3	4	0	2	2	0	5	3	5	3	4
5	-1	-1	0	3	3	0	5	-1	5	-1	-1
5	3	4	5	4	4	5	5	3	5	3	4
5	3	4	5	7	7	5	5	3	5	3	4
5	-1	-1	0	0	0	0	5	-1	5	-1	-1
5	-1	-1	0	2	2	0	5	-1	5	-1	-1
5	7	8	0	3	3	0	5	8	5	7	8
5	10	10	5	4	4	5	5	10	5	10	10
5	10	10	5	7	7	5	5	10	5	10	10
5	10	10	10	8	8	10	5	10	5	10	10
5	7	8	10	10	10	10	5	8	5	7	-8
5	7	8	10	10	10	10	5	8	5	7	8
5	3	4	10	10	10	10	5	3	5	3	4
5	-1	-1	10	10	10	10	5	-1	5	-1	-1
5	5	5	5	10	10	5	5	5	5	5	5
5	-1	-1	0	0	0	5	0	-1	5	-1	-1
5	10	10	5	10	10	5	5	10	5	10	10
5	8	10	10	10	10	10	10	9	5	8	10
5	3	4	0	5	5	0	0	3	5	3	4
5	-1	-1	-1	0	0	-1	-1	-1	5	-1	-1
5	5	5	5	10	10	5	5	5	5	5	5
0	1	1	0	0	0	5	5	1	0	1	1
-1	1	1	-1	0	0	5	5	-1	-1	-1	-1
-1	6	6	-1	0	0	5	5	1	-1	1	1
8	7	8	3	2	2	5	5	4	3	3	4
5	7	8	5	5	5	5	5	4	5	3	4
-1	7	8	-1	5	5	5	5	4	-1	3	4
-1	1	1	-1	0	0	5	5	-1	-1	-1	-1
-1	6	6	-1	0	0	5	5	1	-1	1	1
0	6	6	0	0	0	5	5	1	0	1	1
8	6	6	8	1	1	5	5	1	8	1	1
8	1	1	8	5	5	5	5	-1	8	-1	-1
8	6	6	8	5	5	5	5	1	8	1	1
3	6	6	3	5	5	5	5	1	3	1	1
8	10	10	8	5	5	5	5	10	8	10	10
5	10	10	5	8	8	5	5	10	5	10	10
5	10	10	5	8	8	5	5	10	5	10	10
5	10	10	5	8	8	5	5	10	5	10	10
5	10	10	5	8	8	5	5	10	5	10	10
8	6	6	8	4	4	5	5	1	8	1	1
8	7	8	8	4	4	5	5	4	8	3	4
8	10	10	8	8	8	5	5	10	8	10	10
-1	-1	-1	-1	-1	-1	5	5	-1	-1	-1	-1
-1	-1	-1	-1	-1	-1	5	5	-1	-1	-1	-1
-1	-1	-1	-1	-1	-1	5	5	-1	-1	-1	-1

BLANK PAGE

Appendix A (continued)

No.	Variable Name	Category or range of values	Fossil with cooling tower				Fossil with cooling pond, minimization of ecologic impact, ORNL		Fossil with once-through minimization of ecologic impact, ORNL	
			Composite, PPSP	Cost minimization, PPSP	Minimization of ecologic impact, PPSP	Minimization of socioeconomic impact, ORNL	PPSP	ORNL	PPSP	ORNL
		Bays and estuaries	-1	5	5	-1	-1	-1	-1	-1
		Other water bodies	-1	5	5	-1	-1	-1	-1	-1
		Vegetated wetlands	-1	5	5	-1	-1	-1	-1	-1
		Nonvegetated wetlands	-1	5	5	-1	-1	-1	-1	-1
		Salt flats	-1	5	5	8	-1	7	8	-1
		Beaches	-1	5	5	1	-1	1	1	-1
		Sand other than beaches	8	5	5	6	8	6	6	10
		Bare exposed rock	8	5	5	10	8	10	10	10
		Other barren land	8	5	5	10	8	10	10	10
29	Planned land use and land cover	Residential	-1	5	5	1	-1	1	1	-1
		Commercial and services	-1	5	5	6	-1	6	6	-1
		Industrial	8	5	5	8	8	7	8	3
		Transportation, communications, and utilities	-1	5	5	8	-1	7	8	-1
		Institutional	-1	5	5	1	-1	1	1	-1
		Strip and clustered settlement	-1	5	5	6	-1	6	6	-1
		Open and other	8	5	5	6	8	6	6	8
		Agricultural land	8	5	5	6	8	6	6	8
		Cropland and pasture	8	5	5	1	8	1	1	8
		Forest land	8	5	5	8	8	8	8	8
		Water	-1	5	5	-1	-1	-1	-1	-1
32	Highways and proposed highways	No major highway in cell	5	5	5	a	5	a	a	5
		Four-lane highway or interstate	-1	5	5		-1			-1
		Major two-lane highway	-1	5	5		-1			-1
		Proposed four-lane highway	0	5	5		0			0
		Intersections of interstate and major two-lane highway	-1	5	5		-1			-1
		Intersection of interstate and proposed four-lane highway	-1	5	5		-1			-1
		Intersection of major two lane and proposed four-lane highway	-1	5	5		-1			-1
33	Seismicity	Activity level I	10	10	5	a	5	a	a	10
		Activity level II	3	3	5		5			3
		Activity level III	0	0	5		5			0
34	Fish spawning and nursing areas in Chesapeake Bay	Insignificant population of juvenile yellow perch, white perch, striped bass, or bluefish	a	a	a	a	a	a	a	a
		Fish spawning and nursing areas								
35	30 mile SPF	0 to 0.20	10	5	5		10			10
		0.20 to 0.50	5	5	5		5			5
		0.50 to 1.00	5	5	5		5			-1
		1.00 to 9.00	5	5	5		5			-1
36	Endangered species	No endangered species registered	5	5	5	5	5	5	5	5
		Generalized cave region of Indiana bat	0	5	0	-1	5	-1	-1	0
		Estimated possible range of Indiana bat	0	5	0	4	5	4	4	0
		Observed location of Indiana bat	-1	5	-1	-1	5	-1	-1	-1

Number

Final
sup 2

-1

-1

0

0

10

0

2

10

10

BLANK PAGE

Appendix A (continued)

Cooling tower		Fossil with cooling pond		Fossil with once-through		Nuclear with cooling tower					Nuclear with cooling pond		Nuclear with once-through	
Minimization of ecologic impact.		Minimization of socioeconomic impact.		Minimization of ecologic impact.		Composite			Cost minimization.		Minimization of ecologic impact.		Minimization of socioeconomic impact.	
PPSP	ORNL	PPSP	ORNL	PPSP	ORNL	PPSP	Nominal group 1	Nominal group 2	PPSP	ORNL	PPSP	ORNL	PPSP	ORNL
5	-1	-1	-1	-1	-1	-1	-1	-1	5	5	-1	-1	-1	-1
5	-1	-1	-1	-1	-1	-1	-1	-1	5	5	-1	1	-1	-1
5	-1	-1	-1	-1	-1	-1	0	0	5	5	-1	-1	-1	-1
5	-1	-1	-1	-1	-1	-1	0	0	5	5	-1	-1	-1	-1
5	8	-1	7	8	-1	10	10	10	5	5	4	-1	3	4
5	1	-1	1	1	-1	0	0	0	5	5	-1	-1	-1	-1
5	6	8	6	6	10	2	2	2	5	5	1	10	1	1
5	10	8	10	10	10	10	10	10	5	5	10	10	10	10
5	10	8	10	10	10	10	10	10	5	5	10	10	10	10
5	1	-1	1	1	-1	*	*	*	5	5	-1	-1	-1	-1
5	6	-1	6	6	-1				5	5	1	-1	1	1
5	8	8	7	8	3				5	5	4	3	3	4
5	8	-1	7	8	-1				5	5	4	-1	3	4
5	1	-1	1	1	-1				5	5	-1	-1	-1	-1
5	6	-1	6	6	-1				5	5	1	-1	1	1
5	6	8	6	6	8				5	5	1	8	1	1
5	6	8	6	6	8				5	5	1	8	1	1
5	1	8	1	1	8				5	5	-1	8	-1	-1
5	8	8	8	8	8				5	5	5	6	5	5
5	-1	-1	-1	-1	-1				5	5	-1	-1	-1	-1
5	*	5	*	*	5	10	10	10	5	5	*	5	*	*
5		-1			-1	1	1	1	5	5		-1		
5		-1			-1	1	1	1	5	5		-1		
5		0			0	1	1	1	5	5		0		
5		-1			-1	1	1	1	5	5		-1		
5		-1			-1	1	1	1	5	5		-1		
5	*	5	*	*	10	10	10	10	10	5	*	5	*	*
5		5			3	5	5	5	3	5		5		
5		5			0	0	0	0	0	5		5		
*	*	*	*	*	*	10	10	10	*	*	*	*	*	*
					0	0	0	0						
5		10			10	10	10	10	5	5	*	10	*	*
5		5			5	5	5	5	5	5		5		
5		5			-1	-1	-1	-1	5	5		-1		
5		5			-1	-1	-1	-1	5	5		-1		
5	5	5	5	5	5	10	10	10	5	5	5	5	5	5
0	-1	5	-1	-1	0	5	5	5	5	0	-1	5	-1	-1
0	4	5	4	4	0	-1	-1	-1	5	0	4	5	4	4
-1	-1	5	-1	-1	-1	-1	-1	-1	5	-1	-1	5	-1	-1

Appendix A (continued)

No.	Variable Name	Category or range of values	Fossil with cooling tower				Fossil with cooling pond, minimization of ecologic impact, ORNL	Fossil once- minim of a ill OI
			Composite, PPSP	Cost minimization, PPSP	Minimization of ecologic impact, PPSP	Minimization of socioeconomic impact, PPSP		
37	Excavation requirements	No data available	5	5	5	a	5	a
		Blasting required	10	10	5		5	
		Power grading and some blasting required	8	8	5		5	
		Power grading required	2	2	5		5	
		Dredging required	0	0	5		5	
38	Overburden thickness	No data available	5	5	5	a	5	a
		Thin overburden	8	8	5		5	
		Medium overburden	10	10	5		5	
		Thick overburden	2	2	5		5	
		Variable overburden thickness	5	5	5		5	
39	Aquifer recharge zones	Not an aquifer recharge zone	10	5	10	10	5	10
		Hydrologic unit I of Piedmont and Appalachian Provinces	0	5	0	-1	5	-1
		Hydrologic unit II of Piedmont and Appalachian Provinces	6	5	6	4	5	3
		Hydrologic unit III of Piedmont and Appalachian Provinces	10	5	10	8	5	7
		Sandy aquifers of the Coastal Plain Province	0	5	0	-1	5	-1
40	Five mile SPF	0.0 to 0.20	10	5	5	a	10	a
		0.20 to 0.50	5	5	5		5	
		0.50 to 1.00	5	5	5		5	
		1.00 to 99.0	5	5	5		5	
42	Population density	0 to 16 persons/sq mile	10	5	5	-1	10	-1
		16 to 34 persons/sq mile	9	5	5	-1	9	-1
		34 to 64 persons/sq mile	8	5	5	1	8	1
		64 to 75 persons/sq mile	7	5	5	1	7	1
		75 to 128 persons/sq mile	7	5	5	6	7	6
		128 to 150 persons/sq mile	6	5	5	6	6	6
		150 to 256 persons/sq mile	6	5	5	2	6	8
		256 to 300 persons/sq mile	5	5	5	8	5	8
		300 to 512 persons/sq mile	5	5	5	10	5	10
		512 to 600 persons/sq mile	5	5	5	10	5	10
		600 to 1200 persons/sq mile	5	5	5	10	5	10
		1200 to 2400 persons/sq mile	5	5	5	6	5	8
43	Proximity to highways	>2400 persons/sq mile	5	5	5	6	5	6
		0 to 1 cell	10	10	10	10	5	10
		1 to 2 cells	10	10	10	8	5	8
		2 to 5 cells	5	5	5	5	5	5
		5 to 10 cells	3	3	3	3	5	3
44	Proximity to railroad	>10 cells	0	0	0	0	5	0
		0 to 1 cell	10	10	10	10	5	10
		1 to 2 cells	10	10	10	8	5	8
		2 to 5 cells	8	8	8	5	5	5
		5 to 10 cells	5	5	5	3	5	3
		>10 cells	0	0	0	0	5	0

Appendix A (continued)

Cooling tower		Fossil with cooling pond, minimization of ecologic impact, ORNL		Fossil with once-through minimization of ecologic impact, ORNL		Nuclear with cooling tower						Nuclear with cooling pond, minimization of ecologic impact, ORNL		Nuclear with once-through minimization of ecologic impact, ORNL	
Minimization of ecologic impact, PPSP ORNL		Minimization of socioeconomic impact, PPSP		Minimization of ecologic impact, ORNL		Composite		Cost minimization, PPSP		Minimization of ecologic impact, PPSP ORNL		Minimization of socioeconomic impact, PPSP		Minimization of ecologic impact, ORNL	
PPSP	ORNL	PPSP	ORNL	PPSP	ORNL	PPSP	Nominal group 1	Nominal group 2	PPSP	PPSP	ORNL	PPSP	ORNL	PPSP	ORNL
5	a	5	a	a	a	5	5	5	5	5	a	5	a	a	a
5		5				10	10	10	10	5		5			
5		5				8	8	8	8	5		5			
5		5				2	2	2	2	5		5			
5		5				0	0	0	0	5		5			
5	a	5	a	a	a	5	5	5	5	5	a	5	a	a	a
5		5				8	8	8	8	5		5			
5		5				10	10	10	10	5		5			
5		5				2	2	2	2	5		5			
5		5				5	5	5	5	5		5			
10	10	5	10	10	10	10	10	10	5	10	10	5	10	10	10
0	-1	5	-1	-1	-1	0	0	0	5	0	-1	5	-1	-1	-1
6	4	5	3	5	5	6	6	6	5	6	2	5	1	3	3
10	8	5	7	9	9	10	10	10	5	10	7	5	6	8	8
0	-1	5	-1	-1	-1	0	0	0	5	0	-1	5	-1	-1	-1
5	a	10	a	a	a	10	10	10	5	5	a	10	a	a	a
5		5				5	5	5	5	5		5			
5		5				0	-1	-1	5	5		0			
5		5				0	-1	-1	5	5		0			
5	-1	10	-1	-1	-1	10	10	10	5	5	-1	10	-1	-1	-1
5	-1	9	-1	-1	-1	8	8	8	5	5	-1	8	-1	-1	-1
5	1	8	1	1	1	6	6	6	5	5	-1	6	-1	-1	-1
5	1	7	1	1	1	4	4	4	5	5	-1	4	-1	-1	-1
5	6	7	6	6	6	4	4	4	5	5	4	4	4	4	4
5	6	6	6	6	6	2	2	2	5	5	4	2	4	4	4
5	8	6	8	8	8	2	2	2	5	5	8	2	8	8	8
5	8	5	8	8	8	0	0	0	5	5	8	0	8	8	8
5	10	5	10	10	10	0	0	0	5	5	10	0	10	10	10
5	10	5	10	10	10	0	-1	-1	5	5	10	0	10	10	10
5	10	5	10	10	10	0	-1	-1	5	5	10	0	10	10	10
5	8	5	8	8	8	0	-1	-1	5	5	4	0	4	4	4
5	6	5	6	6	6	0	-1	-1	5	5	-1	0	-1	-1	-1
0	10	5	10	10	10	5	0	0	5	5	10	5	10	10	10
0	8	5	8	8	8	10	3	3	10	10	8	5	8	8	8
6	5	5	5	5	5	5	10	10	5	5	5	5	5	5	5
3	3	5	3	3	3	3	8	8	3	3	3	5	3	3	3
0	0	5	0	0	0	0	6	6	0	0	0	5	0	0	0
0	10	5	10	10	10	10	5	5	10	10	10	5	10	10	10
0	8	5	8	8	8	10	10	10	10	10	8	5	8	8	8
0	5	5	5	5	5	5	9	9	5	5	5	5	5	5	5
0	3	5	3	3	3	3	5	5	3	3	3	5	3	3	3
0	0	5	0	0	0	0	0	0	0	0	0	5	0	0	0

BLANK PAGE

Appendix A (continued)

			Fossil with cooling tower					Fossil with cooling cond. minimization of ecologic impact, ORNL	Fossil with once-through minimization of ecologic impact, ORNL	
Variable		Category or range of values	Composite, PPSP	Cost minimization, PPSP	Minimization of ecologic impact,		Minimization of socioeconomic impact, PPSP			PPSP
No.	Name				PPSP	ORNL				
45	Proximity to stream flow	0 to 1 cell	10	10	5	10	5	10	10	10
		1 to 2 cells	8	9	5	8	5	8	8	8
		2 to 5 cells	5	5	0	5	5	5	5	5
		5 to 10 cells	0	0	0	3	5	3	3	0
		>10 cells	0	0	5	0	5	0	0	0
46	Proximity to residential land use	0 to 1 cell	0	5	5	a	0	a	a	-1
		1 to 2 cells	0	5	5		0			0
		2 to 5 cells	5	5	5		5			5
		5 to 10 cells	5	5	5		5			5
		>10 cells	8	5	5		8			8
47	Proximity to agricultural land use	0 to 1 cell	a	a	a	a	a	a	a	0
		1 to 2 cells								
		2 to 5 cells								
		5 to 10 cells								
		>10 cells								
48	Proximity to transmission lines	0 to 1 cell	10	10	10	10	5	10	10	10
		1 to 2 cells	10	10	10	8	5	8	8	10
		2 to 5 cells	10	10	10	5	5	5	5	10
		5 to 10 cells	10	10	10	3	5	3	3	10
		>10 cells	5	5	5	0	5	0	0	5
49	Proximity to fish spawning and nursing areas in Chesapeake Bay	0 to 1 cell	0	5	0	0	5	0	0	0
		1 to 2 cells	0	5	0	1	5	1	1	0
		2 to 5 cells	3	5	3	3	5	3	3	3
		5 to 10 cells	4	5	4	5	5	5	5	4
		>10 cells	5	5	5	10	5	10	10	5
50	Proximity to airports and airport property	0 to 1 cell	0	5	5	a	0	a	a	0
		1 to 2 cells	0	5	5		0			0
		2 to 5 cells	0	5	5		0			0
		5 to 10 cells	3	5	5		3			3
		>10 cells	5	5	5		5			5
51	Proximity to endangered species	0 to 1 cell	0	5	0	-1	5	-1	-1	0
		1 to 2 cells	0	5	0	5	5	5	5	0
		2 to 5 cells	3	5	3	5	5	5	5	3
		5 to 10 cells	5	5	5	5	5	5	5	5
		>10 cells	5	5	5	10	5	10	10	5
52	Proximity to natural features	0 to 1 cell	0	5	0	-1	5	-1	-1	0
		1 to 2 cells	0	5	0	-1	5	-1	-1	0
		2 to 5 cells	5	5	5	4	5	5	5	5
		5 to 10 cells	8	5	8	5	5	6	6	8
		>10 cells	10	5	10	10	5	10	10	10

^aCategory not included by respondent.

Nuclear v

ite

Nominal miss
group 2

10

10

7

0

-1

0

0

3

6

10

3

4

5

10

10

10

9

8

7

6

-1

0

5

5

5

-1

-1

2

5

10

0

0

3

5

10

0

0

3

5

10

BLANK PAGE

Appendix A (continued)

Minimization of economic impact, PPSP	Fossil with cooling pond, minimization of ecologic impact, ORNL	Fossil with once-through minimization of ecologic impact, ORNL	Nuclear with cooling tower							Nuclear with cooling pond, minimization of ecologic impact, ORNL	Nuclear with once-through minimization of ecologic impact, ORNL
			Composite			Cost minimization, PPSP	Minimization of ecologic impact, PPSP	Minimization of socioeconomic impact, PPSP			
			PPSP	Nominal group 1	Nominal group 2						
5	10	10	10	10	10	10	5	10	5	10	10
5	8	8	8	10	10	8	5	8	5	8	8
5	5	5	5	7	7	5	0	5	5	5	5
5	3	3	0	0	0	0	0	3	0	3	3
5	0	0	0	-1	-1	0	5	0	5	0	0
0	a	a	-1	0	0	5	5	a	-1	a	a
0			0	0	0	5	5		0		
5			5	3	3	5	5		5		
5			5	6	6	5	5		5		
8			8	10	10	5	5		8		
a	a	a	a	3	3	a	a	a	a	a	a
				4	4						
				5	5						
				10	10						
				10	10						
5	10	10	10	10	10	10	10	10	5	10	10
5	8	8	10	9	9	10	10	8	5	8	8
5	5	5	10	8	8	10	10	5	5	5	5
5	3	3	10	7	7	10	10	3	5	3	3
5	0	0	5	6	6	5	5	0	5	0	0
5	0	0	0	-1	-1	5	0	-1	5	-1	-1
5	1	1	0	0	0	5	0	0	5	0	0
5	3	3	3	5	5	5	3	1	5	1	1
5	5	5	4	5	5	5	4	3	5	3	3
5	10	10	5	5	5	5	5	10	5	10	10
0	a	a	0	-1	-1	5	5	a	0	a	a
0			0	-1	-1	5	5		0		
0			0	2	2	5	5		0		
3			3	5	5	5	5		3		
5			5	10	10	5	5		5		
5	-1	-1	0	0	0	5	0	-1	5	-1	-1
5	5	5	0	0	0	5	0	4	5	6	4
5	5	5	3	3	3	5	3	4	5	6	4
5	5	5	5	5	5	5	5	4	5	6	4
5	10	10	5	10	10	5	5	10	5	10	10
5	-1	-1	0	0	0	5	0	-1	5	-1	-1
5	-1	-1	0	0	0	5	0	-1	5	-1	-1
5	5	5	5	3	3	5	5	4	5	5	5
5	6	6	8	5	5	5	8	5	5	6	6
5	10	10	10	10	10	5	10	10	5	10	10

Appendix B

**CORRELATION MATRIX OF CELL SUITABILITY SCORES OBTAINED FROM
CALCULATIONS OF VARIOUS SITING CRITERIA MATRICES**

Appendix B

CORRELATION MATRIX OF CELL SUITABILITY SCORES OBTAINED FROM CALCULATIONS OF VARIOUS SITING CRITERIA MATRICES

Technology/siting objective/respondent	Variable number	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14	V15	V16
Fossil with cooling tower/composite of all objectives/PPSP ¹	V1	1.0	0.83	0.70	0.18	0.93	0.75	0.88	0.16	0.57	0.64	0.21	0.18	0.25	0.41	0.36	0.41
Fossil with cooling tower/minimization of construction costs/PPSP	V2		1.0	0.28	-0.07	0.77	0.95	0.26	-0.04	0.40	0.50	0.21	0.19	0.27	0.38	0.38	0.39
Fossil with cooling tower/minimization of adverse ecologic impact/PPSP	V3			1.0	-0.12	0.58	0.17	0.99	-0.17	0.76	0.13	0.44	0.41	0.34	0.48	0.43	0.39
Fossil with cooling tower/minimization of socioeconomic impact/PPSP	V4				1.0	0.44	-0.01	-0.12	0.99	0.62	0.59	-0.32	-0.35	-0.26	0.29	-0.34	-0.28
Nuclear with cooling tower/composite of all objectives/PPSP	V5					1.0	0.77	0.57	0.44	0.74	0.78	-0.02	-0.07	0.04	0.27	0.20	0.29
Nuclear with cooling tower/minimization of construction costs. 3P	V6						1.0	0.18	0.02	0.49	0.56	0.10	0.07	0.20	0.32	0.30	0.37
Nuclear with cooling tower/minimization of adverse ecologic impact/PPSP	V7							1.0	-0.16	0.12	0.16	0.45	0.43	0.35	0.48	0.42	0.38
Nuclear with cooling tower/minimization of socioeconomic impact/PPSP	V8								1.0	0.63	0.59	-0.29	-0.33	-0.22	-0.27	-0.32	0.25
Nuclear with cooling tower/composite of all objectives/First Nominal Group	V9									1.0	0.92	-0.05	-0.12	0.01	-0.01	0.10	0.01
Nuclear with cooling tower/minimization all objectives/Second Nominal Group	V10										1.0	0.08	0.01	0.05	0.11	0.03	0.09
Nuclear with cooling tower/minimization of adverse ecologic impact/ORNL ²	V11											1.0	0.99	0.94	0.95	0.94	0.89
Nuclear with cooling pond/minimization of adverse ecologic impact/ORNL	V12												1.0	0.93	0.94	0.95	0.87
Nuclear once-through/minimization of adverse ecologic impact/ORNL	V13													1.0	0.85	0.82	0.93
Fossil with cooling tower/minimization of adverse ecologic impact/ORNL	V14														1.0	0.98	0.96
Fossil with cooling pond/minimization of adverse ecologic impact/ORNL	V15															1.0	0.93
Fossil once-through/minimization of adverse ecologic impact/ORNL	V16																1.0

¹PPSP - Power Plant Siting Program, Maryland Department of Natural Resources.

²ORNL - Oak Ridge National Laboratory.