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# An Evaluation and Comparison of Nuclear Powerplant Siting Methodologies

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# AN EVALUATION AND COMPARISON OF NUCLEAR POWERPLANT SITING METHODOLOGIES*

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ABSTRACT

Methodologies for election of nuclear powerplant sites obtained from recent licensing dockets were found to fit into six major categories. By means of decision analysis techniques, specific examples from each methodology were evaluated against a list of 18 attributes for an "ideal" methodology. Results showed a distinct preference among the methodologies which was independent of differences in preference structure among three individuals. Site selection methodologies were applied to areas in Utah and Illinois to determine whether the different methodologies would select the same candidate plant sites or not. Results were generally consistent, but some potential sites were eliminated prematurely by selection techniques which include exclusion principles rather than relative weighting techniques.

## PREFACE

### REACTOR SITE SELECTION METHODOLOGY EVALUATION

The Reactor Site Selection Methodology Evaluation project began at Sandia Laboratories in February 1976 under the sponsorship of the Site Designation Standards Branch, Office of Standards Development, Nuclear Regulatory Commission (NRC). The project had two main objectives: (1) to develop a systematic approach for the critical review and evaluation of alternative site selection procedures and (2) to evaluate perturbations of site rankings caused by the characteristics of the various procedures or methodologies.

The first objective of the project was met by the decision analysis performed by Woodward-Clyde Consultants, San Francisco, California. These siting methodology objectives were developed through a series of interviews with individuals from NRC and other organizations concerned with siting who were familiar with nuclear powerplant siting. Attributes (measures of effectiveness) were developed to measure the degree of attainment of each objective. The objectives included high quality of analysis, a concern for the public perception of the site selection process, and a desire for practicality in the methodology. The quality of analysis objective contained subobjectives relating to candidate site identification, site selection, and sensitivity analysis. The public perception objective contained subobjectives relating to understandability and perceived public input into the site selection process; the practicality objective, subobjectives relating to expertise required for implementing the methodology and cost. Different siting methodologies were rated on the various attributes, and these ratings were combined (using a multi-attribute utility function) into one overall measure of the effectiveness of each methodology.

There were 18 attributes developed to measure the extent to which the various objectives were met by siting studies. In order to illustrate its applicability, the decision analysis technique was applied to siting methodologies described in 11 Environmental Reports submitted to NRC as part of construction permit applications and 1 final environmental statement prepared by NRC. Those 12 studies were selected after a review of 41 Environmental Reports submitted to NRC between July 1972 and September 1976.

Using the objective attributes, three utility functions were constructed that represented alternative points of view about the relative importance of the various objectives which were expressed by participants in the siting process. The 3 different utility functions were used to rank the 12 siting studies. The decision analysis and its conclusions are presented in "An Evaluation of Nuclear Powerplant Siting Methodologies," which makes up the second part of this report.

The second objective of this project, evaluation of perturbations of site rankings resulting from inherent characteristics of selection methodologies, is met by empirical analysis presented in the study, "A Comparison of Nuclear Powerplant Siting Methodologies," which makes up the third part of this report. Manipulations simulating the site selection methodologies currently being used by power utilities were performed on computerized data bases for northern Illinois and eastern Utah. Interface Computer Services, Chicago, Illinois, performed the required computer analysis for the Illinois data base. Dames & Moore, Los Angeles, California, performed the Utah siting study and assisted Sandia Laboratories in the subsequent analysis.

As part of the analysis, three separate issues were investigated. Comparisons were made between exclusion and comparison (weighted) screening, which are techniques used to identify site areas at the regional level. Selection sensitivity and other aspects of weighting structures used in comparison screening were examined. Finally, the effect of choosing different attributes and suitability functions was evaluated for the site selection process.

A comparison of regional screening techniques was undertaken for each of the data bases by defining minimal criteria requirements for exclusion screening and rating all criteria for comparison screening. These criteria were applied to both data bases. Maps showing acceptable or suitable sites were generated and compared to determine similarities or conflicts among sites selected by both techniques.

By means of basic statistical measures, the comparison screening technique was examined further to evaluate the sensitivity of its results to the weighting structure used to create those results. This included the determination of the true weight of each factor and the comparison of changes in the analysis selection to changes in the criteria weights.

Finally, a demonstration was presented on the impact made on site selection results where different attributes and suitability functions are selected. This analysis illustrated in a qualitative manner the difference in specific site evaluations (or rank ordering) that may occur as a result of (1) the site selection factors chosen for inclusion in the analysis and (2) the data and criteria used to define a specific area.

Together the two studies begin to establish basic measures for judging the adequacy of procedures used to identify, evaluate, and select nuclear powerplant sites. It is demonstrated that the adequacy of the methodology, independent of its application, can be evaluated and compared to alternative methods. However, the empirical studies show that the critical review of a particular site selection is dependent not only on the methodology that is employed but also on the site selection factors that are used, the formulation of those factors, and, to some extent, the geographic locale of the study.

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PART I

# AN EVALUATION AND COMPARISON OF NUCLEAR POWERPLANT SITING METHODOLOGIES

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PART I

# AN EVALUATION AND COMPARISON OF NUCLEAR POWERPLANT SITING METHODOLOGIES

## CHAPTER I

## INTRODUCTION

Many different methodologies have been and are being used to identify potential powerplant sites. In addition, numerous factors or site selection criteria have been employed by these methodologies to measure site suitability. This variety has made it difficult to evaluate the adequacy of siting studies. The objective of this study is to evaluate the changes that may occur among specific site rankings as a result of the particular characteristics of the various site selection methodologies and the criteria they employ.

In order to achieve the study objective, it was first necessary to determine which methodologies were currently being used. Several sources of information existed, including documentation of siting studies which had been done and discussion of potential methodologies in the literature. It was decided that for the purpose of this study it would be better to concentrate on the methodologies which had actually been used in siting studies and reported in chapters on alternative site evaluation contained in Environmental Reports (ERs) because these methods had been practically demonstrated. However, this approach had two drawbacks. The first drawback concerns the time period over which the studies were conducted. Some reports document studies which were conducted as long as 6 years ago, while even the more current studies are at least 3 years old. A literature search indicated that siting studies performed today often employ more rigorous approaches than did those performed in the past. Because of this time factor, it cannot be assumed that all of the methods described in the ERs represent contemporary siting methods. The second drawback concerns the grouping of siting methods into convenient classifications for further analysis. For each siting study, general siting methodologies were modified to best suit the particular setting of the siting study. As a result, few studies utilized identical methods. These two drawbacks, however, are not considered significant enough to negate the use of the ERs as a data base; therefore, as previously noted, ERs were used as the primary data source for definition of existing siting methodologies.

Forty-one ERs submitted after July 1972, as part of construction permit applications, were reviewed. Eleven of these reports were chosen for detailed review based on completeness on the subject of site selection and on representation of the full range of methodologies being used. The similarities and differences of the methodologies were noted and a classification scheme, which is presented in Chapter II, was devised.

A data base was needed in order to compare the results of the applications of the different methodologies in the same context. It was recognized that the differences between the results of the methodology applications might be controlled, to a large extent, by geographic factors. Therefore, it was decided that two data bases representing different regions of the country would be useful. Descriptions of the two data bases chosen are contained in Chapter I of Part III.

Several of the methodologies used in the past are of a qualitative nature; this is in contrast to other methodologies which are clearly more quantitative. The qualitative methods reviewed have no clear analytical structure and emphasize different factors for different sites. Because of this nonspecific approach, it was not possible to accurately simulate the use of these site selection methods with the test data bases in a way that would allow comparison with other more quantitative methods. Therefore, it was shown that the assumptions made concerning levels of suitability in terms of a particular siting factor, described in qualitative terms, have an effect on the ranking of sites, and that the implicit degree of importance assigned to a particular factor also affects ranking.

Manipulations simulating several of the quantitative methodologies currently in use were performed on the data bases to provide information in the following analyses:

1. The comparison between exclusion screening and comparison (weighted) screening,
2. The effect of weighting structures, and
3. The effect of choosing different suitability levels for a particular siting factor.

These analyses are presented in Chapter I of Part III, as is the effect of using different criteria to measure suitability for a particular factor.

Several basic conclusions were drawn from the comparative analysis and are discussed in Chapter IV. The work presented in this report has pointed to several additional investigations that should be performed. These additional investigations, together with the results of the current study, will form the basis for a much more complete and critical review of processes used to select nuclear powerplant sites.

## CHAPTER II

## SITING METHODOLOGIES CURRENTLY USED BY UTILITIES

### Introduction

The alternate site evaluation chapters of 41 ERs submitted between July 1972 and September 1976 as part of construction permit applications were reviewed in order to determine which siting methodologies were being used by utility companies. Eleven of these siting studies, and one contained in a Final Environmental Statement (FES) prepared by the Nuclear Regulatory Commission (NRC), were chosen to receive detailed classification of the methodologies they employed. These 12 siting studies were chosen because they were representative of the range of methodologies used and because their ERs contained sufficient information on which to base a reasonable classification assessment.

Although the siting procedures used by the utilities are diverse in the number of steps involved, they can generally be divided into three phases.*

- Phase I--Determination of Candidate Areas: The Region of Interest (ROI) is screened to locate Candidate Areas for a site.
- Phase II--Determination of Candidate Sites: The Candidate Areas are screened to locate Candidate Sites.
- Phase III--Determination of Proposed Site: The Candidate Sites are evaluated and compared to determine the Proposed Site.

For this study, a candidate area will be defined as a collection of contiguous cells of sufficiently high suitability. A candidate site will be defined as one cell within such an area. The cell size (1.5 miles [2.4 km] on a side for the Utah study area and 1.2 miles [2 km] on a side for the Illinois study area) is large enough to accommodate two or three nuclear powerplants. The location actually chosen for the powerplant could fall within some portion of a cell, on the boundary between two cells, or at the intersecting boundaries of four cells. Increasing the number of plants to be located would increase the chance that the latter two circumstances might occur.

### Three-Phase Model

Region of Interest

Any siting study is conducted within an ROI which is determined on the basis

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*The process usually starts with a defined Region of Interest (ROI) and ends with a Proposed Site. (See Reference 1 for terminology definitions.)

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of reasonably well-understood political, social, economic, and technical considerations. Several different definitions of the ROI have been used in recent siting studies. These definitions include utility service area, utility service area plus some specified border, the area within state boundaries, and regional power pool service areas. The choice of ROI boundaries is primarily a political matter for the type of siting studies evaluated here and therefore has not been addressed. The ROI has been treated as a predefined area. However, it should be noted that as the political problems of local siting increase and as improvements in technology permit ever-increasing transmission distances, the recent trend has been toward ever-increasing size for the ROI.

Phase I--Determination of Candidate Areas

Regional analysis is essentially a screening process to select those areas in which a more concentrated effort should be applied to identify potential sites. Financial, legal, and time limitations generally dictate that this screening be based solely on published data.

Phase II--Determination of Candidate Sites

The selection of candidate sites is often done in two steps. First, potential sites are defined in the candidate areas. A screening of these potential sites results in candidate sites. More detailed additional analysis and data are required for this phase than are required for candidate area selection. Typically, some site-specific data are obtained by survey and by other reconnaissance methods in order to assure better data quality for the final phase.

Phase III--Determination of Proposed Site (Final Site Selection)

The methodologies used to compare and evaluate candidate sites in order to select the proposed site are more diverse and generally more complex than those used for the previous two phases. The number of siting criteria employed and the reliability of the data for Phase III are usually greater than for the candidate site selection phase.

## Classification of Site Selection Procedures

Review of the alternate site evaluation chapters of the 41 ERs used for this study showed that essentially 6 different siting methodologies have been employed. These six methodologies were used in many different combinations among the three phases of the site selection process, and the precise application of the methodology may vary greatly depending upon the phase for which it is used. Although no uniform terminology has evolved in the siting field, for the purpose of this work the six methodologies are identified and the phases of the general siting procedure in which they are applied are defined in Table I.

The definitions of each of the selection methodologies as applied to each of the three phases of the site selection process are contained in the following section.

TABLE I

Siting Methodologies Appropriate to Each Phase of the Site Selection Process

| Siting Methodology | Phase I | Phase II | Phase III |
|---|---|---|---|
| Favorability Selection | X | X | X |
| Comparison Screening | X | X | X |
| Qualitative Comparison | Same as Favorability | | X |
| Cost Effectiveness | - | - | X |
| Site Rating | - | - | X |
| Exclusion Screening | X | X | X |

Favorability Selection

Candidate Areas -- Candidate areas are selected because of one or more favorable characteristics. The siting criteria can be applied either sequentially or concurrently. Sequential application implies that second siting criteria would be applied only to the area remaining after the first criteria were applied. Concurrent application involves simultaneous consideration of the criteria. In the latter case, an area might have a single weak point yet still remain in the study because of one or more compensating positive features.

This screening procedure is typically done in a qualitative manner and can be highly subjective. Areas are selected because they have one or more particularly favorable characteristics. In the recent past, the most important of the favorability criteria have been location within the utility service area and nearness to a source of cooling water. Equally favorable locations may exist elsewhere, but if an adequate number of candidate areas is identified, no attempt is made to develop these alternate areas. The definition of adequate depends largely upon those performing the study.

Candidate Sites -- The preceding comments concerning favorability selection at the candidate area selection phase are also applicable to this phase. The main difference involves the siting criteria applied. Criteria such as proximity to powerload, cooling water, and major faults are easily applied at the regional level. More site-specific criteria such as topography, transmission access, land use, and ecological sensitivity are more readily applied in this phase.

Proposed Site -- Occasionally an individual site is found which has sufficiently favorable characteristics that it is proposed on the basis of its merit rather than on the basis of an alternate site evaluation.

Exclusion Screening

Candidate Areas -- A set of explicitly stated exclusionary criteria, e.g., no national parks, less than 10 miles (16 km) from a water source, etc., is applied to

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the ROI. The candidate areas are those which remain after this screening. The emphasis here is on defining minimum standards of acceptability.

Candidate Sites -- Additional exclusionary criteria are applied to the candidate areas in order to aid in the selection of the candidate sites. Exclusion screening cannot be the sole methodology used at this stage since it does not select sites but merely reduces the areas in which candidate sites can be located. Eventually, some comparison of the remaining areas would be needed in order to locate and evaluate candidate sites.

Comparison Screening

Candidate Areas -- A set of explicitly stated criteria, or siting issues, is established and utility ratings assigned to each category within each criterion. A map is prepared covering the entire ROI for each criterion (siting issue). A set of weights is established which determines the relative importance of each of the criteria as part of the site area suitability assessment. The weights are applied to the ratings for each issue and a composite score is developed. The score for each site area is compared to other areas in order to rank-order the site areas and identify the most suitable area or areas. For selection of candidate areas, general criteria that vary over larger regions (as opposed to criteria that vary rapidly over small regions) are compared using a rating and importance-ratio weighting structure.

Candidate Sites -- The same procedure as that used in candidate area selection is applied. However, additional site-specific data are used with increasingly complex or discriminating criteria.

Proposed Sites -- Again a weighting structure provides the format for comparison. More specific criteria are used and the evaluation may be disaggregated at this point into costs, environmental impacts, and socioeconomic changes.

Qualitative Comparison

A qualitative discussion of each of the siting criteria is presented for each candidate site and the proposed site is chosen. The backup for the decision is predominantly qualitative. The trade-offs used between siting criteria are seldom apparent.

The classification is used only for the third phase of the siting process. It should be noted that its use for the first and second phases would be indistinguishable from the favorability selection classification.

Cost-Effectiveness Analysis

The proposed site is chosen based solely on a cost analysis for the candidate sites. Generally, the cost analysis includes only those costs directly associated with development (construction, engineering, etc.). Occasionally, such factors as socioeconomic impacts are assigned a dollar cost and included in the analysis. A qualitative description of environmental impacts is included in response to the

NEPA requirements, but this methodology is generally used most often when the environmental impacts for all candidate sites are approximately equivalent.

Site Rating

A rating scheme is applied to each of the candidate sites and the proposed site is chosen based on the outcome. Site rating is similar to comparison screening, but the evaluation criteria (or issues) are determined by the strongest features of the sites under actual investigation. For this reason, site rating is only applicable to Phase III of the siting process.

## Classification of Selected Siting Studies

The majority of the 41 siting studies reviewed appeared to use favorability selection for both candidate area and site selection. However, this may not reflect the methodology actually used but rather may have resulted because the ER presented insufficient information concerning the site selection process. If exclusionary criteria or acceptability scales were employed but not discussed in the ER, the appearance of having used favorability selection would result.

The 12 siting studies selected for this study were chosen for their detailed classification of the site selection methodologies they employed. Table II identifies the methodologies used for the three phases of the siting process for each of the studies. Some additional features of these studies are also discussed.

The Blue Hills Station siting study stated that the environmental impacts at the candidate sites were equivalent.[2] The Callaway Plant siting study used the same methodologies as the Blue Hills Station with the exception that no exclusionary criterion was stated.[3]

The Douglas Point Nuclear Generating Station siting study[4] used favorability selection for both the candidate area and site selection phases. The ER study for this plant used qualitative comparison to select the proposed site, whereas the FES study used a site rating scheme.[5] This latter scheme involved ranking the three candidates (1, 2, or 3) on each of 10 siting criteria. The Jamesport Nuclear Power Station siting study used the same methods as the Douglas Point FES study with the addition of exclusion screening in the selection of candidate sites.[6] For its specific site rating scheme, the five candidate sites were rated 1, 2, or 3 (1 = preferred, 2 = favorable, 3 = acceptable) on each of five engineering criteria and seven environmental criteria. The ratings were added and the sites ranked. The sites were also ranked from a total cost standpoint. The final site was first on both rankings. The Fulton Generating Station siting study methodology differed from that of the Douglas Point FES study by its use of exclusion screening to determine candidate areas.[7] The Fulton study rating scheme consisted of assigning a value of 1 = preferred or 2 = acceptable to each of nine siting criteria. Each criterion contained from five to nine factors and was rated according to the average of its factor values. [illegible] was rated [illegible] of its criterion ratings.

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TABLE II

Methodology Classification for Selected Siting Studies

| Siting Study | Date | Phase I Candidate Areas | Phase II Candidate Sites | Phase III Proposed Sites |
|---|---|---|---|---|
| Blue Hills Station | Aug. 1974 | FS and ES | FS and ES | CE |
| Callaway Plant | 1974 | FS | FS | CE |
| Douglas Point Nuclear Generating Station (FES) | 1976 | FS | FS | SR |
| Jamesport Nuclear Power Station | 1974 | FS | FS and ES | SR |
| Fulton Generation Station | 1973 | ES | FS | SR |
| Douglas Point Nuclear Generating Station (ER) | 1973 | FS | FS | QC |
| Marble Hill Nuclear Generating Station | 1975 | FS | FS | QC |
| NEP Nuclear Powerplant | 1976 | ES | FS | QC |
| River Bend Station | 1975 | FS | FS | QC |
| Palo Verde Nuclear Generating Station | 1974 | ES and CS | ES and CS | FS |
| South Texas Project | 1974 | FS and CS | FS | CS |
| Tyrone Energy Park | 1974 | ES | ES and CS | CS |

Legend

CE = Cost-Effectiveness Analysis
CS = Comparison Screening
ES = Exclusion Screening
FS = Favorability Selection
QC = Qualitative Comparison
SR = Site Rating

The Marble Hill Nuclear Generation Station[8] and River Bend Station[9] siting studies both used favorability selection to determine candidate areas and sites and qualitative comparison to select the proposed site. The NEP Nuclear powerplant siting study followed the same methodology except that it used exclusion screening to determine candidate areas.[10]

The Palo Verde Nuclear Generating Station siting study comparison screening used a 0 to 5 scale based on degree of acceptability.[11] The siting criteria were given weighting factors and the composite rating determined candidate areas and sites. The proposed site was picked primarily on favorability selection since data acquisition for qualitative comparison with other sites would have upset the study time schedule.

The South Texas Project siting study used a combination of favorability selection and comparison screening to select candidate areas.[12] Candidate sites were chosen by favorability selection. Comparison screening was used to select the final site; each candidate site was rated on a 0 to 5 acceptability scale based on six siting criteria and on cost differential. The criteria were weighted and a site ranking done.

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The Tyrone Energy Park siting study used comparison screening to narrow three candidate sites to a single proposed site.[13] The sites were rated on a 1 = poor to 4 = excellent scale for the different criteria. The criteria were then weighted and the sites ranked.

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AN EVALUATION OF NUCLEAR POWERPLANT SITING METHODOLOGIES

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PART II

# AN EVALUATION OF NUCLEAR POWERPLANT SITING METHODOLOGIES

## I. OVERVIEW OF METHODOLOGY EVALUATION

### 1.1 Scope of Evaluation

Sandia Laboratories contracted with Woodward-Clyde Consultants to assist in an analysis of alternative methodologies for selecting nuclear power plant sites. The overall purpose of the project was to provide a rationale and substantive assistance to help the Nuclear Regulatory Commission (NRC) in specifying guidelines for methodologies to be used in siting studies. Specifically, distinctive characteristics of adequate methodologies were to be identified, although it was not the purpose of the study to determine a single "best" siting methodology. To identify these characteristics, an evaluation of site selection methodologies was conducted.

A variety of methodologies has been either proposed for use or actually used in nuclear power plant site selection. Since our purpose was to assist the NRC in specifying guidelines for actual siting studies, we evaluated only methodologies that had been used previously in siting studies for Environmental Reports submitted to the NRC.



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Three main characteristics produce complexity in evaluating methodologies. First, it is difficult to determine exactly what constitutes a methodology. Different procedures are often referred to by the same name, if indeed any name is used. Second, the objectives to be achieved by a siting study (aside from site identification) often are not clearly articulated. Third, individuals have different perceptions of the relative importance of achieving various objectives of a methodology. Thus, a methodology may be evaluated very favorably by one person and unfavorably by another because each attaches different degrees of importance to those aspects of siting which the methodology handles well or poorly.

The assessment of methodologies is complicated by the fact that a particular application may have flaws that are easily correctable but which reduce its usefulness as a siting study: that is, the flaws are not inherent in the methodology used, but rather result from the implementation of the methodology in a particular siting study. This report evaluates methodologies as they were actually implemented and, in addition, as they might have been applied if various correctable mistakes had not been made.

The objectives of siting methodologies were determined in meetings with individuals familiar with nuclear power plant siting. These individuals included professionals at Sandia Laboratories, NRC, consulting firms engaged in conducting siting studies, and utility companies which commission and conduct siting studies. Eighteen lower level objectives were specified. For each, an attribute scale was constructed to indicate the degree to which the various methodologies met the corresponding objectives.

Four individuals discussed with us their relative preferences for achieving the various objectives. The individuals had different perspectives and responsibilities in the nuclear power plant siting process. Based on these interviews, three separate multiattribute utility functions representing different points of view regarding the various objectives were constructed. Although the preferences encoded in the three utility functions differ substantially, the final ranking of methodologies is almost identical using any of the utility functions. This occurred because the better methodologies were better on essentially all the attributes. Thus, it was not necessary to obtain agreement on a single utility function for use in this evaluation.

## 1.2 Selection of Methodologies for Evaluation

The alternate site evaluation chapters of forty-one Environmental Reports (ER) and one Final Environmental Statement (FES) submitted as part of construction permit applications to the Nuclear Regulatory Commission between July 1972 and September 1976 were reviewed by Sandia Laboratories. This review identified the siting methodologies actually being used by utility companies. Twelve of the studies were selected for detailed evaluation of the methodologies used. The twelve studies were chosen because they are representative of the range of methodologies used by utilities and because the ERs or FES contain sufficient information on which to base a reasonable evaluation.

Although the siting procedures used by the utilities differ in number of steps, they generally involve three phases. The procedure begins with an established Region of Interest and ends with a Proposed Site:*

Phase I. Determination of Candidate Areas: The Region of Interest is screened to locate Candidate Areas for a site.

Phase II. Determination of Candidate Sites: The Candidate Areas are screened to locate Candidate Sites.

Phase III. Determination of Proposed Site: The Candidate Sites are evaluated and compared to determine the Proposed Site.

1.2.1 Determination of Candidate Areas. With the regional analyses, one is performing a screening to select areas where a more concentrated

*Specific definitions for these terms and others used in this section are contained in: "Regulatory Guide 4.2, Revised; Preparation of Environmental Reports for Nuclear Power Stations." United States Nuclear Regulatory Commission, Office of Standards Development, July 1976.

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effort will be applied to identify potential sites. Basically three different procedures are used by the nuclear industry to determine Candidate Areas:

1. Favorability Selection: Areas are chosen because of one or more favorable characteristics. Siting criteria can be applied either sequentially or concurrently. Sequential application implies that the second siting criterion would be applied only to those areas remaining after the first criterion was applied. Concurrent application involves applying all the siting criteria to the entire Region of Interest and choosing Candidate Areas based on the combined suitability of the area.

2. Exclusion Screening: The Candidate Areas are those that remain after a set of exclusionary siting criteria is applied to the Region of Interest. Examples of exclusionary criteria include: in a federal park, more than ten miles from a water source, and less than five miles from an active fault.

3. Comparison Screening: Areas are rated on a scale based on degree of acceptability for one or more siting criteria. The ratings are combined (the various siting criteria are assigned weighting factors based on the importance of each) and the areas are ranked. Those areas having an acceptable rating or ranking become the Candidate Areas.



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Of the three methodologies the third is the most quantitative; the first, the least. For favorability selection, areas are picked because they are particularly favorable based on one or more criteria. Equally favorable locations may exist elsewhere; but if an "adequate" number of areas is identified, no attempt is made to identify the others. The definition of "adequate" depends on the person or persons doing the study. With exclusion screening, an area is excluded based on one criterion. In this case, equally undesirable locations may still remain in the Candidate Areas, but those will presumably be identified in subsequent phases of the siting study.

1.2.2 Determination of Candidate Sites. After the Candidate Areas are determined, potential sites within those areas are located.

Additional and more detailed analyses and data are required for the potential sites in order to select from them a set of Candidate Sites. Site-specific data should be employed along with survey and reconnaissance information in this process.

The procedures used to select Candidate Sites are the same as those for selecting Candidate Areas. Only the number of siting criteria employed and the quality of the data differ. Again, the three siting methodologies used to select Candidate Sites are: (1) favorability selection; (2) exclusion screening; and (3) comparison screening.

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1.2.3 Determination of Proposed Site. The procedures used to determine the Proposed Site are more diverse and generally are more complex than those used for the previous phases. The number of siting criteria employed and the quality of the data are usually greater than in the Candidate Site selection phase. The five procedures used to select the Proposed Site are:

1. Favorability Selection: Occasionally a site having a sufficient number of favorable conditions is proposed on the basis of its merits alone rather than through an alternate site evaluation.

2. Qualitative Comparison: The siting criteria are discussed for each Candidate Site and the Proposed Site is chosen. The support for the decision is primarily qualitative.

3. Cost-Effectiveness Analysis: Choice of the Proposed Site is chosen based on engineering costs. A qualitative description of environmental impacts is included. This methodology is generally used when the environmental impacts for all Candidate Sites are approximately equivalent.

4. Site Rating: A rating scheme is applied to the Candidate Sites; its outcome determines the Proposed Site. The basis for the tradeoffs among the different siting criteria is rarely clear. No weighting factors are used.

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5. Comparison Screening: The procedure is the same as that discussed under Candidate Area selection.

1.2.4 Classification of Selected Siting Studies. Table 1.1 identifies the methodologies evaluated in this report by the siting study in which each was used and by the manner in which the three phases of site selection were performed. A more detailed discussion of each methodology is given in Section 5 and in Appendix 4.

The majority of the siting studies reviewed appeared to use favorability selection for both Candidate Area and Site selection. This classification may not reflect the actual procedure used but could have resulted from insufficient information having been presented in the ER. If, although they might have been used, exclusion criteria or acceptability scales were not presented in the ER, the appearance - and hence the classification - of favorability selection would result.

## 1.3 Outline of Report

The main sections of this report correspond to the different tasks conducted as part of the evaluation of nuclear power plant site selection methodologies. Section 2 discusses the evaluation approach used in the study. Section 3 treats the objectives of siting methodologies. Specific attributes (measures of effectiveness) to assess the extent to which a methodology meets each objective are presented in Section 4.

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Table 1.1 SITING STUDY METHODOLOGIES

| | Phase I Determination of Candidate Areas | | | Phase II Determination of Candidate Sites | | | Phase III Determination of Proposed Site | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Favorability Selection | Exclusion Screening | Comparison Screening | Favorability Selection | Exclusion Screening | Comparison Screening | Favorability Selection | Qualitative Comparison | Cost-Effectiveness Analysis | Site Rating | Comparison Screening |
| Blue Hills Station | X | X | | X | X | | | | X | | |
| Callaway Plant | X | | | X | | | | | X | | |
| Douglas Point Nuclear Generating Station (PAS) | X | | | X | | | | | | X | |
| Jamesport Nuclear Power Station | X | | | X | X | | | | | X | |
| Fulton Generating Station | | X | | X | | | | | | X | |
| Douglas Point Nuclear Generating Station (ER) | X | | | X | | | | X | | | |
| Marble Hill Nuclear Generating Station | X | | | X | | | | X | | | |
| NEP Nuclear Power Plant | | X | | X | | | | X | | | |
| River Bend Station | X | | | X | | | | X | | | |
| Palo Verde Nuclear Generating Station | | X | X | | X | X | X | | | | |
| South Texas Project | X | | X | X | | | | | | | X |
| Tyrone Energy Park | | X | | | X | X | | | | | X |

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Section 5 rates the various methodologies on each of the attribute scales. Section 6 discusses the multiattribute utility structures used to amalgamate the various attributes into one overall evaluation (objective) function. The results of evaluating the methodologies are presented in Section 7; the implications of those results are discussed in Section 8. Various supportive technical material is presented in appendices.

## 2. EVALUATION APPROACH: DECISION ANALYSIS

The major complexities in evaluating nuclear power plant siting methodologies are:

1. specifying the objectives of the methodologies

2. constructing measures to indicate the degree to which the objectives are achieved

3. describing methodologies in terms of the degree to which they meet the objectives

4. assessing the relative importance of the various objectives

Decision analysis explicitly addresses each of these complexities in a formal and logically consistent manner. For this reason, and because the contract required it, decision analysis was chosen to examine the siting methodologies.* A summary of the theoretical foundations of decision analysis is given in Appendix 1. A more detailed presentation of the theory and practice of decision analysis is given collectively in von Neumann and Morgenstern [4]; Raiffa [3]; Brown, Kahr, and [illegible]n [1]; and Keeney and Raiffa [2]. This section provides an overview of the approach.

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*Decision analysis was not selected as one of the siting methodologies to be evaluated since, through 1976, it had not been used in Environmental Reports filed with the Nuclear Regulatory Commission.



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## 2.1 Description of the Decision Analysis Approach

Decision analysis is a systematic procedure which can help evaluate alternatives in accordance with the preferences and judgments of various experts and affected parties. For discussion, decision analysis can be broken down into the following steps:

- structuring the problem
- describing the consequences of each alternative
- determining the preference structure
- rationally synthesizing information

Let us discuss these steps in more detail.

Structuring the Problem. Structuring involves definition of the problem scope, identification of a set of objectives, specification of attributes (i.e., measures of effectiveness) to indicate the degree to which each objective is achieved, and determination of alternatives to be evaluated. Also, individuals whose preferences are important to the analysis are identified. (Decision analysis provides a framework in which different viewpoints can be considered in evaluating the alternatives if desired.)

Describing the Consequences of Each Alternative. A description of the consequences of each alternative is given in terms of the attributes. If there are uncertainties in estimating consequences, a complete specification of the consequences of choosing a particular alternative will require the quantification of probabilities for the different possible consequences. The consequences (and, if necessary, probabilities) are determined from data, models, or the professional judgment of experts.

Determining the Preference Structure. In this step, the preferences of the individuals concerned with the problem are quantified. The process involves quantifying the various concerned individuals' value tradeoffs between achievement of competing objectives and, if necessary, quantifying their attitudes toward risk-taking. Utility theory is used to express preferences in a mathematical form called a utility function. Such a function is assessed by asking the decision maker various preference questions.

Synthesizing the Information. Synthesis, which integrates the information gathered in previous steps, is computational and interpretive. It consists of calculating the expected utility for each alternative and examining the reasons for the overall levels of utility. Sensitivity analysis may be included in this step; it is often appropriate to vary the consequences of each alternative and the utility functions to determine how this affects the ranking of the alternatives.

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## 2.2 Decision Analysis of Site Selection Methodologies

To overview the analysis of nuclear power plant site selection methodologies, a description of the four steps of the examination is given here.

Structuring the problem involved specifying both the objectives hierarchy and an attribute to measure each of the lower level objectives. The twelve siting methodologies to be evaluated were also selected.

To describe the consequences of each alternative, the degree to which each of the methodologies measured up in terms of the attribute scales was quantified. Since there were eighteen scales (one for each lower level objective), the methodologies were fully described by eighteen pieces of data. One datum rated a methodology on one attribute.

To determine the preference structure, interviews were held with four individuals closely familiar with aspects of nuclear power plant siting problems. As a result, three utility functions were constructed: one representing the viewpoint of a consultant, one representing the viewpoint of a staff member of Sandia Laboratories, and one combining the viewpoints of two NRC staff members.*

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*It is important to stress that the viewpoints represented personal opinions and not official policy. Furthermore, the utility assessments were all conducted to be rough first-cuts of the preference structures. The ensuing analysis then indicated that refined assessments were not required to carry out the purposes of this study.



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The final step was synthesis of information. Using each of the three utility functions, an evaluation of the twelve methodologies was conducted. A ranking of the methodologies resulted. Weak components of the methodologies were identified.

In this evaluation, our intent was to structure the problem carefully in step 1 and then to conduct an analysis of methodologies utilizing some simplification in steps 2 and 3. This would indicate which aspects of these steps were critical to the evaluation and worthy of additional effort. Thus, in step 2 the methodologies were described deterministically rather than by using probabilities to indicate uncertainties about the methodologies. In step 3, we assumed each of the single-attribute utility functions was linear and concentrated on the value tradeoffs among attributes (i.e., the relative importance among objectives). As illustrated by the analysis in Section 7, these simplifications, which initially seemed appropriate, proved in fact to be inconsequent to the overall results of the study. Hence, it was not necessary to construct a more sophisticated model. The original model captured the essential features of the problem.

Decision analysis had several advantages for evaluating nuclear power plant siting methodologies:

- The process of specifying objectives and attributes led to a clear, explicit definition of the evaluation problem.

- Decision analysis provided a logical mechanism for quantitatively considering value tradeoffs among multiple objectives.

- Quantification allowed appraisal of the sensitivity of evaluation conclusions to different assessments of the relative importance of various objectives.

- The explicit, quantitative nature of a decision analysis provided a complete documentation of the evaluation.

The remainder of this report discusses the evaluation of site selection methodologies in detail.

REFERENCES - Section 2


1. Brown, R.V., A.S. Kahr and C. Peterson. Decision Analysis for the Manager. New York: Holt, Rinehart and Winston, 1974.

2. Keeney, R.L., and H. Raiffa. Decisions with Multiple Objectives. New York: Wiley, 1976.

3. Raiffa, H. Decision Analysis. Reading, Massachusetts: Addison-Wesley, 1968.

4. von Neumann, J., and O. Morgenstern. Theory of Games and Economic Behavior. Princeton, New Jersey: Princeton University Press, 1947.


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# 3. OBJECTIVES FOR EVALUATING SITE SELECTION METHODOLOGIES

## 3.1 Structure of Objectives

The objectives of siting methodologies were determined in meetings with individuals familiar with nuclear power plant siting. The process was iterative, with changes made in the objectives structure over a period of several months based on the comments of the individuals interviewed.

The final objectives for the evaluation are illustrated in Figure 3.1. To simplify the figure, short keywords are used for each objective. A complete definition of each objective is given in Subsection 3.2.

As Figure 3.1 shows, the objectives in the evaluation of siting methodologies are arranged hierarchically. For example, the Quality of Analysis objective has three layers of subobjectives under it. The discussion in Sections 4 and 6 shows a useful feature of decision analysis: attributes (measures of effectiveness) need to be specified only for the lowest level objectives in the hierarchy. Thus, we can see from Figure 3.1 that eighteen attributes must be specified in the evaluation. The mathematical procedures of utility theory enable us to combine the attributes to obtain evaluation functions for the higher level objectives in the hierarchy.

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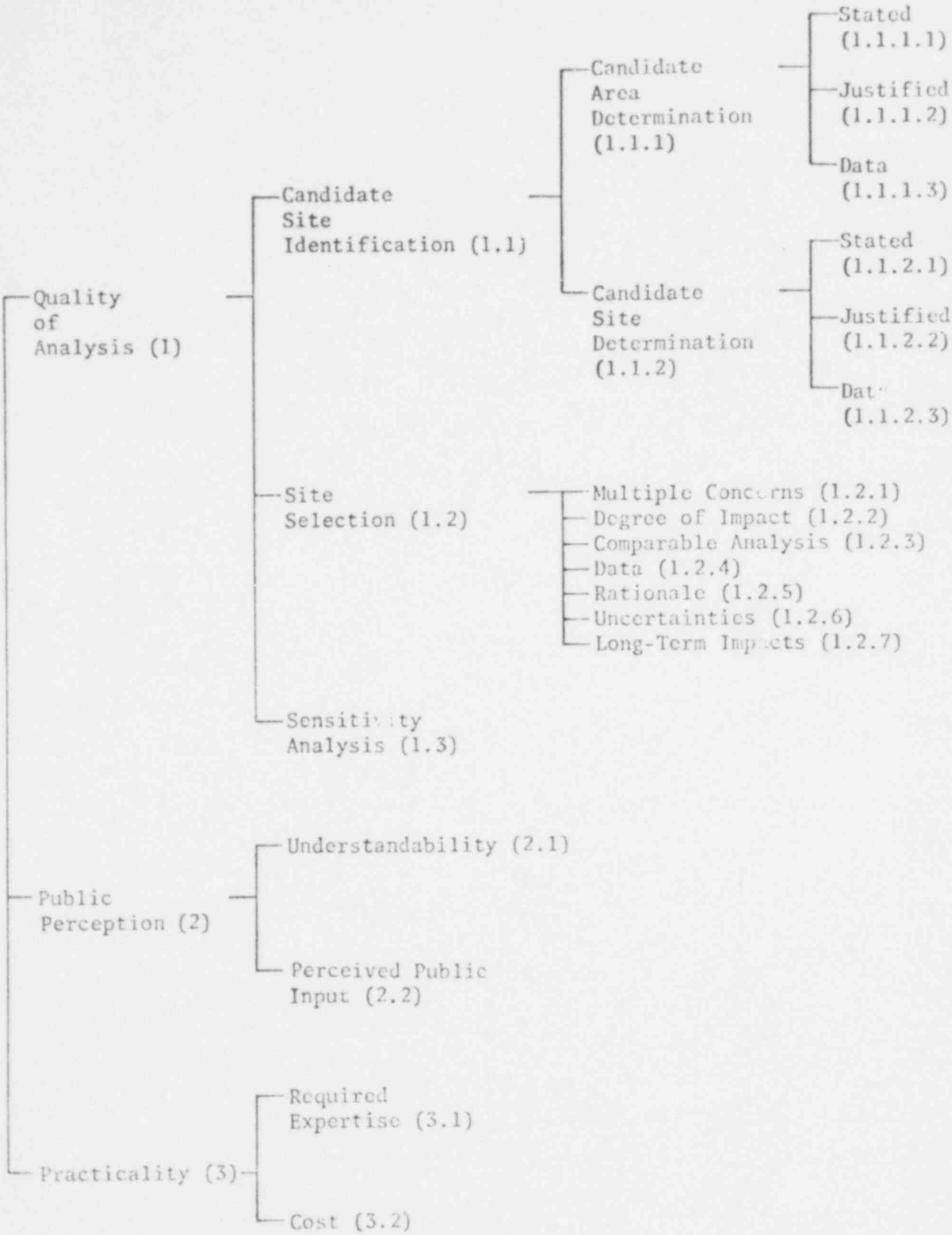


Figure 3.1 OBJECTIVES HIERARCHY

3.2 Definition of Objectives

The objectives used to evaluate nuclear siting methodologies are defined below. The numbering scheme corresponds to that in parentheses following each objective in Figure 3.1. Note that decimal points separate references to different levels in the objectives hierarchy. Thus, for example, 1.2.7 refers to the seventh subobjective (Long-Term Impacts) under the second subobjective (Site Selection) under the first objective (Quality of Analysis). The objectives are:

1. Quality of Analysis: The methodology should be sound, defensible, and useful to NRC in its decision making. In particular,

   1.1 Candidate Site Identification: The Candidate Site Identification portion of the methodology should be sound, defensible, and useful to NRC in its decision-making process. This means,

      1.1.1 Candidate Area Determination: For Candidate Area determination:

         1.1.1.1 The screening criteria should be clearly stated.

         1.1.1.2 The screening criteria should be explicitly justified.



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1.1.1.3 Sufficient data should be used to implement the screening criteria accurately.

1.1.2 Candidate Site Determination: For Candidate Site determination:

1.1.2.1 The selection criteria should be clearly stated.

1.1.2.2 The selection criteria should be explicitly justified.

1.1.2.3 Sufficient data should be used to implement the selection criteria accurately.

1.2 Site Selection: The procedure for selecting a site should be clearly supported. This means,

1.2.1 The multiple concerns in siting should be considered. These include:

- environmental, engineering/economic, socio-economic, health, and safety issues
- intangibles
- differential impacts over society

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1.2.2 The varying degrees of impact that the Candidate Sites will have with regard to each of the multiple concerns should be considered.

1.2.3 The analysis of all Candidate Sites should be comparable both in level of detail and in analysis method to that for the primary site.

1.2.4 Sufficient data should be used to justify statements made.

1.2.5 The rationale should be provided for the method used to integrate the analysis results and to select a site.

1.2.6 Uncertainties in data and natural variations in conditions at the Candidate Sites should be considered.

1.2.7 The impacts of a nuclear power plant at each Candidate Site over the long run should be considered.

1.3 Sensitivity Analysis: It should be possible to explore the sensitivity of the study conclusions to changes in data and other inputs.

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2. Public Perception: The method should directly and demonstrably address the concerns of interested public groups. In particular,

   2.1 Understandability: The method should be understandable to the enlightened layman.

   2.2 Perceived Public Input: The method should appear to and actually involve the public directly in the Site Selection process.

3. Practicality: It should be possible to carry out the method in a real-world environment. In particular,

   3.1 Expertise: The skills needed to implement the method should be widely available.

   3.2 Cost: The method should . relatively inexpensive to implement.

## 4. ATTRIBUTES TO MEASURE DEGREE OF ATTAINMENT OF OBJECTIVES

### 4.1 Selection of Attributes

It is necessary to specify an attribute (measure of effectiveness) for each of the eighteen lowest level objectives in the evaluation of site selection methodologies. No natural scale existed to measure the degree of attainment for any of the objectives. (This is true even for cost, which would seem to have a natural scale of dollars. The cost of applying a methodology depends, however, on the region of application. For example, costs for applying a specified methodology in Arizona may differ from those for its use in Massachusetts.)

For all eighteen lowest level objectives, scales were constructed to serve as attributes. These were developed in conjunction with the individuals who aided in the specification of objectives for the evaluation. In addition, the scales were modified in light of experience using them to describe different siting methodologies. The final attribute scales, described in Subsection 4.2, allow accurate depiction of the differences among the various siting methodologies.

### 4.2 Description of Attribute Scales

For ease in later mathematical work with the attribute scales, algebraic symbols were assigned to represent each attribute. These symbols are defined in Table 4.1. The subscripts on the symbols are the



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Table 4.1 DEFINITION OF SYMBOLS FOR ATTRIBUTES

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1. Quality of Analysis

   1.1 Candidate Site Identification

   1.1.1 Candidate Area Determination

   $X_{1111}$ = Screening criteria clearly stated
   $X_{1112}$ = Screening criteria explicitly justified
   $X_{1113}$ = Sufficient data used

   1.1.2 Candidate Site Determination

   $X_{1121}$ = Selection criteria clearly stated
   $X_{1122}$ = Selection criteria explicitly justified
   $X_{1123}$ = Sufficient data used

   1.2 Site Selection

   $X_{121}$ = Multiple concerns considered
   $X_{122}$ = Degree of impact considered
   $X_{123}$ = Comparable analysis of candidate sites
   $X_{124}$ = Sufficient data used
   $X_{125}$ = Selection rationale provided
   $X_{126}$ = Uncertainties considered
   $X_{127}$ = Long-term impacts considered

   1.3 Sensitivity Analysis

   $X_{13}$ = Sensitivity analysis possible

2. Public Perception

   $X_{21}$ = Understandability of methodology
   $X_{22}$ = Perceived public input

3. Practicality

   $X_{31}$ = Expertise required to use methodology
   $X_{32}$ = Cost of using methodology

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same as the numbers assigned to objectives in Figure 3.1 except that the decimal points have been omitted.

The definitions of the possible levels of each attribute are given below. . .e numerical levels have no exact relative meaning, except that larger numbers indicate more preferred levels. Thus, for example, a level of 2 on an attribute scale is better than a level of 1, but it is not necessarily twice as good. Basically, the numbers are a shorthand; they represent a particular scale level and eliminate the need to write out the complete definition of that scale level at each reference.

1. Quality of Analysis

1.1 Candidate Site Identification

1.1.1 Candidate Area determination

1.1.1.1 Screening criteria clearly stated ($X_{1111}$)

0. No criteria explicitly stated.
1. Some criteria explicitly stated, but some types not stated (e.g., intangibles).
2. All screening criteria explicitly but qualitatively stated.



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3. Essentially all screening criteria explicitly and quantitatively stated.

1.1.1.2 Screening criteria explicitly justified ($X_{1112}$)

0. No criteria explicitly justified.
1. Some criteria explicitly justified, but some types not justified.
2. All screening criteria justified.

1.1.1.3 Sufficient data used ($X_{1113}$)

0. Little or no data available to implement criteria accurately.
1. Data available to implement some criteria accurately, but data not available for some types.
2. Data available to implement all criteria accurately.

1.1.2 Candidate Site determination

1.1.2.1 Selection criteria clearly stated ($X_{1121}$)



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0. No selection criteria explicitly stated.
1. Some criteria explicitly stated, but some types not stated.
2. All criteria explicitly but qualitatively stated.
3. Essentially all screening criteria explicitly and quantitatively stated.

1.1.2.2 Selection criteria explicitly justified ($X_{1122}$)

0. No criteria explicitly justified.
1. Some criteria explicitly justified, but some types not justified.
2. All criteria justified.

1.1.2.3 Sufficient data used ($X_{1123}$)

0. Little or no data available to implement criteria accurately.
1. Data available to implement some criteria accurately, but data not available for some types.

2. Data available to implement all criteria accurately.

1.2 Site Selection

1.2.1 Multiple concerns considered ($X_{121}$)

0. The existence of multiple concerns recognized but without consideration of tradeoffs.
1. The major concerns and tradeoffs qualitatively discussed in some detail.
2. Tradeoffs quantitatively analyzed for some concerns but not for others (e.g., intangibles).
3. Limited quantitative value tradeoffs (e.g., linear substitutability) made among all concerns, but the basic for the tradeoffs among the different attributes not provided.
4. Limited quantitative value tradeoffs made among all concerns with the basis for the tradeoffs among the different attributes provided.
5. More complex and careful tradeoff analysis performed.

1.2.2 Degree of impact considered ($X_{122}$)

0. Not considered.

1. Degree of impact recognized qualitatively but not quantified.

2. Degree of impact quantified for some concerns but not for some types.

3. Degree of impact quantified for all concerns.

1.2.3 Comparable analysis of Candidate Sites ($X_{123}$)

0. Candidate Sites discussed only qualitatively, with the primary site discussed in more detail.

1. Candidate Sites analyzed quantitatively using same method as for primary site but in limited detail.

2. All Candidate Sites analyzed quantitatively in comparable detail.

1.2.4 Sufficient data used ($X_{124}$)

0. Data available but accuracy in substantial doubt.

1. Major elements of the analysis supported by good data, but some data either missing or of questionable accuracy.

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2. Accurate data backing the entire Site Selection analysis.

1.2.5 Selection rationale provided ($X_{125}$)

0. Decision mechanism not clearly presented.
1. Mechanism clearly presented.

1.2.6 Uncertainties considered ($X_{126}$)

0. Single values with no clear meaning used.
1. Single values used with acknowledgement of a few uncertainties and natural variations but no quantification of them.
2. Single values used with acknowledgement of most major uncertainties and natural variations but no quantification of them.
3. Major uncertainties and natural variations analyzed quantitatively.

1.2.7 Long-term impacts considered ($X_{127}$)

0. Not considered (except perhaps for discounting of monetary costs).
1. Discussed qualitatively for some aspects of the Site Selection.
2. Discussed quantitatively for some aspects of the Site Selection.

1.3 Sensitivity analysis possible ($X_{13}$)

0. No sensitivity analysis results presented and insufficient data presented to enable the reader to do any himself.

1. The means available for a limited sensitivity analysis. (The analysis may actually be done in the report, or data sufficient for the reader to do it may be presented.)

2. Sensitivity analysis results presented for many major components of the Site Selection study.

3. Virtually complete sensitivity analysis results presented.

2. Public Perception

2.1 Understandability of methodology ($X_{21}$)

0. Requires special technical knowledge to understand anything.

1. The general approach can be understood without technical knowledge but not the specific calculations needed to implement it.

2. No special knowledge required to understand the approach or its implementation.

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2.2 Perceived Public Input ($X_{22}$)

0. No direct public participation in the site selection process.
1. Direct public participation in process.

3. Practicality

3.1 Expertise required to use methodology ($X_{31}$)

0. Specialized and not widely known techniques required (e.g., decision analysis).
1. Specialized but relatively well known skills required (e.g., cost/benefit).
2. Routinely available skills only required (e.g., engineering economy).

3.2 Cost of using methodology ($X_{32}$)

0. High cost.
1. Medium cost.
2. Low cost.

## 5. QUANTITATIVE DESCRIPTION OF SITING METHODOLOGIES

### 5.1 Discussion of Siting Studies Evaluated

Siting studies presented in eleven Environmental Reports and one Final Environmental Statement were chosen for detailed classification of the site selection methodologies they employed. Table 5.1, which is equivalent to Table 1.1, identifies the methodologies used for the three phases of the siting process for each of the twelve studies. Specific details of the studies are discussed in the following paragraphs.*

The Blue Hills Station siting study [1] used a combination of exclusion screening and favorability selection at both the Candidate Area and Site selection phases. The study used a cost-effectiveness analysis to select the proposed site. It was stated that the environmental impacts at the Candidate Sites were equivalent. The Callaway Plant siting study [2] used the same methodologies except that no exclusionary criteria were stated.

The Douglas Point Nuclear Generating Station siting study used favorability selection for both the Candidate Area and Site selection

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*Recall from Subsection 1.2 that the majority of the siting studies reviewed appeared to use favorability selection for both Candidate Area and Site selection. This classification may not reflect the methodology actually used, but may have resulted from insufficient information being presented in the ER concerning the site selection process. If exclusionary criteria or acceptability scales were employed but not discussed in the ER, the appearance of having used screening would result.

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Table 5.1 SITING STUDY METHODOLOGY CLASSIFICATIONS

| Siting Study | Phase I Candidate Areas | Phase II Candidate Sites | Phase III Proposed Site |
|---|---|---|---|
| Blue Hills Station | FS and ES | FS and ES | CE |
| Callaway Plant | FS | FS | CE |
| Douglas Point Nuclear Generating Station (FES) | FS | FS | SR |
| Jamesport Nuclear Power Station | FS | FS and ES | SR |
| Fulton Generating Station | ES | FS | SR |
| Douglas Point Nuclear Generating Station (ER) | FS | FS | QC |
| Marble Hill Nuclear Generating Station | FS | FS | QC |
| NEP Nuclear Power Plant | ES | FS | QC |
| River Bend Station | FS | FS | QC |
| Palo Verde Nuclear Generating Station | ES and CS | ES and CS | FS |
| South Texas Project | FS and CS | FS | CS |
| Tyrone Energy Park | ES | ES and CS | CS |

Legend

CE = Cost-Effectiveness Analysis
CS = Comparison Screening
ES = Exclusion Screening
FS = Favorability Selection
QC = Qualitative Comparison
SR = Site Rating

phases. The ER study [3] used a qualitative comparison to select the Proposed Site, whereas the FES study [4] used a site rating scheme. This latter scheme involved ranking the three Candidate Sites on each of ten siting criteria. The Jamesport Nuclear Power Station siting study [5] used the same methods as the Douglas Point FES study, with the addition of exclusion screening in the selection of Candidate Sites. For its specific site rating scheme, the five candidate sites were rated 1, 2, or 3 (1 = preferred, 2 = favorable, 3 = acceptable) on five engineering criteria and seven environmental criteria. The ratings were added to rank the sites. The sites were also ranked from a total-cost standpoint. The final Jamesport site was first on both rankings. The Fulton Generating Station siting study [6] methodology differed from that of the Douglas Point FES study by its use of exclusion screening to determine Candidate Areas. The Fulton study rating scheme consisted of assigning a value of 1 = preferred or 2 = acceptable to factors within nine siting criteria. Each criterion contained from five to nine factors. Each criterion was rated according to the average of its factor values. Each site was in turn rated according to the average of its criterion ratings.

The Marble Hill Nuclear Generating Station [7] and River Bend Station [8] siting studies both used a favorability selection to determine Candidate Areas and Sites and a qualitative comparison to select the Proposed Site. The NEP Nuclear Power Plant siting study [9] was the same except that it used exclusion screening to determine Candidate Areas.

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The Palo Verde Nuclear Generating Station siting study [10] used exclusion screening and comparison screening to determine Candidate Areas and Sites. Areas were rated on a 0 to 5 scale based on degree of acceptability. The siting criteria were given weighting factors and the composite rating determined Candidate Areas and Sites. The Proposed Site was picked primarily on favorability selection, since data acquisition at other sites would have upset the time schedule.

The South Texas Project siting study [11] used a combination of favorability selection and comparison screening to select Candidate Areas. Candidate Sites were chosen by favorability selection. The sites were rated on a 0 to 5 acceptability scale on six siting criteria and on cost differential. The criteria were weighted to provide a site ranking.

The Tyrone Energy Park siting study [12] used exclusion screening to determine Candidate Areas and exclusion and comparison screening to determine Candidate Sites. The three Candidate Sites were narrowed to a Proposed Site by means of comparison screening. The sites were rated on a 1 = poor to 4 = excellent scale for the different criteria. The criteria were then weighted and the sites ranked.

## 5.2 Description of Methodologies

Evaluation of the twelve siting methodologies according to the attributes defined earlier was carried out using data presented in the ERs and FES. During determination of scale levels for each attribute



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for the various siting methodologies, it became apparent that there were flaws of two types in the application of the methodologies. First, there were some difficulties that could easily be corrected without changing the methodology. For example, some of the siting studies did not contain explicit statements of all the screening criteria used in the Candidate Area determination. This is a methodological flaw, but one that could easily be corrected without changing the basic methodology used in the study. Other methodological flaws were intrinsic to the approach used and could not be changed without changing the methodology. For example, some methodologies did not consider uncertainties in the input information. There would be no way to consider these without changing the methodology substantially.

In order to evaluate the methodologies more accurately, it was decided to determine attribute levels describing the methodology in each study as it was actually implemented and, in addition, as it potentially could be implemented if the minor flaws were avoided. The attribute levels describing each methodology as implemented are given in Table 5.2, and the levels describing the methodologies as they potentially might be implemented are given in Table 5.3. For reference, the best possible ratings for each attribute are listed in these tables. A detailed explanation of the reasons for each attribute level is given in Appendix 4.

Examining these two tables leads to several conclusions. First, although all twelve of the methodologies as actually applied are somewhat

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Table 5.2 ATTRIBUTE VALUES FOR METHODOLOGIES AS ACTUALLY APPLIED

| | Quality of Analysis | | | | | | | | | | | | | | Public Perception | | Practicality | | Dominated Methodologies |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Candidate Area Determination | | | Candidate Site Determination | | | Proposed Site Determination | | | | | | | Sensitivity Analysis | | | | | |
| Attribute | $X_{1111}$ | $X_{1112}$ | $X_{1113}$ | $X_{1121}$ | $X_{1122}$ | $X_{1123}$ | $X_{121}$ | $X_{122}$ | $X_{123}$ | $X_{124}$ | $X_{125}$ | $X_{126}$ | $X_{127}$ | $X_{13}$ | $X_{21}$ | $X_{22}$ | $X_{31}$ | $X_{32}$ | |
| Best Possible Ratings | 3 | 2 | 2 | 3 | 2 | 2 | 5 | 3 | 2 | 2 | 1 | 3 | 2 | 3 | 2 | 1 | 2 | 2 | |
| Blue Hills Station | 2 | 2 | 2 | 3 | 2 | 2 | 0 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 2 | 0 | 2 | 2 | |
| Callaway Plant | 1 | 1 | 2 | 1 | 1 | 2 | 1 | 2 | 2 | 2 | 1 | 1 | 0 | 1 | 2 | 0 | 2 | 2 | |
| Douglas Point Nuclear Generating Station (FES) | 2 | 2 | 2 | 2 | 2 | 2 | 0 | 2 | 2 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 2 | 2 | |
| Jamesport Nuclear Power Station | 2 | 2 | 2 | 1 | 0 | 2 | 3 | 2 | 2 | 2 | 1 | 0 | 0 | 1 | 2 | 0 | 2 | 2 | X |
| Fulton Generating Station | 0 | 0 | 2 | 0 | 0 | 2 | 3 | 2 | 2 | 1 | 1 | 0 | 0 | 1 | 2 | 0 | 2 | 2 | X |
| Douglas Point Nuclear Generating Station (ER) | 2 | 2 | 2 | 2 | 2 | 2 | 0 | 2 | 2 | 2 | 0 | 0 | 1 | 0 | 2 | 0 | 2 | 2 | |
| Marble Hill Nuclear Generating Station | 2 | 2 | 2 | 0 | 0 | 2 | 0 | 2 | 2 | 2 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 2 | X |
| NEP Nuclear Power Plant | 3 | 2 | 2 | 1 | 1 | 2 | 0 | 1 | 2 | 2 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 2 | X |
| River Bend Station | 2 | 2 | 2 | 2 | 0 | 2 | 0 | 2 | 2 | 2 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 2 | X |
| Palo Verde Nuclear Generating Station | 3 | 1 | 2 | 3 | 2 | 2 | 4 | 3 | 2 | 2 | 1 | 1 | 1 | 2 | 2 | 0 | 2 | 1 | |
| South Texas Project | 2 | 1 | 2 | 2 | 1 | 2 | 4 | 3 | 2 | 2 | 1 | 0 | 0 | 2 | 2 | 0 | 2 | 1 | X |
| Tyrone Energy Park | 3 | 2 | 2 | 2 | 1 | 2 | 4 | 3 | 2 | 2 | 1 | 0 | 0 | 1 | 2 | 0 | 2 | 2 | |

Table 5.3 ATTRIBUTE VALUES FOR METHODOLOGIES AS THEY POTENTIALLY MIGHT BE APPLIED

| | Quality of Analysis | | | | | | | | | | | | | | Public Perception | | Practicality | | Dominated Methodologies |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Candidate Area Determination | | | Candidate Site Determination | | | Proposed Site Determination | | | | | | | Sensitivity Analysis | | | | | |
| Attribute | $x_{1111}$ | $x_{1112}$ | $x_{1113}$ | $x_{1121}$ | $x_{1122}$ | $x_{1123}$ | $x_{121}$ | $x_{122}$ | $x_{123}$ | $x_{124}$ | $x_{125}$ | $x_{126}$ | $x_{127}$ | $x_{13}$ | $x_{21}$ | $x_{22}$ | $x_{31}$ | $x_{32}$ | |
| Best Possible Ratings | 3 | 2 | 2 | 3 | 2 | 2 | 5 | 3 | 2 | 2 | 1 | 3 | 2 | 3 | 2 | 1 | 2 | 2 | |
| Methodology I: Blue Hills/Callaway | 3 | 2 | 2 | 3 | 2 | 2 | 1 | 3 | 2 | 2 | 1 | 2 | 1 | 1 | 2 | 0 | 2 | 2 | X |
| Methodology II: Douglas Point (FES)/ Jamesport/Fulton | 3 | 2 | 2 | 3 | 2 | 2 | 4 | 3 | 2 | 2 | 1 | 2 | 1 | 1 | 2 | 0 | 2 | 2 | X |
| Methodology III: Douglas Point (ER)/ Marble Hill/NEP/ River Bend | 3 | 2 | 2 | 3 | 2 | 2 | 1 | 2 | 2 | 2 | 1 | 2 | 1 | 0 | 2 | 0 | 2 | 2 | X |
| Methodology IV: Palo Verde/South Texas | 3 | 2 | 2 | 3 | 2 | 2 | 4 | 3 | 2 | 2 | 1 | 2 | 1 | 3 | 2 | 0 | 2 | 1 | |
| Methodology V: Tyrone | 3 | 2 | 2 | 3 | 2 | 2 | 4 | 3 | 2 | 2 | 1 | 2 | 1 | 2 | 2 | 0 | 2 | 2 | |



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different, when the potential for the methodologies is examined (Table 5.3) there are only five distinct methodologies. All the methodologies in Table 5.2 are variations of these five, which differ in the degree to which easily correctable errors were avoided in applying the methodology.

The tables also show that six of the twelve methodologies as actually applied are dominated. That is, for the dominated methodologies there is another methodology which is at least as good on all attributes and better on at least one attribute. The dominated methodologies could never be rated as the best regardless of what objective (utility) function was used to do the rating.

Three of the five methodologies as they might potentially have been applied are also dominated. The two nondominated entries in Table 5.3, methodologies IV and V, differ from each other only in the levels of attributes $X_{13}$ (Sensitivity Analysis) and $X_{32}$ (Cost). Thus, the preferred methodology will depend on whether the evaluator judges the increased ability of methodology IV to perform sensitivity analysis to be worth the extra cost.

The situation is not so simple in Table 5.2. If, however, the levels of $X_{1112}$ (screening criteria explicitly justified) and $X_{32}$ (Cost) were each raised by one for the Palo Verde methodology, then it would dominate all the other methodologies in the table. Furthermore, it rates much higher on some attributes than most of the other methodologies.



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Thus, unless a great deal of importance is attached to justifying screening criteria explicitly and to keeping cost down, we would expect the Palo Verde methodology to be the preferred one.

In the next section objective, or utility, functions are presented and used to rank the methodologies.



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2. Calloway Plant, Units 1 and 2. Environmental Report, Docket 50483-12. 1974.

3. Douglas Point Nuclear Generating Station, Units 1 and 2. Environmental Report, Docket 50448-12. August 8, 1973.

4. Douglas Point Nuclear Generating Station, Units 1 and 2. Final Environmental Statement, Docket 50448-15. March 1976.

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6. Fulton Generating Station, Units 1 and 2. Environmental Report, Docket 50463-3. 1973.

7. Marble Hill Nuclear Generating Station, Units 1 and 2. Environmental Report, Docket 50546-3. September 11, 1975.

8. River Bend Station, Units 1 and 2. Environmental Report, Docket 50458-10. 1973.

9. NEP Nuclear Power Plant, Units 1 and 2. Environmental Report, Docket 50568. September 6, 1976.

10. Palo Verde Nuclear Generating Station, Units 1, 2, and 3. Environmental Report, Docket 50528-6. 1974.

11. South Texas Project, Units 1 and 2. Environmental Report, Docket 50498-17. July 1, 1974.

12. Tyrone Energy Park, Units 1 and 2. Environmental Report, Docket 50484-9. 1974.

## 6. MULTIATTRIBUTE UTILITY FUNCTIONS FOR EVALUATING METHODOLOGIES

The discussion in Section 5 indicates that the relative rankings of the different methodologies may depend on the relative importance attached to the different objectives. To investigate this, multiattribute utility theory was used to construct utility (objective) functions that combined the eighteen attributes presented in Section 4 to obtain a single measure of the overall effectiveness of each methodology. These utility functions have a number of parameters which can be varied to account for different assessments of the relative importance of the various objectives.

We interviewed four individuals involved in aspects of nuclear siting studies as discussed in Subsection 2.2. Three sets of utility function parameters representing the spectrum of viewpoints found in our interviews were determined. The three different utility functions were used to rank the different methodologies.

The spirit of the utility assessments was as follows. In our initial interview, we planned to ascertain that the attributes we had defined were meaningful to the problem and to obtain a reasonable, but somewhat rough, overall utility function. Then we intended to evaluate the methodologies with these utility functions to determine, among other things, if more defined utility assessments were necessary. The initial utility assessments were simplified for convenience in three respects:

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1. All the assumptions necessary to verify the appropriateness of a particular utility structure were not investigated to the degree permitted by the methodology.

2. The single-attribute utility functions, whose scales were constructed to provide linear preferences, were simply assumed to indeed be linear.

3. The scaling factors were assigned in part from assessing the relative importance of the various attributes rather than by explicitly assessing value tradeoffs among attributes.

The results of the rankings (see Section 7) using these utility functions and the sensitivity analysis indicated that these assumptions could not have distorted the implications of the analysis. Hence, no further refinement of the utility functions was conducted. This section indicates details of how the utility functions used in ranking the site selection methodologies were determined.

## 6.1 Structure of Utility Functions

Careful thought in defining the attributes and subsequent discussions with the interviewees indicated it was reasonable to assume at each level in the objectives hierarchy that the necessary utility and preferential independence conditions held for a multiplicative or additive decomposition of the utility function. These independence conditions, which are illustrated below, are discussed in more detail in Appendix 3. The utility function structure that results from these decompositions is shown in Table 6.1. In this table u(x) represents the utility function over all the attributes, the various subscripted u's are utility functions over subsets of the attributes, and the subscripted k's and K's are constants. Table 6.1 shows that the utility function u(x) is completely determined if single-attribute utility functions are found for each of the eighteen attributes discussed in Section 4 and, in addition, several constants are specified.

To provide an intuitive feeling for utility and preferential independence, let us consider determining the overall structure of u(x) as a function of the three component attributes $X_1$, $X_2$, and $X_3$. If the assessment of the utility function over $X_1$ does not depend on the levels of $X_2$ and $X_3$, then we say that $X_1$ is utility independent of the pair $X_2$, $X_3$. This implies $u_1(x_1)$ exists and, in particular, it does not depend on $X_2$ and $X_3$. If the value tradeoffs between attributes $X_1$ and $X_2$ do not depend on the level of $X_3$, then the pair $X_1$, $X_2$ is preferentially independent of $X_3$. This implies that the relative value of the scaling factors $k_1$ and $k_2$ does not depend on $x_3$.

If $X_i$, i = 1, 2, 3, is utility independent of the other two attributes and if each of these pairs of attributes is preferentially independent of $X_i$, i = 1, 2, 3, then either the additive or multiplicative



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Table 6.1 UTILITY FUNCTION DECOMPOSITIONS INDICATING THE ADDITIVE AND MULTIPLICATIVE FORMS

$$u(x) = \begin{cases} \sum_{i=1}^{3} k_i u_i(x_i) & \text{additive.} \\ \frac{1}{K}\left\{\prod_{i=1}^{3} [K k_i u_i(x_i)+1]-1\right\} , & K \neq 0 \text{ , multiplicative.} \end{cases} \quad (6.1)$$

$$u_i(x_i) = \begin{cases} \sum_{j=1}^{N_i} k_{ij} u_{ij}(x_{ij}) \\ \frac{1}{K_i}\left\{\prod_{j=1}^{N_i} [K_i k_{ij} u_{ij}(x_{ij})+1]-1\right\} , & K_i \neq 0 \end{cases} \quad (6.2)$$

$i = 1, 2, 3;\ N_1 = 3;\ N_2 = 2;\ N_3 = 2$

$$u_{1j}(x_{1j}) = \begin{cases} \sum_{m=1}^{N_{1j}} k_{1jm} u_{1jm}(x_{1jm}) \\ \frac{1}{K_{1j}}\left\{\prod_{m=1}^{N_{1j}} [K_{1j} k_{1jm} u_{1jm}(x_{1jm})+1]-1\right\} , & K_{1j} \neq 0 \end{cases} \quad (6.3)$$

$j = 1, 2;\ N_{11} = 2;\ N_{12} = 7$

$$u_{11mn}(x_{11mn}) = \begin{cases} \sum_{m=1}^{3} k_{11mn} u_{11mn}(x_{11mn}) \\ \frac{1}{K_{11m}}\left\{\prod_{m=1}^{3} [K_{11m} k_{11mn} u_{11mn}(x_{11mn})+1]-1\right\} , & K_{11m} \neq 0 \end{cases} \quad (6.4)$$

$m = 1,2$

form in (6.1) of Table 6.1 must hold. Similar conditions are required for the decomposed forms of the component utility functions in Table 6.1.

In assessing the utility functions, questions were asked of the interviewees to determine whether the appropriate independence conditions held. In particular, the critical assumption for rough assessments is preferential independence. We determined that the relative importance of pairs of attributes did not depend on the other attributes. Roughly speaking this meant, for instance, that objective 1 was three times as important as objective 2 when objective 3 was at an undesirable level. Then objective 1 would still be three times as important as objective 2 when objective 3 was at a desirable level. Each of the interviewees felt such assumptions seemed reasonable as an approximation at each level in the objectives hierarchy.

## 6.2 Determination of Single-Attribute Utility Functions

When the attribute scales for the siting methodology evaluation were being constructed, the scale values were selected partly in an attempt to obtain linear utility functions over each attribute. In cases where it appeared linearity would not be reasonable, the scale values were redefined to gain linearity. Thus, for preliminary analysis purposes, it was reasonable to assume that the utility function over each attribute was linear. This assumption resulted in the utility functions presented in Table 6.2.



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Table 6.2 SINGLE-ATTRIBUTE UTILITY FUNCTIONS

$$u_{1111}(x_{1111}) = .333x_{1111},\ x_{1111} = 0, 1, 2, 3$$

$$u_{1112}(x_{1112}) = .500x_{1112},\ x_{1112} = 0, 1, 2$$

$$u_{1113}(x_{1113}) = .500x_{1113},\ x_{1113} = 0, 1, 2$$

$$u_{1121}(x_{1121}) = .333x_{1121},\ x_{1121} = 0, 1, 2, 3$$

$$u_{1122}(x_{1122}) = .500x_{1122},\ x_{1122} = 0, 1, 2$$

$$u_{1123}(x_{1123}) = .500x_{1123},\ x_{1123} = 0, 1, 2$$

$$u_{121}(x_{121}) = .200x_{121},\ x_{121} = 0, 1, \ldots, 5$$

$$u_{122}(x_{122}) = .333x_{122},\ x_{122} = 0, 1, 2, 3$$

$$u_{123}(x_{123}) = .500x_{123},\ x_{123} = 0, 1, 2$$

$$u_{124}(x_{124}) = .500x_{124},\ x_{124} = 0, 1, 2$$

$$u_{125}(x_{125}) = x_{125},\ x_{125} = 0, 1$$

$$u_{126}(x_{126}) = .333x_{126},\ x_{126} = 0, 1, 2, 3$$

$$u_{127}(x_{127}) = .500x_{127},\ x_{127} = 0, 1, 2$$

$$u_{13}(x_{13}) = .333x_{13},\ x_{13} = 0, 1, 2, 3$$

$$u_{21}(x_{21}) = .500x_{21},\ x_{21} = 0, 1, 2$$

$$u_{22}(x_{22}) = x_{22},\ x_{22} = 0, 1$$

$$u_{31}(x_{31}) = .500x_{31},\ x_{31} = 0, 1, 2$$

$$u_{32}(x_{32}) = .500x_{32},\ x_{32} = 0, 1, 2$$

## 6.3 Determination of Utility Function Scaling Factors

The major input in specifying the scaling factors (i.e., the k's) in Table 6.1 involved obtaining the interviewees' responses to questions involving the importance of the various objectives. For instance, with the ranges of the attributes given in Section 4 we would ask, "If you could move all the attributes measuring objective 1 or all the attributes measuring objective 2 or all the attributes measuring objective 3 from their worst to their best levels, which would you prefer?" Note that this is somewhat like asking, "Is Quality of Analysis, Public Perception, or Practicality the most important?" A response of Quality of Analysis indicates that $k_1$ in (6.1) must be greater than either $k_2$ or $k_3$. If Public Perception is second in importance, then $k_2$ is greater than $k_3$. If Quality of Analysis is more important than Public Perception and Practicality combined, then $k_1$ must be greater than $k_2$ plus $k_3$.

Such considerations involving combinations of different levels of the objectives hierarchy yielded a relative ranking of all the k's for utility models at each level in the objectives hierarchy as specified in Table 6.1. Some value tradeoffs were assessed as a check on the relative values of scaling factors. When necessary, adjustments were made to bring about consistency.

A standard lottery question was asked to determine the absolute value of $k_1$ from which each other k could be determined. (See Appendix 3

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for a discussion of such lotteries.) From the k's, one can directly calculate all the K's needed in Table 6.1.

From the responses of the interviewees, the three sets of parameters shown in Table 6.3 were constructed. (See Appendix 3 for a discussion of how the responses are used to determine the parameters.) Note that the sets of parameters shown in the table do not represent the utility functions of specific individuals, but rather the different points of view expressed. As mentioned earlier, four individuals were interviewed and their responses were amalgamated to obtain the parameter sets shown.

Within any component utility function in Table 6.1, the relative size of each scaling factor is indicative of the relative importance attached to the objective associated with that parameter. An examination of the parameter values in Table 6.3 shows substantial disagreement about the relative importance of the different objectives used in the evaluation of site selection methodologies. In fact, the only major agreement is that the Quality of Analysis objective is much more important than the Public Perception and/or Practicality objectives.

These differences in parameter values quantify some of the disagreements within the nuclear community about the importance of various aspects of nuclear power plant siting methodologies. When we first obtained the three sets of utility function parameters, we were concerned that the major disagreements might make it difficult to reach firm

Table 6.3 PARAMETERS FOR UTILITY FUNCTIONS

| Scaling Factor | Attribute | Utility Function 1 | Utility Function 2 | Utility Function 3 |
|---|---|---|---|---|
| $k_1$ | Quality of Analysis | .667 | .800 | .850 |
| $k_2$ | Public Perception | .267 | .150 | .079 |
| $k_3$ | Practicality | .033 | .050 | .150 |
| $k_{11}$ | Candidate Site Identification | .460 | .210 | .750 |
| $k_{12}$ | Site Selection | .360 | .560 | .375 |
| $k_{13}$ | Sensitivity Analysis | .180 | .230 | .250 |
| $k_{111}$ | Candidate Area Determination | .450 | .800 | .750 |
| $k_{112}$ | Candidate Site Determination | .550 | .800 | .250 |
| $k_{1111}$ | Screening Criteria Clearly Stated | .273 | .250 | .750 |
| $k_{1112}$ | Screening Criteria Explicitly Justified | .181 | .250 | .500 |
| $k_{1113}$ | Sufficient Data Used | .546 | .500 | .625 |
| $k_{1121}$ | Selection Criteria Clearly Stated | .273 | .250 | .750 |
| $k_{1122}$ | Selection Criteria Explicitly Justified | .181 | .250 | .500 |
| $k_{1123}$ | Sufficient Data Used | .546 | .500 | .625 |
| $k_{121}$ | Multiple Concerns | .208 | .275 | .075 |
| $k_{122}$ | Degree of Impact | .250 | .275 | .150 |
| $k_{123}$ | Comparable Analysis | .042 | .403 | .150 |
| $k_{124}$ | Sufficient Data | .042 | .403 | .120 |
| $k_{125}$ | Selection Rationale | .125 | .183 | .038 |
| $k_{126}$ | Uncertainties | .126 | .183 | .113 |
| $k_{127}$ | Long-Term Impacts | .208 | .147 | .150 |
| $k_{21}$ | Understandability | .429 | .200 | .850 |
| $k_{22}$ | Public Input | .571 | .800 | .250 |
| $k_{31}$ | Expertise Required | 1 | .100 | .750 |
| $k_{32}$ | Cost | 0 | .900 | .250 |



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conclusions about the relative ranking of the different siting methodologies. As the analysis in the next section shows, however, the same methodology is ranked as best by all three utility functions and the relative rankings of all the methodologies are fairly similar with the different functions.

## 7. EVALUATION OF METHODOLOGIES

The ranking of the siting methodologies as they were applied using the three different multiattribute utility functions is given in Table 7.1. The rankings for the methodologies as they potentially might have been applied are presented in Table 7.2. The utilities of the various methodologies for both cases are displayed graphically in Figure 7.1. The tables and figure show that the rankings are fairly similar for all three utility functions. In fact, the rankings of the methodologies as they potentially might be applied are identical for the three utility functions. For the methodologies as actually applied, the most preferred methodology (Palo Verde) is the same for all three utility functions, and the five best methodologies (Palo Verde, South Texas, Tyrone, Blue Hills, and Jamesport) are the same. South Texas, however, ranks fourth using utility function 3 while with the other two functions it ranks second. An examination of the utility function parameters shows that utility function 3 places much more importance on justifying the screening criteria for Candidate Areas (attribute $X_{1112}$) than do the other two utility functions. Thus, the failure of the South Texas methodology to justify all its screening criteria results in the lower ranking by utility function 3.

The relative insensitivity of the evaluation results to the different utility functions seems surprising at first. But examination of the attribute ratings in Tables 5.2 and 5.3 shows that in general the

Table 7.1 RANKINGS OF METHODOLOGIES AS ACTUALLY APPLIED

| | Utility Function 1 | | Utility Function 2 | | Utility Function 3 | |
|---|---|---|---|---|---|---|
| Rank | Methodology | Utility | Methodology | Utility | Methodology | Utility |
| 1 | Palo Verde Nuclear Generating Station | .721 | Palo Verde Nuclear Generating Station | .768 | Palo Verde Nuclear Generating Station | .921 |
| 2 | South Texas Project | .641 | South Texas Project | .740 | Tyrone Energy Park | .887 |
| 3 | Tyrone Energy Park | .625 | Tyrone Energy Park | .713 | Blue Hills Station | .882 |
| 4 | Blue Hills Station | .618 | Blue Hills Station | .692 | South Texas Project | .863 |
| 5 | Jamesport Nuclear Power Station | .550 | Jamesport Nuclear Power Station | .679 | Jamesport Nuclear Power Station | .838 |
| 6 | Callaway Plant | .530 | Callaway Plant | .664 | Douglas Point Nuclear Generating Station (ER) | .835 |
| 7 | Douglas Point Nuclear Generating Station (ER) | .521 | Fulton Generating Station | .604 | Douglas Point Nuclear Generating Station (FES) | .829 |
| 8 | Douglas Point Nuclear Generating Station (FES) | .495 | Douglas Point Nuclear Generating Station (ER) | .590 | NEP Nuclear Power Plant | .817 |
| 9 | Fulton Generating Station | .478 | Douglas Point Nuclear Generating Station (FES) | .589 | River Bend Station | .807 |
| 10 | River Bend Station | .464 | River Bend Station | .568 | Callaway Plant | .801 |
| 11 | NEP Nuclear Power Plant | . 56 | Marble Hill Nuclear Generating Station | .561 | Marble Hill Nuclear Generating Station | .780 |
| 12 | Marble Hill Nuclear Generating Station | .432 | NEP Nuclear Power Plant | .557 | Fulton Generating Station | .699 |

Table 7.2 RANKINGS OF METHODOLOGIES AS THEY POTENTIALLY MIGHT BE APPLIED

| Rank | Utility Function 1 | | Utility Function 2 | | Utility Function 3 | |
|---|---|---|---|---|---|---|
| | Methodology | Utility | Methodology | Utility | Methodology | Utility |
| 1 | Methodology IV: Palo Verde/South Texas | .785 | Methodology IV: Palo Verde/South Texas | .840 | Methodology IV: Palo Verde/South Texas | .960 |
| 2 | Methodology V: Tyrone | .744 | Methodology V: Tyrone | .801 | Methodology V: Tyrone | .949 |
| 3 | Methodology II: Douglas Point (FES)/ Jamesport/Fulton | .703 | Methodology II: Douglas Point (FES)/ Jamesport/Fulton | .740 | Methodology II: Douglas Point (FES)/ Jamesport/Fulton | .926 |
| 4 | Methodology I: Blue Hills/Callaway | .672 | Methodology I: Blue Hills/Callaway | .72[illegible] | Methodology I: Blue Hills/Callaway | .918 |
| 5 | Methodology III: Douglas Point (ER)/ Marble Hill/NEP/ River Bend | .611 | Methodology III: Douglas Point (ER)/ Marble Hill/NEP/ River Bend | .648 | Methodology III: Douglas Point (ER)/ Marble Hill/NEP/ River Bend | .836 |

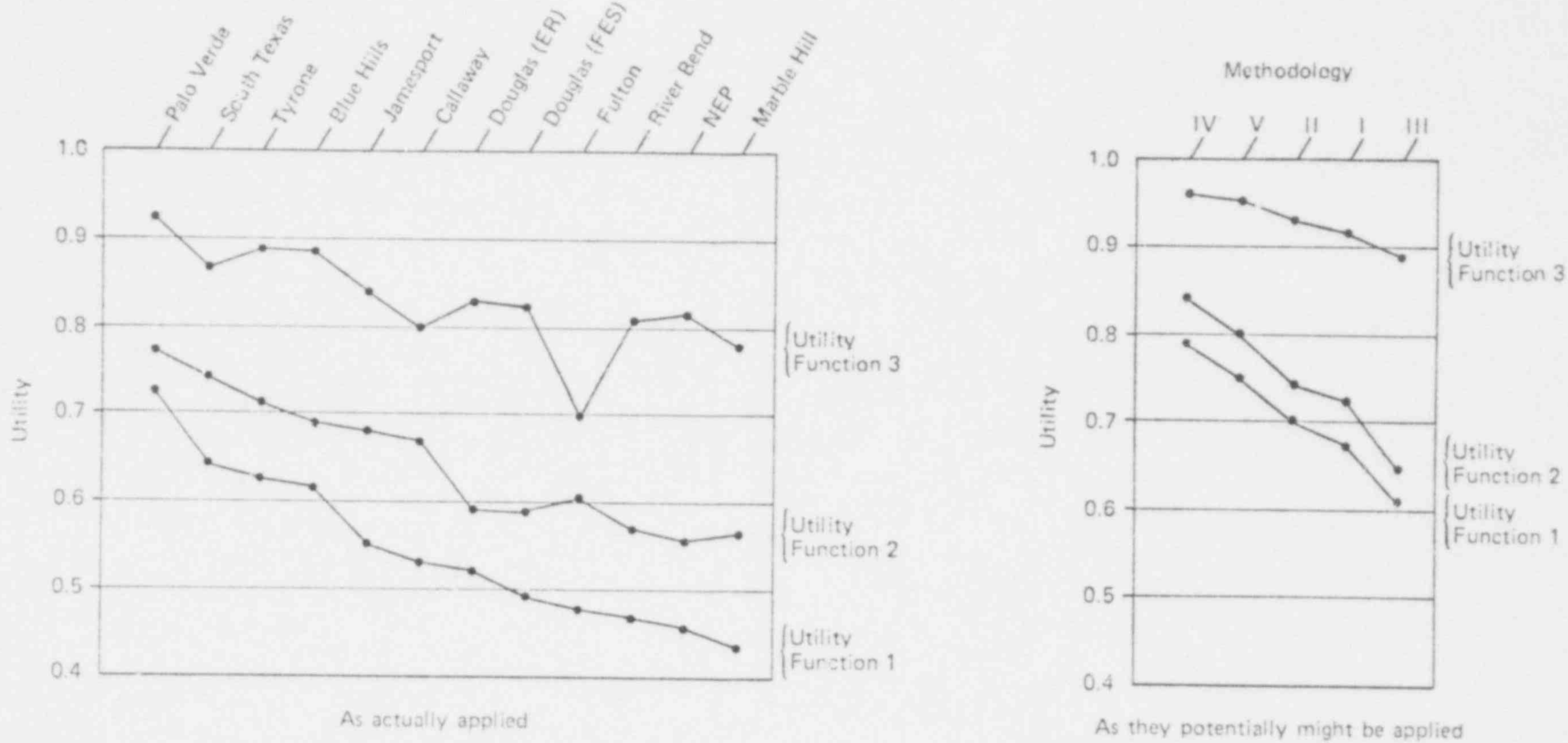


Figure 7.1 RANKINGS OF METHODOLOGIES



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better methodologies have good ratings on most of the attributes. Thus, the particular importance attached to each attribute is not too significant, resulting in the relative insensitivity of the rankings to the particular utility function parameters.

The implications of the results presented here are discussed in Section 8.

# 8. IMPLICATIONS OF THE ANALYSIS AND RECOMMENDATIONS FOR FURTHER STUDY

## 8.1 Implications of Results

There are three main contributions of this study:

1. The specification of a set of objectives desired from a methodology for evaluating potential nuclear power plant sites. Attributes to measure the degree to which a methodology met these objectives were constructed.

2. The evaluation of methodologies as they have been used and as they might potentially be used. Even though the methodologies were evaluated from three significantly different viewpoints, the rankings of the methodologies were very similar in all three cases.

3. The identification of specific weaknesses in the best methodologies. These concern selecting a Proposed Site from the Candidate Sites and not providing mechanisms for involving the public in the site selection process.

The principal purpose of this study was to identify strengths and weaknesses of methodologies used for nuclear power plant site selection. The attributes in Section 4 define what is meant by strengths and



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weaknesses and the utility function analysis in Sections 6 and 7 rates the methodologies. These attributes provide a convenient "checklist" for evaluating the methodology used in any siting study and for identifying its strengths and weaknesses.

The best rated methodologies generally use a combination of either favorability selection or exclusion screening and comparison screening. This combination allows Candidate Sites to be identified efficiently from easily accessible data, and also allows a quantitative analysis of the various multiple concerns in site selection as well as the degree of impact the site will have with respect to each of the concerns. The quantitative nature of this methodology permits sensitivity analysis to be done to identify the critical factors that influence the selection of a Proposed Site.

A comparison of Tables 5.2 and 5.3 and Tables 7.1 and 7.2 shows that all the methodologies have been applied considerably below their potential. In particular, the screening and selection criteria used for Candidate Area and Site determination are often not explicitly stated in the ER. In many cases, an explicit justification of why the criteria were used is not given. These methodological flaws would be relatively easy to correct. With the flaws, the value of the Site Selection section of the ER is substantially reduced, since it is impossible to determine the basic criteria that were used to select Candidate Sites.

With many of the methodologies, a rationale is not provided for selecting a Proposed Site. Also, an investigation of the major uncertainties about the possible impacts, especially long-term impacts, of a proposed nuclear power plant on the site is lacking or nonexistent. Once again, these weaknesses are easily correctable, which would significantly increase the value of the Site Selection section of the ER.

Table 5.3 indicates that, even when fully utilized, the best of the methodologies (i.e., methodologies IV and V) have important shortcomings. In particular, neither considers value tradeoffs among the multiple concerns of Site Selection as carefully as currently available analysis methods would allow, nor does either quantify uncertainties and long-term impacts for the sites. Finally, none of the methodologies allows for direct public participation in the Site Selection process.

## 8.2 Limitations of the Study

Two cautions need to be made regarding the analysis. First, we have analyzed only the methodologies used in the siting studies we examined. There are many nonmethodological characteristics of a study that might make it a poor study even though the methodology used was good. For example, the screening criteria used for Candidate Area determination might be clearly stated and justified and accurate data used to implement them, but the justification might be unacceptable to NRC. Thus, the Candidate Area determination would be poor even though the methodology used was good.

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Finally, this study was limited to methodologies that were used in ERs that have been submitted to NRC. Other methodologies, such as cost/benefit and decision analysis, have been proposed for use in power plant siting. However, since they have not been used in reports submitted to NRC, they were not considered here. It is possible that some of these methodologies overcome the difficulties shared by all the methodologies analyzed here.

## 8.3 Recommendations for Further Study

There appear to be three major directions for possible extensions of the work discussed here. These involve, respectively, the three main contributions of this study outlined in Subsection 8.1.

The objectives and their attributes specified in Sections 3 and 4 were developed over time in discussions with several individuals familiar with aspects of nuclear power siting. Yet, they could of course be improved upon. Further work on this should involve a broader spectrum of individuals concerned about nuclear power siting, as well as more in-depth interviews to articulate more completely what exactly is desired of a nuclear power plant siting methodology.

The evaluation aspect of the study could be extended in several manners. Since all the methodologies currently in use have shortcomings, it may be worthwhile to investigate other methodologies that have been proposed for siting studies but have not yet been used in reports submitted



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to NRC. Some of these may overcome shortcomings in currently used methodologies.

Our utility assessments utilized technically trained individuals associated with nuclear power plant siting. Our results indicated substantial disagreement about the relative importance of different siting methodology objectives even with this relatively homogeneous group. It may be desirable to assess the preferences of a broader range of individuals. In particular, the views of various public interest groups concerned with nuclear power plant siting might be useful to NRC. Possibly their preferences would differ from those of siting specialists. If this were the case, it would be interesting to know if those differences led to different rankings of the methodologies.

Finally, it was not necessary for our analysis to settle on a single utility function. If the structure developed in this report were to be used to rank the methodologies in siting studies on an ongoing basis, however, then it might be useful to agree upon a single utility function for this purpose. Further work needed to develop this function would include additional interviews with the individuals with whom we worked on this study to pinpoint more accurately the reasons for their disagreement over the relative importance of different objectives. Detailed discussions would possibly lead to changes of viewpoint and a closer consensus on the utility function. If not, some policy decisions would be needed as to which function should be used.

The third contribution of this study was to identify weaknesses in the best methodologies. It would seem appropriate to develop methodological techniques to alleviate those weaknesses. Better procedures are needed for aspects of the process of selecting a Proposed Site from Candidate Sites and for including the public in the decision-making process. For Site Selection, better procedures are required to utilize complex value tradeoffs among competing concerns of siting and to address the uncertainties and long-term impacts inherent in nuclear power plant siting. For public participation, techniques are needed to communicate relevant information to the public and receive clear perceptions, judgments, and values from the public in such a manner that they may be responsibly included in the evaluation of Proposed Sites. The end purpose of such an extension would be to provide the NRC with better information on which to base its decision making.

## APPENDIX 1

## THEORETICAL BACKGROUND FOR THE EXISTENCE OF UTILITY FUNCTIONS

The axioms of decision analysis [1] define a formal logic for evaluating alternatives where the consequences of those alternatives may be uncertain. Because there were no uncertainties among the alternatives (i.e., the methodologies) in this study, not all the assumptions are relevant. Specifically, the assumptions utilized in this study imply the existence of a utility function to model the preferences of the evaluator.

The von Neumann-Morgenstern utility function used is valid for evaluations with uncertainty and hence uses lottery techniques in assessment. This utility function was chosen for three reasons:

1. If the deterministic analysis indicated uncertainties were important, we intended to incorporate them; thus, a von Neumann-Morgenstern utility function would have been necessary.

2. The assessments required for a von Neumann-Morgenstern utility function are generally easier than those required for deterministic value structures.

3. The utility of each methodology will provide not only a ranking of the methodologies, but will also give some indication how much better one methodology is than another.

Before stating the axioms of utility theory, we define our notation. A simple lottery, written $L(x_1,p,x_2)$, is a probabilistic event characterized by two possible consequences, which will be designated by $x_1$ and $x_2$, and by their respective probabilities of occurrence, designated by p and 1-p. The symbols $>$, $\sim$, and $<$ will be read "is preferred to," "is indifferent to," and "is either preferred to or indifferent to," respectively. Thus, $x_1 \sim L(x_2,p,x_3)$ says that $x_1$ is indifferent to the lottery which yields either $x_2$ with probability p or $x_3$ with probability 1-p.

The axioms stated here which imply the existence of a utility function are only slightly modified from the formulation of Pratt, Raiffa, and Schlaifer [1].

Axiom 1: Existence of Relative Preferences. For every pair of consequences $x_1$ and $x_2$, preferences exist such that either $x_1 \sim x_2$, $x_1 > x_2$, or $x_2 < x_1$.

Axiom 2: Transitivity. For any lotteries $L_1$, $L_2$, and $L_3$, the following hold:

i) $L_1 \sim L_2$ and $L_2 \sim L_3$ implies that $L_1 \sim L_3$

ii) $L_1 > L_2$ and $L_2 \sim L_3$ implies that $L_1 > L_3$, etc.

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Since a consequence can be interpreted as a degenerate lottery (i.e., $p = 1$), axioms 1 and 2 together imply the existence of a ranking of the relative desirabilities of the various possible consequences. They do not say that an individual can articulate this, nor do they require that this ranking be stationary over time. Let us designate as $x^o$ a consequence which is not preferred to any of the other consequences for a problem and as $x^*$ a consequence which is at least as preferred as each of the other consequences. Therefore, one possibility is that $x^o$ and $x^*$ designate the least and most preferred consequences, although they may represent hypothetical consequences such that $x^* > x$ and $x > x^o$ for all possible x.

Axiom 3. Comparison of Simple Lotteries. Given the preference order $x_1 > x_2$, then

i) $L_1(x_1,p_1,x_2) > L_2(x_1,p_2,x_2)$ if $p_1 > p_2$,

ii) $L_1(x_1,p_1,x_2) \sim L_2(x_1,p_2,x_2)$ if $p_1 = p_2$.

Axiom 4. Quantification of Preference. For each possible consequence x, the evaluator can specify a number $\pi(x)$, where

$$0 \leq \pi(x) \leq 1, \text{ such that } x \sim L(x^*, \pi(x), x^o).$$

Axioms 3 and 4 taken together establish a measure of the relative desirabilities of the various consequences to the evaluator. The $\pi(x)$ value, or indifference probability as it is called, is that measure.



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The measure $\pi(x)$ in Axiom 4 indicates the relative preferences for x. Clearly, since the standards $x^o$ and $x^*$ for measuring $\pi(x)$ are somewhat arbitrary, different $\pi$ functions may be assessed for a specific individual in a particular situation. To be consistent with these axioms, however, all possible functions must be positive linear transformations of each other. Any positive linear transformation of $\pi$ of the form

$$u(x) = a + b\pi(x), \; b > 0$$

is referred to as a utility scale for consequence x. The quantity u(x) is said to be the utility of consequence x. If one accepts the above axioms, one should always prefer alternatives that maximize expected utility. There are no alternative procedures for making decisions consistent with these axioms.

Since maximizing expected utility is equivalent to maximizing the expected value of $\pi$, the arbitrary choice of $x^*$ and $x^o$ has no influence on the actual decision. Utility provides a relative scale analogous to the temperature scales, and two scales which are positive linear transformations of each other are identical for decision-making purposes.

REFERENCES — Appendix 1


1. Pratt, J.W., H. Raiffa, and R. Schlaifer. "The Foundations of Decision Under Uncertainty: An Elementary Exposition." Journal of the American Statistical Association 59:353-357.




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## APPENDIX 2

## MEASUREMENT SCALES FOR QUANTIFYING ATTRIBUTES

In all formal analyses of the alternatives in decision problems, there must be some attempt to indicate the degree to which each objective is achieved by the various alternatives. This necessitates the establishment of a scale (or scales) for each objective on which to indicate this achievement. For important decision problems, the process of defining these scales should be logically consistent and systematic. At the same time, it is inherently subjective; it must encompass professional judgment, knowledge, and experience.

For any particular problem, the analyst wishes to specify a set of scales which are useful for examining the alternatives. The set of properties which render such a set useful are discussed in detail in Keeney and Raiffa [1]. This appendix concerns the specification of individual scales in the set. The process of integrating all these scales in a manner useful for evaluating the alternatives involves value judgments weighting the importance of various levels of achievement in different objectives. This topic is discussed in Appendix 3.

In this study, scales needed to be constructed for each of the eighteen lower level attributes. For each attribute, we wanted to accomplish three purposes with this scale:

1. define different levels of achievement on the attribute to describe the different characteristics of the methodologies

2. select scale levels such that, loosely speaking, the difference in utility between adjacent levels was the same, i.e., the utility function over the scale would be linear

3. guarantee that the ratings of each methodology in terms of the attribute levels clearly articulated the strengths and weaknesses of the methodologies

To accomplish purpose 1, we began to list levels of achievement. This process was basically creative in nature and involved several repetitions with individuals knowledgeable about the nuclear siting process. As seen from Subsection 4.2, in the end some attributes required only two levels and others required as many as five.

After more than three levels were constructed for any particular scale, preliminary utility assessments were conducted to see if it was reasonable to assume the difference in utility between adjacent levels was equivalent. In most cases, this seemed to be an appropriate assumption. When it did not seem appropriate, we created an additional attribute level to make the assumption more accurate.

In categorizing the methodologies, careful attention was paid to whether the attribute levels distinguished clearly among the methodologies. In some cases, additional points were added to scales in this phase of the study. In others, coalescing two levels seemed appropriate and was done. The result was to include enough points to identify differences in methodologies, but not so many as to obscure those differences which seemed fundamental.

REFERENCES - Appendix 2

1. Keeney, R. L., and H. Raiffa. Decisions with Multiple Objectives. New York: Wiley, 1976.

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## APPENDIX 3

## DETERMINATION OF UTILITY FUNCTIONS

To use the theory presented in Appendix 1 in an evaluation, it is necessary to determine a utility function. This appendix discusses the theory and procedures used to find the utility functions presented in Section 6.

The evaluation approach in this study uses attributes, or measures of effectiveness, to describe each alternative being evaluated. The selection or construction of such attributes was discussed in Appendix 2. In this appendix we will assume that an acceptable set of attributes $X_1, X_2, \ldots, X_N$ has been specified. Then to find a utility function u for use in the evaluation, it is necessary to find a function $u(x_1, x_2, \ldots, x_N)$ over the N attributes where $x_n$ represents a specific value of $X_n$. Generally, various independence conditions are exploited to simplify the determination of u.

### A3.1 Utility and Preferential Independence

For notational convenience let

$$\overline{X}_i = (X_1, X_2, \ldots, X_{i-1}, X_{i+1}, \ldots, X_n) \text{ and}$$
$$\overline{X}_{ij} = (X_1, X_2, \ldots, X_{i-1}, X_{i+1}, \ldots, X_{j-1}, X_{j+1}, \ldots, X_n).$$

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Then $X_i$ is <u>utility independent</u> of $\bar{X}_i$ if preferences for risky choices (lotteries) over $X_i$ with the value of $\bar{X}_i$ held fixed do not depend on the fixed value of $\bar{X}_i$. The set $(X_i, X_j)$ is <u>preferentially independent</u> of $\bar{X}_{ij}$ if preferences for consequences differing only in the values of $X_i$ and $X_j$ do not depend on the value of $\bar{X}_{ij}$.

The following two theorems due to Keeney [1,2,3] exploit utility and preferential independence to simplify the assessment of u.

<u>Theorem 1.</u> For a set of attributes $(X_1, X_2)$ if $X_1$ is utility independent of $X_2$ and $X_2$ is utility independent of $X_1$, then

$$u(x_1, x_2) = k_1u_1(x_1) + k_2u_2(x_2) + k_{12}u_1(x_1)u_2(x_2)$$

where

i) $u(x_1^o, y_1^o) = 0$ and $u(x_1^*, x_2^*) = 1$ for arbitrary $x_1^o$, $x_2^o$, $x_1^*$, $x_2^*$ such that $(x_1, x_2^o) > (x_1^o, x_2^o)$ and $(x_1^o, x_2^*) > (x_1^o, x_2^o)$,

ii) $u_i(x_i)$ is a conditional utility function on $X_i$ with $u_i(x_i) = 0$ and $u_i(x_i^*) = 1$, for i = 1, 2, and

iii) $k_1 = u(x_1^*, x_2^o)$, $k_2 = u(x_1^o, x_2^*)$, and $k_{12} = 1-k_1-k_2$.

<u>Theorem 2.</u> For a set of attributes $(X_1, X_2, \ldots, X_N)$, $N \geq 3$ if, for some i, $X_i$ is utility independent of $\bar{X}_i$ and $(X_i, X_j)$ is preferentially independent of $\bar{X}_{ij}$, j = 1, 2, . . ., i-1, i+1, . . ., N, then either

$$u(x_1, x_2, \ldots, x_N) = \sum_{n=1}^{N} k_n u_n(x_n)$$

or

$$ku(x_1, x_2, \ldots, x_N) + 1 = \prod_{n=1}^{N} [kk_n u_n(x_n) + 1]$$

where

i) $u(x_1^o, x_2^o, \ldots, x_N^o) = 0$ and $u(x_1^*, x_2^*, \ldots, x_N^*) = 1$.

ii) $u_n(x_n)$ is a conditional utility function on $X_n$ with $u_n(x_n^o) = 0$ and $u_n(x_n^*) = 1$, $n = 1, 2, \ldots, N$,

iii) $k_n = u(x_1^o, x_2^o, \ldots, x_{n-1}^o, x_n^*, x_{n+1}^o, \ldots, x_N^o)$, and

iv) $-1<k \neq 0$ is the solution to $1+k = \prod_{n=1}^{N}(1+kk_n)$.

If the conditions for one of these theorems to hold are true, then the determination of u is simplified. It is only necessary to find N single-attribute utility functions, $u_n(x_n)$, $n = 1, 2, \ldots, N$, and N parameters $k_1, k_2, \ldots, k_N$.

The questions needed to establish utility or preferential independence are discussed in detail in Keeney and Raiffa [3] so only a brief summary will be given here. To verify that $(X_1, X_2)$ is preferentially independent of $\bar{X}_{12}$, specified values of $\bar{X}_{12}$ are assumed and the person whose utility function is being assessed is asked how much of $X_1$ he would give up for a specified improvement in the value of $X_2$. Then, new values are specified for $\bar{X}_{12}$ and the same question about $X_1$ and $X_2$ repeated. If the tradeoff between $X_1$ and $X_2$ is independent of the value of $\bar{X}_{12}$, then preferential independence of $(X_1, X_2)$ from $\bar{X}_{12}$ is a reasonable assumption.

The questions necessary to establish utility independence are similar except that they require the consideration of simple situations with uncertainty.

## A3.2 Determination of Conditional Utility Functions and Parameters

If the conditions of either Theorem 1 or 2 hold then, as noted above, it is only necessary to find $u_n(x_n)$, $n = 1, 2, \ldots, N$ and $k_1, k_2, \ldots, k_N$ to complete the determination of the utility function $u(x_1, x_2, \ldots, x_N)$. Section 6 noted that it was adequate in this study to assume each of the conditional utility functions was linear. This was true because when the attribute scales were being developed, a conscious effort was made to define them so linearity would hold. As various experts were interviewed, it developed that linearity was not a good approximation for some of the attributes. In those cases the attribute scales were redefined until linearity was approximately true. (In situations where linearity is not true, standard utility assessment techniques [3, 4] could be used to find the conditional utility functions.)

A variety of different questions can be answered to determine the $k_n$'s [2, 3]. For example, the person whose utility function is being

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etermined could be asked to consider a situation where $x_n$ is at its best possible value $x_n^*$ and the other attributes are at their worst possible values $x_1^o, x_2^o, \ldots, x_{n-1}^o, x_{n+1}^o, \ldots, x_N^o$. He would then be asked to compare $(x_1^o, x_2^o, \ldots, x_{n-1}^o, x_n^*, x_{n+1}^o, \ldots, x_N^o)$ with an uncertain situation which has a probability p of yielding $x_1^*, x_2^*, \ldots, x_N^*)$ and a probability 1-p of yielding $(x_1^o, x_2^o, \ldots, x_N^o)$ and to find the value of p where he is indifferent between the certain and uncertain situations. This value of p is equal to $k_n$.

In the evaluation of siting methodologies, a variety of different questions was used with the individuals interviewed to determine information about scaling constants. As mentioned in the text, we carried out preliminary interviews with several experts on the expectation that later, more formal interviews would follow. These follow-up conversations proved unnecessary, however, when the ranking of methodologies was found to be insensitive to the exact values of the scaling constants. In the preliminary interviews qualitative questions were sometimes asked to gain information about the relative sizes of different scaling constants. If the exact values of the constants had been important, these qualitative questions would have been followed by quantitative questions of the type discussed in the preceding paragraph. But because of the insensitivity of the evaluation to scaling constant values, we did not carry out the quantitative questioning with some of the experts interviewed.

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As a final point regarding utility assessment, the attributes in the two theorems presented above do not have to be scalers. They may be vectors made up of groups of scalar attributes. This fact was exploited in the hierarchical decomposition procedure used to determine the utility function in Section 6.

REFERENCES – Appendix 3


1. Keeney, R.L. "Utility Functions for Multiattributed Consequences." Management Science 18: 276-287.

2. Keeney, R.L. "Multiplicative Utility Functions." Operations Research 22: 22-34.

3. Keeney, R.L., and H. Raiffa. Decisions with Multiple Objectives. New York: Wiley, 1976.

4. Schlaifer, R. Analysis of Decisions Under Uncertainty. New York: McGraw-Hill, 1969.




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## Appendix 4

## REASONS FOR SITING METHODOLOGY ATTRIBUTE VALUES

This appendix states the rationale for the attribute values presented in Section 5. The data were provided by Sandia Laboratories. The twelve studies analyzed here were selected after an initial, less detailed consideration of forty-one Environmental Reports submitted to the Nuclear Regulatory Commission between July 1972 and September 1976. The studies are listed in alphabetical order.

## BLUE HILLS

| Attribute | Methodology As Used | Methodology Potential | Rationale |
|---|---|---|---|
| 1.1.1.1 | 2 | 3 | Although most of the criteria were explicitly and quantitatively stated, the power demand center proximity was the determining criterion and it was only qualitatively discussed. This is not a methodological flaw, but rather a siting study flaw. |
| 1.1.1.2 | 2 | 2 | All criteria were discussed and justified. |
| 1.1.1.3 | 2 | 2 | Literature contains sufficient data for regional screening criteria. |
| 1.1.2.1 | 3 | 3 | Criteria are expressed in terms of cost where appropriate; the others are very clearly discussed. Guidelines are stated as existing, although they were not given in the ER. |
| 1.1.2.2 | 2 | 2 | All criteria were discussed and justified. |
| 1.1.2.3 | 2 | 2 | Literature data were used appropriately at this phase. |
| 1.2.1 | 0 | 1 | Cost data were given for engineering concerns, but environmental criteria were treated separately. This type of methodology involves treating the two separately, but a qualitative discussion of tradeoffs could still be included. |
| 1.2.2 | 2 | 3 | The differences between sites are well quantified for most attributes. If environmental objectives were covered better, the methodology could quantify the degree of achievement. |
| 1.2.3 | 2 | 2 | The same type of data is available and analyzed for the alternative sites. |

| Attribute | Methodology As Used | Methodology Potential | Rationale |
|---|---|---|---|
| 1.2.4 | 2 | 2 | A good deal of data is presented for all of the criteria and is appropriately referenced. |
| 1.2.5 | 1 | 1 | Since the alternate nuclear sites are essentially equivalent environmentally and from an engineering feasibility standpoint, relative cost is the deciding factor. |
| 1.2.6 | 1 | 2 | Uncertainties are not covered except for the conservative estimates of the parameters involved in the exclusion radius calculation. |
| 1.2.7 | 1 | 1 | Future population is covered by the calculation referred to above. |
| 1.3 | 1 | 1 | The assumed cost estimates for many of the engineering attributes are given. |
| 2.1 | 2 | 2 | The informed public can understand cost estimates and a qualitative discussion of environmental factors. |
| 2.2 | 0 | 0 | No public participation. |
| 3.1 | 2 | 2 | No special expertise was required. |
| 3.2 | 2 | 2 | Estimate based on above and the fact that data were obtained primarily from literature. |

CALLAWAY PLANT

| Attribute | Methodology As Used | Methodology Potential | Rationale |
|---|---|---|---|
| 1.1.1.1 | 1 | 3 | Many criteria are listed, and some are listed as determining criteria, but it is not clear exactly which were actually used and what the quantitative cutoffs were. This is not a methodological flaw, but rather a siting study flaw. |
| 1.1.1.2 | 1 | 2 | Reasons for use of some criteria (proximity to load center, seismicity) were discussed, but not in great detail, and many criteria were simply listed. |
| 1.1.1.3 | 2 | 2 | Literature searches would provide sufficient data for the regional screening criteria. |
| 1.1.2.1 | 1 | 3 | Although the category of criteria are listed, it is not clear what the cutoffs were. The methodology is capable of containing clear definitions of the criteria. In fact, this study might have used definitive criteria and simply not included them in the report. |
| 1.1.2.2 | 1 | 2 | Many of the criteria were simply listed with no discussion or justification. |
| 1.1.2.3 | 2 | 2 | Literature search data are sufficient for this stage of the siting process. |
| 1.2.1 | 1 | 1 | The preferred site was inferior to the others in only one respect – the relatively high pumping head for makeup water – and this was easy to justify in light of the importance of other considerations. |
| 1.2.2 | 2 | 3 | The differences between sites are well quantified for most attributes. In particular, if the environmental objective and degree of achievement were covered better, this siting study would be as good as the methodology could be. |

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| Attribute | Methodology | | Rationale |
| --- | --- | --- | --- |
| | As Used | Potential | |
| 1.2.3 | 2 | 2 | The same type of data is available and analyzed for the alternative sites. |
| 1.2.4 | 2 | 2 | A good deal of data is presented for all of the criteria and is appropriately referenced. |
| 1.2.5 | 1 | 1 | The preferred site is superior in all respects but one and is the obvious choice. If, however, different sites were superior based on environmental and cost considerations, the decision mechanism would not be clear, since the methodology does not cover tradeoffs between the two areas. |
| 1.2.6 | 1 | 2 | The uncertainties in the cost estimates are discussed and it is concluded that they all have an equal probability of varying greatly. Some cost estimates categories were not included because they would have been less than the possible variance in other categories. |
| 1.2.7 | 0 | 1 | Although no long-term impacts were covered in this study, several (future population and land use) could easily be handled by the methodology. |
| 1.3 | 1 | 1 | The cost estimates for many of the engineering attributes are given and some discussion is presented as to their possible variance. |
| 2.1 | 2 | 2 | The cost estimates are easy to understand, although the socioeconomic cost impact model is slightly more difficult. |
| 2.2 | 0 | 0 | No public participation. |
| 3.1 | 2 | 2 | No special expertise was required. |
| 3.2 | 2 | 2 | Estimate based on above and the fact that data were obtained primarily from literature. |

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DOUGLAS POINT

| Attribute | ER Methodology As Used | ER Methodology Potential | FES Methodology As Used | FES Methodology Potential | Rationale |
|---|---|---|---|---|---|
| 1.1.1.1 | 2 | 3 | 2 | 3 | The reasons for area elimination are given, but only qualitatively. |
| 1.1.1.2 | 2 | 2 | 2 | 2 | All screening criteria are discussed and justified. |
| 1.1.1.3 | 2 | 2 | 2 | 2 | The necessary data are available. |
| 1.1.2.1 | 2 | 3 | 2 | 3 | See 1.1.1.1. |
| 1.1.2.2 | 2 | 2 | 2 | 2 | See 1.1.1.2. |
| 1.1.2.3 | 2 | 2 | 2 | 2 | See 1.1.1.3. |
| 1.2.1 | 0 | 1 | 0 | 4 | No discussion is given about possible tradeoffs. |
| 1.2.2 | 2 | 2 | 2 | 3 | A qualitative discussion is given for the level of achievement on some attributes and a quantitative treatment for a few. The FES ranking system of 1, 2, or 3 on each attribute gives at least a comparative ranking. |
| 1.2.3 | 2 | 2 | 2 | 2 | The same treatment is given each of the alternate sites. |
| 1.2.4 | 2 | 2 | 1 | 2 | The ER has qualitative data only in many cases but that appears adequate. The FES ranking does not appear to correlate exactly with the data table presented. |
| 1.2.5 | 0 | 1 | 0 | 1 | The decision mechanisms are not clearly presented in either case. |
| 1.2.6 | 0 | 2 | 0 | 2 | No uncertainties are discussed. |
| 1.2.7 | 1 | 1 | 1 | 1 | Aquatic ecology and land use are addressed to some extent. |

| Attribute | ER Methodology: As Used | ER Methodology: Potential | FES Methodology: As Used | FES Methodology: Potential | Rationale |
|---|---|---|---|---|---|
| 1.3 | 0 | 0 | 1 | 1 | An insufficient amount of hard data is presented in the ER. If the rankings given in the FES are taken as accurate, then a limited sensitivity analysis could be done. |
| 2.1 | 2 | 2 | 1 | 2 | The ER discussions are easy to follow although the decision mechanism is not obvious. The validity of the FES methodology is hard to understand. |
| 2.2 | 0 | 0 | 0 | 0 | No public participation. |
| 3.1 | 2 | 2 | 2 | 2 | No special expertise is required. |
| 3.2 | 2 | 2 | 2 | 2 | The estimate is based on the above and the fact that it appears relatively few data were required. |

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FULTON

| Attribute | Methodology As Used | Methodology Potential | Rationale |
|---|---|---|---|
| 1.1.1.1 | 0 | 3 | Criteria not stated. |
| 1.1.1.2 | 0 | 2 | Criteria not justified. |
| 1.1.1.3 | 2 | 2 | The necessary data are available. |
| 1.1.2.1 | 0 | 3 | See 1.1.1.1. |
| 1.1.2.2 | 0 | 2 | See 1.1.1.2. |
| 1.1.2.3 | 2 | 2 | See 1.1.1.3. |
| 1.2.1 | 3 | 4 | Many criteria are rated on a 1 to 2 scale, but the rationale for the scheme used to combine them is not given. |
| 1.2.2 | 2 | 3 | The 1 to 2 rating scale qualitatively addresses the degree of achievement of objectives. |
| 1.2.3 | 2 | 2 | The same type of data are available and analyzed for the alternative sites. |
| 1.2.4 | 1 | 2 | In some cases data are not provided to justify statements. |
| 1.2.5 | 1 | 1 | The analysis and hence the decision mechanism are easy to follow. |
| 1.2.6 | 0 | 2 | No uncertainties are discussed. |
| 1.2.7 | 0 | 1 | Although long-term impacts were not covered in this study, several could easily be handled by the methodology. |
| 1.3 | 1 | 1 | Sensitivity analysis could be done on the 1 to 2 rating scheme. |
| 2.1 | 2 | 2 | No special knowledge is required to understand the method. |

| Attribute | Methodology As Used | Methodology Potential | Rationale |
|---|---|---|---|
| 2.2 | 0 | 0 | No public participation. |
| 3.1 | 2 | 2 | No special expertise is required. |
| 3.2 | 2 | 2 | Estimate based on above and the fact that data were obtained primarily from literature. |



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JAMESPORT

| Attribute | Methodology As Used | Methodology Potential | Rationale |
|---|---|---|---|
| 1.1.1.1 | 2 | 3 | The primary screening criteria of transmission line cost, water availability and cost, and population density are explicitly but qualitatively discussed. |
| 1.1.1.2 | 2 | 2 | The criteria are all discussed and justified. |
| 1.1.1.3 | 2 | 2 | Literature contains sufficient data for regional screening criteria. |
| 1.1.2.1 | 1 | 3 | The ER does not cover how the initial sites were chosen, but does elaborate on the criteria that were used to narrow the list. A report which might contain the criteria is referenced. This is not a methodological flaw, but rather a specific study flaw. |
| 1.1.2.2 | 0 | 2 | The criteria are not justified in the ER, although they might be in the referenced report. The methodology could include the justification. |
| 1.1.2.3 | 2 | 2 | Literature data should suffice at this stage. |
| 1.2.1 | 3 | 4 | Many criteria in the areas of engineering considerations and environmental impact are rated on a 1 to 3 scale and the equal-weighted values are added up. An "acceptable" value on an engineering consideration is treated as equal to an "acceptable" value on an environmental impact consideration. |
| 1.2.2 | 2 | 3 | The rating scale of "preferred," "favorable," or "acceptable" qualitatively addresses the degree of achievement of objectives, although some are quantitatively covered. |

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| Attribute | Methodology As Used | Methodology Potential | Rationale |
|---|---|---|---|
| 1.2.3 | 2 | 2 | The same analysis and detail were used in the evaluation of sites. |
| 1.2.4 | 2 | 2 | Complete and referenced data back up the analysis. |
| 1.2.5 | 1 | 1 | The analysis and hence the decision mechanism are easy to follow. |
| 1.2.6 | 0 | 2 | Uncertainty is not covered. |
| 1.2.7 | 0 | 1 | Operational environmental impacts are discussed. |
| 1.3 | 1 | 1 | A great deal of data backs up the analysis and the reader could do some sensitivity analysis himself. |
| 2.1 | 2 | 2 | The approach is easy to follow. |
| 2.2 | 0 | 0 | No public participation. |
| 3.1 | 2 | 2 | No special expertise required. |
| 3.2 | 2 | 2 | Estimate based on above and the fact that data gathering did not appear to be very complicated. |

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| Attribute | Methodology As Used | Methodology Potential | Rationale |
|---|---|---|---|
| 1.1.1.1 | 2 | 3 | The reasons for area elimination are qualitatively discussed. |
| 1.1.1.2 | 2 | 2 | The reasons for area elimination on certain criteria are clearly addressed. |
| 1.1.1.3 | 2 | 2 | Data exist in the literature to implement the criteria. |
| 1.1.2.1 | 0 | 3 | Although the criteria which were used to pick the sites were not stated, several studies were listed as having taken place and their criteria could have been listed. |
| 1.1.2.2 | 0 | 2 | Since no criteria were listed, they could not be justified. |
| 1.1.2.3 | 2 | 2 | Although the actual criteria were not listed, it was assumed that part of the reason for picking them would have been the existence of sufficient data. |
| 1.2.1 | 0 | 1 | No discussion was given about tradeoffs. |
| 1.2.2 | 2 | 2 | Comparisons between sites were made and individual site limitations discussed. Cost estimates were made for some attributes. |
| 1.2.3 | 2 | 2 | All sites were analyzed in a qualitative manner (except for cost estimates). |
| 1.2.4 | 2 | 2 | There is no apparent problem with the data. |
| 1.2.5 | 0 | 1 | The ER states that the decision was based on the cost differences and engineering and environmental considerations, yet cost differences is the only obvious superiority. The decision mechanism could be clear if the proposed site is clearly superior in each category. |



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| Attribute | Methodology As Used | Methodology Potential | Rationale |
|---|---|---|---|
| 1.2.6 | 0 | 2 | No uncertainties were discussed. |
| 1.2.7 | 0 | 1 | No long-term impacts were discussed. |
| 1.3 | 0 | 0 | Since very few hard data are presented, one cannot do a sensitivity analysis. |
| 2.1 | 2 | 2 | A qualitative description of attributes is easy to follow, but the method by which a decision is reached from it is not. |
| 2.2 | 0 | 0 | No public participation. |
| 3.1 | 2 | 2 | No special expertise is required. |
| 3.2 | 2 | 2 | The estimate is based on the above and the fact that the data requirements were minimal. |



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NEP NUCLEAR POWER PLANT

| Attribute | Methodology As Used | Methodology Potential | Rationale |
|---|---|---|---|
| 1.1.1.1 | 3 | 3 | The screening criteria are explicitly and quantitatively stated. |
| 1.1.1.2 | 2 | 2 | The criteria are discussed and justified. |
| 1.1.1.3 | 2 | 2 | Data exist in the literature to implement the criteria. |
| 1.1.2.1 | 1 | 3 | Only the criteria used at the screening stage were explicitly stated. Additional ones must have been used, but they were not discussed. |
| 1.1.2.2 | 1 | 2 | See 1.1.2.1 |
| 1.1.2.3 | 2 | 2 | See 1.1.1.3 |
| 1.2.1 | 0 | 1 | No discussion at all was given of possible tradeoffs. |
| 1.2.2 | 1 | 2 | Comparisons between sites were made and individual site limitations were discussed. Cost estimates were made for some attributes. Some attributes (ecology) simply stated there might be some impact. |
| 1.2.3 | 2 | 2 | All alternate sites were analyzed in the same detail. |
| 1.2.4 | 2 | 2 | There is no apparent problem with the data. |
| 1.2.5 | 0 | 1 | The ER states that the decision was based on cost differences and engineering and environmental considerations, yet it is not obvious how. The decision mechanism could be clear if the proposed site is clearly superior in each category. |

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| | Methodology | | |
|---|---|---|---|
| Attribute | As Used | Potential | Rationale |
| 1.2.6 | 0 | 2 | No uncertainties were discussed. |
| 1.2.7 | 0 | 1 | No long-term impacts were discussed. |
| 1.3 | 0 | 0 | Since very few hard data are presented, one cannot do a sensitivity analysis. |
| 2.1 | 2 | 2 | A qualitative description of the attributes is easy to follow, although how the decision is arrived at is not clear. |
| 2.2 | 0 | 0 | No public participation. |
| 3.1 | 2 | 2 | No special expertise is required. |
| 3.2 | 2 | 2 | The estimate is based on the above and the fact that the data requirements were minimal. |

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## PALO VERDE

| Attribute | Methodology: As Used | Methodology: Potential | Rationale |
|---|---|---|---|
| 1.1.1.1 | 3 | 3 | The screening criteria are all qualitatively discussed and elimination criteria are quantitatively stated. The rating and weighting scheme is discussed thoroughly and quantitatively presented. |
| 1.1.1.2 | 1 | 2 | The study did not explain why one could not be any distance away from the groundwater supply. This is an example of a particular study flaw rather than a methodological flaw. |
| 1.1.1.3 | 2 | 2 | Sufficient data are available in the literature to implement the criteria. |
| 1.1.2.1 | 3 | 3 | The 0 to 5 scales on which the criteria were rated provide quantitative visibility and the weighting scheme was explicitly discussed. The criteria which resulted in the final candidate site selection were very clearly presented. |
| 1.1.2.2 | 2 | 2 | The water availability criterion was justified at this stage and the reasons for the primary and secondary factor concept were discussed explicitly. |
| 1.1.2.3 | 2 | 2 | The absence of site-specific geological data made it difficult to implement the geology criterion accurately, but this is a universal problem at this screening level. |
| 1.2.1 | 4 | 4 | Geology was an absolute criterion. The remaining criteria were given differing weights. The scales for individual criteria were all related to a master scale. |
| 1.2.2 | 3 | 3 | The rating given to the site for a given criterion showed the degree of achievement. |

| Attribute | Methodology As Used | Methodology Potential | Rationale |
|---|---|---|---|
| 1.2.3 | 2 | 2 | The sites were given the same detail of analysis until the geology was done. The time criterion kept some from having the same detail of investigation, although the time criterion itself was clearly stated. |
| 1.2.4 | 2 | 2 | The data appear to be complete and accurate with the possible exception of the seismic data. The classification of some sites as requiring detailed data which would take too long to collect appears accurate, however. |
| 1.2.5 | 1 | 1 | The rating and weighting analysis scheme and the time consideration problem are clearly presented. |
| 1.2.6 | 1 | 2 | No uncertainties were discussed other than the possibilities of backup water supplies. |
| 1.2.7 | 1 | 1 | Long-term land use impacts were discussed in some cases. For example, certain plant locations would stop the encroachment of urban development on the desert. |
| 1.3 | 2 | 3 | Complete sensitivity analysis was done at the valley and region level, but when the study reached the alternate site evaluation stage sensitivity analysis was not done. Geology became an all-important factor. |
| 2.1 | 2 | 2 | The study is easy to follow and the justification for the criteria is complete. |
| 2.2 | 0 | 0 | No public participation. |
| 3.1 | 2 | 2 | No special expertise was required. |
| 3.2 | 1 | 1 | Estimate based on above and the fact that the regional level screening was very complete. |



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RIVER BEND

| Attribute | Methodology As Used | Methodology Potential | Rationale |
|---|---|---|---|
| 1.1.1.1 | 2 | 3 | The screening criteria are qualitatively discussed. |
| 1.1.1.2 | 2 | 2 | All screening criteria are discussed and justified. |
| 1.1.1.3 | 2 | 2 | Sufficient data exist in the literature for this siting phase. |
| 1.1.2.1 | 2 | 3 | The criteria are listed and data are included for each area for each criteria, but quantitative cutoffs are not discussed. |
| 1.1.2.2 | 0 | 2 | No discussion is given concerning why the particular criteria are used. |
| 1.1.2.3 | 2 | 2 | See 1.1.1.3 |
| .2.1 | 0 | 1 | No discussion was given of possible tradeoffs. |
| 1.2.2 | 2 | 2 | Comparisons between sites were made and individual site limitations were discussed. Cost estimates were made for some attributes. |
| 1.2.3 | 2 | 2 | The alternate sites were analyzed in the same detail. |
| 1.2.4 | 2 | 2 | There is no apparent problem with the data. |
| 1.2.5 | 0 | 1 | The ER states that the decision was based on cost differences and engineering and environmental considerations, yet this is not obvious. The decision mechanism could be clear if the proposed site is clearly superior in each category. |
| 1.2.6 | 0 | 2 | No uncertainties were discussed. |



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| Attribute | Methodology As Used | Methodology Potential | Rationale |
|---|---|---|---|
| 1.2.7 | 0 | 1 | No long-term impacts were discussed. |
| 1.3 | 0 | 0 | Since very few hard data are presented, one cannot do a sensitivity analysis. |
| 2.1 | 2 | 2 | A qualitative description of the attributes is easy to follow, although how a decision is arrived at is not. |
| 2.2 | 0 | 0 | No public participation. |
| 3.1 | 2 | 2 | No special expertise is required. |
| 3.2 | 2 | 2 | The estimate is based on the above and the fact that the data requirements were minimal. |



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SOUTH TEXAS

| Attribute | Methodology As Used | Methodology Potential | Rationale |
|---|---|---|---|
| 1.1.1.1 | 2 | 3 | Although the criteria are very clearly stated, elimination was based on "too far from" in several cases rather than on quantitative cutoffs. |
| 1.1.1.2 | 1 | 2 | There is little discussion of why different criteria were used. |
| 1.1.1.3 | 2 | 2 | Published data existed and were used to implement the criteria. |
| 1.1.2.1 | 2 | 3 | There is little discussion of why different criteria were used or why different weighting factors were assigned to them. |
| 1.1.2.2 | 1 | 2 | There is little discussion of why different criteria were used or why different weighting factors were assigned to them. |
| 1.1.2.3 | 2 | 2 | Published data and aerial photographs were sufficient to implement the criteria accurately. |
| 1.2.1 | 4 | 4 | Each factor was rated on a 0 to 5 scale and the rating assigned various weights. The individual 0 to 5 scales correspond to a master scale based on degree of acceptability. |
| 1.2.2 | 3 | 3 | The ratings for the different criteria quantify the degree of achievement. |
| 1.2.3 | 2 | 2 | The alternate sites were all analyzed in comparable detail to the primary site. |
| 1.2.4 | 2 | 2 | No reason exists to question the accuracy of the data. |
| 1.2.5 | 1 | 1 | The rating and weighting scheme is clearly presented. |

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| Attribute | Methodology As Used | Methodology Potential | Rationale |
|---|---|---|---|
| 1.2.6 | 0 | 2 | No uncertainties are discussed. |
| 1.2.7 | 0 | 1 | No long-term impacts are discussed. |
| 1.3 | 2 | 3 | Sufficient numerical data are presented for the reader to do a sensitivity analysis at the regional evaluation phase and the study states sensitivity analysis was done at the alternate site evaluation stage. |
| 2.1 | 2 | 2 | The analysis is easy to follow. |
| 2.2 | 0 | 0 | No public participation. |
| 3.1 | 2 | 2 | No special expertise was needed. |
| 3.2 | 1 | 1 | The estimate is based on the above and the fact that a fair amount of data was presented at the alternate site evaluation stage, but not at the regional screening phase. |

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TYRONE ENERGY PARK

| Attribute | Methodology As Used | Methodology Potential | Rationale |
|---|---|---|---|
| 1.1.1.1 | 3 | 3 | The screening criteria were clearly and quantitatively stated (greater than three miles from water, greater than ten miles from a railroad, less than five miles from a population center, etc.). |
| 1.1.1.2 | 2 | 2 | Although each justification was not clearly spelled out, few were used and most were obvious. |
| 1.1.1.3 | 2 | 2 | Published data were sufficient at this stage. |
| 1.1.2.1 | 2 | 3 | Many of the selection criteria were explicitly and quantitatively stated. However, the flatness of the land was an important criterion, yet it was not clearly defined. |
| 1.1.2.2 | 1 | 2 | The criteria and their weightings were incompletely discussed and justified. |
| 1.1.2.3 | 2 | 2 | Sufficient data were available to perform the study. |
| 1.2.1 | 4 | 4 | The different concerns were all rated on the same 1 to 4 scale (1 = poor to 4 = excellent) and assigned different weights for the final additions and ranking. |
| 1.2.2 | 3 | 3 | The degree of achievement is quantified by the rating given and the cost estimates made, where applicable. |
| 1.2.3 | 2 | 2 | The same level of analysis was used for the three alternate sites. |
| 1.2.4 | 2 | 2 | The data appear reasonable and accurate. |
| 1.2.5 | 1 | 1 | The decision mechanism is presented in detail. |



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| Attribute | Methodology As Used | Methodology Potential | Rationale |
|---|---|---|---|
| 1.2.6 | 0 | 2 | Uncertainty is not discussed. |
| 1.2.7 | 0 | 1 | Long-term impacts are not discussed. |
| 1.3 | 1 | 2 | A limited sensitivity analysis could be done on the alternate site evaluation phase, but insufficient data are presented for the earlier phases. That the data for the initial thirty sites (then narrowed to three alternate sites) were not included in the report was a major study flaw in the area of sensitivity analysis. |
| 2.1 | 2 | 2 | The approach is easy to follow if it is read thoroughly. |
| 2.2 | 0 | 0 | No public participation. |
| 3.1 | 2 | 2 | No special expertise required. |
| 3.2 | 2 | 2 | Estimate based on above and the fact that data collection did not appear to be overly difficult. |

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PART III

# A COMPARISON OF NUCLEAR POWERPLANT SITING METHODOLOGIES

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PART III

# A COMPARISON OF NUCLEAR POWERPLANT SITING METHODOLOGIES

## CHAPTER I

## ANALYSIS OF EMPIRICAL DATA

### Introduction

Given the several alternative methodologies available for identification of candidate site areas and the selection and evaluation of specific sites, a data base was established to exercise these methodology alternatives and compare the results. Several available data bases were found which were assumed to be suitable for this study. It was decided that at least two data bases should be used in order to examine the regional differences of the various criteria that may affect the comparison of alternative siting methodologies. The data bases used for the study include a data base for northern Illinois and a second data base for northeastern Utah.

The data base for northern Illinois was developed by Argonne National Laboratory (ANL) in order to test SITE, a siting computer program developed by ANL.[14] Northern Illinois is characteristic of the eastern Plains States where the terrain is relatively flat. The ecological environment is characterized by a fairly uniform degree of activity. In addition, Illinois has greater quantities of cooling water available than are available in the western United States. The northeastern Utah data base was adapted from a data base developed by Dames & Moore (D&M) for the evaluation of Nuclear Energy Center siting opportunities as part of a subcontract from the Western Interstate Energy Board (WIEB).[15] In addition to developing the comparison screening methodology used in this report, the WIEB study developed a data base of siting parameters at regional scale data resolution for the 11 western states. A segment of this data base covering the northeastern portion of Utah, approximately 180 by 180 miles (290 by 290 km), was selected to characterize the west and southwest region of the country excluding the Pacific Coastal region and the Pacific Northwest region west of the Cascade Mountains. The region characterized by the Utah data base is predominantly arid and sparsely populated and it is subject to greater seismic activity and much more varied ecological activity than the Illinois data base region.

These two data bases were readily available for use in this report and, in addition, both had already been encoded in a computerized format. This facilitated rapid data manipulation and use of computer-based mapping systems to display the results. The latter feature was essentially for comparison of experimentation results.

Selection and Description of Regional Evaluation Methodologies

Of the three siting methodologies typically used for regional evaluation, two can be exercised and evaluated using the computerized data bases available for Utah and Illinois. These two, the exclusion screening and comparison screening techniques, rely on an area-wide data base that is sequentially or simultaneously screened to identify acceptable or most suitable siting areas within the regional area of consideration.

The third siting methodology used at the regional evaluation phase, favorability selection, does not necessarily deal with the entire ROI. One or more site selection experts select those areas which are to be searched for potential sites. The procedure for this selection involves the review of several site selection factors on an area-wide basis. This review, together with the local experience and judgment of the siting experts, is applied in order to select a group of seemingly good site areas. The suitability of these areas is obviously dependent on how familiar the siting experts are with the ROI and with the general criteria used during the course of their selection. For these reasons, favorability selection is not appropriate for a systematic and comprehensive evaluation of an entire regional data base such as is done in this study.

To compare the two quantitative techniques, an exclusion screening evaluation and a comparison screening evaluation were developed for each data base. The resulting siting area identification maps were compared for both study areas, and similarities and differences were noted. The purpose of this comparison was to determine if both techniques identify the same areas or if one technique identifies similar areas as well as additional areas; the latter would indicate a superior ability to discriminate among suitable site areas.

In addition to the basic comparison of the two screening techniques, several other evaluations were performed. An examination of the techniques to determine the general sensitivity of a weighting structure used in a comparison screening was conducted. The objective was to determine what level of confidence could be achieved in the results of a comparison screening where subjective evaluations are considered in the development of specific weights. Another topic considered in the evaluation was specific site selection criteria or issues. The effect that a specific criterion may have on the resulting suitability evaluation for a site, based on the assumptions used for that issue, was explored.

Using the computer-based mapping systems, three basic regional analyses were performed:

1. Sequential or exclusion screening and comparison (weighted) screening were conducted using the same site selection factors and the results compared,
2. The effect of weighting structures was examined to measure the sensitivity of the solution to th[illegible]ighting structure, and
3. The effect of choosing different site selection factors (criteria) or stating the same general factor from different viewpoints was examined.

Particular emphasis was placed on the comparison of the best sites or site areas that resulted from the application of the alternative selection methodologies to illustrate the difference in methods. The role that specific site selection factors (issues) play in the selection of sites was also carefully considered. It was recognized, however, that in either case the results of the comparisons were, to a large extent, controlled by the data es and the regional physical differences contained in the two data bases.

## Utah Example

### Utah Data Base

The Utah data base extends from the Uinta Mountains on the north to the confluence of the Green and Colorado Rivers in the south. The study area shown in Figure 1 extends from Salt Lake City in the west to the border of the state of Colorado on the east and includes approximately 32,000 square miles (83,000 $km^2$). The computerized format of the data is based on a grid cell that is 1.5 by 1.5 miles (2.4 by 2.4 km). There are 14,400 individual 2.25-square-mile (5.8-$km^2$) grid cells in the study area.

As mentioned previously, the Utah data base was abstracted from a data base prepared for the WIEB study.[15] The purpose of the WIEB data base was to assess the feasibility of locating Nuclear Energy Centers (producing a minimum of 6 GW[e]). This data base includes the 11 westernmost states exclusive of Alaska and Hawaii and is fairly general in nature for the following two reasons:

1. It was used to site a facility requiring a large land area, and
2. The study region was extremely large geographically.

The grid cell used to represent the data for the WIEB study contained a 100-square-mile (259-$km^2$) area, which is a scale much larger than is typically used for more conventional nuclear generating station co... nts. However, it was determined that these data could be converted to a smaller grid cell size without overextending the apparent resolution of the data.

It should be be noted that the purpose of the subject study is to compare and evaluate the several site selection procedures currently used by utilities for siting nuclear powerplants. Given this problem statement, the use of a specific data base is not required to assure the credibility or accuracy of specific sites that may be identified but rather to illustrate the differences that may result in specific site locations given different site selection methodologies. For this reason, the accuracy of geographic location or content of the data base need not be rigorously assured, as would be required for a siting study. In several cases, the data have been deliberately altered to illustrate a specific point at the cost of abstracting the results of the study. None of the sites identified in the study area is known to be, or expected to be, under development, consideration, or study by any utility or regulatory agency.


Figure 1. Utah Study Area

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In keeping with this qualification, several factors were added to enhance the ability of the Utah data base to illustrate the differences or similarities in siting methods.

Included in the siting data base are 10 site selection factors. Each factor represents a site selection criterion and is applied using several methods to identify the most suitable or acceptable site areas, where the site area may contain one or more actual sites. Each of the factors is selected for inclusion in the evaluation because it either represents regulatory requirements, engineering cost considerations, or ecological or sociopolitical issues. For each of the factors, a map is prepared, in the grid cell format, and stored in the computer for overlay or comparative analysis. A general description of the specific issues and background on their purposes as part of the site area selection process is contained in Appendix A.

Utah Exclusion Screening

Exclusion screening is based on the premise that for each major siting criterion, a threshold value can be defined that a potential powerplant location must meet. In this way each of the issue maps can be divided into two zones: acceptable and not acceptable. An overlaying of the several issue maps can identify the zone which passes all tests or meets each criterion. This zone is then assumed to be an acceptable siting area.

To generate the exclusion screening case for Utah, each of the 10 issues was reviewed and a reasonable criterion for acceptability threshold was established for each map. These maps were then overlaid to determine those areas acceptable for site location. The threshold values of the level of acceptability for each criterion is shown in Table III.

Table I

Exclusion Screening Criteria--Utah

| | Issue | Minimum Criteria |
|---|---|---|
| 1 | Seismic Risk | < 0.2g acceleration |
| 2 | Ecology | No rare or endangered species |
| 3 | Population Density | < 0.4 SPF[a] |
| 4 | Transportation Access | ≤ 10 units (cost/distance) |
| 5 | Landform | > 20 percent gentle slopes |
| 6 | Transmission Access | ≤ 90 units (cost/distance) |
| 7 | Land Use | No protected lands[b] |
| 8 | Soils | < rating = 7 |
| 9 | Air Traffic Hazard | > 2 miles from air traffic corridor |
| 10 | Cooling System Suitability | ≤ $185/kW |

[a] Site population factor

[b] Suitability rating

Based on the threshold values shown in Table I, each issue map was translated into a binary decision map where the value of zero represented those areas below the threshold level for a specific criterion and a value of one represen' d those areas above the threshold level. These maps were then added together and those cells that totaled to a score of 10 satisfied all of the 10 siting criteria. Those values less than 10 indicated the number of screens passed; this number subtracted from 10 indicated the number of screens failed. The computer-generated histogram, shown in Figure 2, indicates the frequency distribution of the number of exclusion screening criteria satisfied.

SUMMARY OF MAPS

| VALUE | FREQ * | LESS THAN | EQUAL GREATER | 0 : 861 : 1722 : 2583 : 3444 : 4305 : |
|---|---|---|---|---|
| 10 | 181 | 98.74 | 1.26 | **** |
| 9 | 1595 | 87.63 | 12.37 | ******************** |
| [illegible] | 4305 | 57.65 | 42.35 | **************************************************************** |
| 7 | 3802 | 31.17 | 68.83 | ********************************************************* |
| 6 | 2351 | 14.79 | 85.21 | ******************************** |
| 5 | 1501 | 4.34 | 95.66 | ***************** |
| 4 | 565 | .40 | 99.60 | ****** |
| 3 | 49 | .06 | 99.94 | * |
| 2 | 9 | 0.00 | 100.00 | * |
| 1 | 0 | 0.00 | 100.00 | * |

14358 CELLS FROM 0 TO 100 MEAN = 7.052 MINIMUM VALUE = 2.000 MAXIMUM VALUE = 10.00

Figure 2. Frequency Distribution of the Number of Exclusion Criteria Satisfied--Utah

Areas that satisfied all criteria and were acceptable for powerplant location are shown as the darkest symbol (6) on the map in Figure 3. The remaining portion of the map shows the geographic distribution of the number of exclusion criteria satisfied. Comparisons of this map with the individual issue maps in Appendix A show several interesting ways in which the individual issues strongly influence the overall exclusion screening. The diagonal light areas radiating from the right in Figure 3 represent air corridors (see Figure A-9 in Appendix A). The diagonal boundary running from the upper right corner in Figure 3 to the middle of the lower border, with the darker-shaded areas on the right, represents the most suitable seismic area (see Figure A-1). Immediately to the right of the upper and middle portions of the seismic border in Figure 3 is the transmission border (see Figure A-6) with the most suitable area on the left, closer to the main load centers.

Utah Comparison Screening

To conduct a comparison screening, each of the siting issues is evaluated independently and a suitability rating function (SRF) for each of the issues is defined.*

---

*In decision theory, the suitability function would be termed a utility function. However, for clarity of meaning for the lay reader, the term "suitability" is used to indicate the relative degree to which an area exhibiting a given characteristic would be suitable in contrast to other areas exhibiting different characteristics.

Figure 3. Exclusion Screening--Utah

This suitability function represents the relat[illegible] suitability of each of the categories within a specific issue for location of the powerplant. This relative ranking is fixed on a predefined scale such that all areas within the study area, excluding legally restricted areas, can be evaluated and compared on this high-to-low suitability scale. The suitability functions actually used for this study are shown in Figure 4. For each of these 10 functions, the y-axis measures the suitability which is given as the relative rating assigned for each possible value of issue parameter (shown on the x-axis of each function). Some of these suitability functions are continuous (e.g., seismic risk, population), while others are discrete or discontinuous (e.g., ecology, landform). The choice between continuous and discrete suitability functions is based upon the way in which the parameter of each particular issue produces its impact. The two paragraphs following Figure 4 illustrate the reasoning used to develop the suitability functions.

350 592

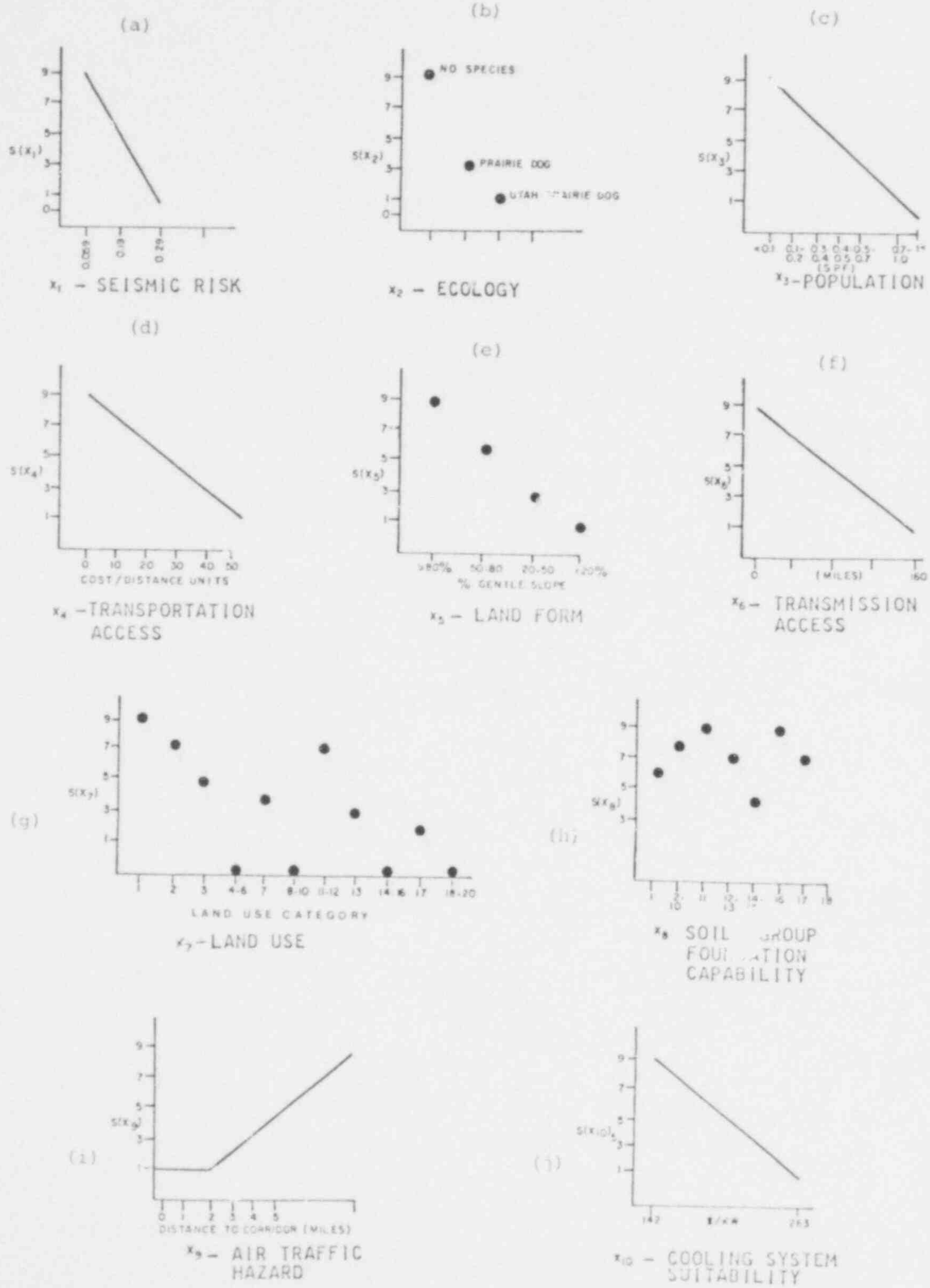


Figure 4. Suitability Rating Functions--Utah

The seismic suitability function can be evaluated and compared in terms of the extra cost of the design and construction features required to satisfy the seismic design criteria. The D&M investigations, in connection with Nuclear Energy Center siting studies, surveyed expert opinion and developed a utility function showing the dependence of excess seismic design cost per kW(e) as a function of the horizontal ground motion providing the SRF 50-year effective peak acceleration.[15] This utility function is shown in Figure A-2 in Appendix A. The utility function is used to translate the category numbers depicted in the map in Figure A-1 into utility values which have a range from 1 to 9.

To develop the suitability function for the population issue, it was assumed that the level of suitability should be directly proportional to the number of people exposed to accidental radiation from any nuclear powerplant at the site. Such a linear relationship would only apply, however, if exposure were equal for all individuals. The potential impact on an individual is directly related to the distance from that individual to the reactor. Thus, if distance is considered, impacts are not equal for all individuals. However, the effect of distance is incorporated into the calculation of SRF which normalizes the population distribution with respect to distance. Therefore, a linear relationship, as shown in Figure 4, can be used for utility with respect to SRF.

Projections for the years 1985 and 2020 were translated into utility values. If an area exceeded either 0.5 for 1985 or 1.0 for 2020, it was restricted from further consideration. The remaining areas were assigned utility values from the utility function according to their projected 2020 SPF value. The 2020 projection was used to achieve a more conservative evaluation.

After the rating or suitability functions have been determined by technical analysis for each of the individual issues, the importance values, or ratios, are determined relative to each other. The importance ratio relates the importance of one specific issue to the importance of other issues when considering the overall measure of suitability for plant location. This importance ratio represents the weight that each of the issues will have in the decisionmaking process or how much each of the individual factors will contribute to the assessment of suitability. These importance ratios are generally subjective, in contrast to the suitability functions, shown in Figure 4, which are mainly determined by technical analysis. These importance ratios are typically determined by scaling with preference structures or using a group decision process such as the Delphi.[16,17] In either case, a final set of importance ratios for each of the issues is developed and used to weight each of the factor maps when creating a composite suitability map. These importance ratios for the comparison screening case are shown in Table II.

Using the importance ratios in Table II and the suitability functions shown in Figure 4, a suitability value was computed using a weighted overlay technique for each grid cell in the study area. This suitability score represents the numerical rank ordering of all grid cells within the study area where the higher scoring cells are determined to be most suitable for plant location. The suitability map, shown





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in Figure 5, was derived using the specific suitability functions and importance ratios defined for the case study.

TABLE II

Importance Ratios for Comparison Screening

| Issue | Importance Ratio |
|---|---|
| Seismic Risk | 1.82 |
| Ecology | 0.88 |
| Population Density | 1.36 |
| Transportation Access | 0.78 |
| Landform | 0.88 |
| Transmission Access | 0.76 |
| Land Use | 0.73 |
| Foundation Capability | 0.70 |
| Air Traffic Hazard | 0.50 |
| Cooling System Suitability | 1.49 |

Comparison of Figure 5 with the individual issue maps in Appendix A identifies two primary issue boundaries. The seismic border on Figure 5 runs from near the upper right corner to the middle of the lower border of the study area, as it did with the exclusion screening. The border near the middle of the left side of Figure 5, with the higher suitability on the right, is due to the ecology issue (see Figure A-2). The completely white areas running vertically on the left side of Figure 5 are from the fault zones indicated in Figure A-1.

In contrast to the exclusion screening process, the comparison screening process develops a suitability score on a continuous scale to allow zones of relative suitability to be defined. For example, the scores for each cell within the study area are shown on a histogram in Figure 6 and evaluated as a statistical population. Figure 6 clearly shows the degree of "acceptability" achieved in the ROI and provides quantitative guidance relating to the overall discrimination of the method. Thus, information is obtained which guides the selection of a cutoff level for identifying candidate sites or in setting display intervals. To graphically depict the process of identifying zones of relative suitability and to also recognize the relative resolution of data used in the comparison screening process, display intervals are used where groups of suitability scores are combined into the same interval. Typically, the top 1, 2, or 2-1/2 percent of all cells are combined into the first interval and identified as candidate siting areas. These are the darkest areas in Figure 5. Areas of lesser suitability are grouped into descending display intervals and are shown as lighter tones of gray on the display map. As mentioned previously, those areas that are blank, or white, are areas that were restricted for specific reasons in the evaluation process.


Figure 5. Comparison Screening--Utah

SUMMARY OF MAPS

| VALUE | FREQ * | LESS THAN | EQUAL GREATER | 0 : 236 : 472 : 708 : 944 : 1180 : |
|---|---|---|---|---|
| 100 | 0 | 100.00 | .00 | * |
| 99 | 0 | 100.00 | .00 | * |
| 98 | 0 | 100.00 | .00 | * |
| 97 | 0 | 100.00 | .00 | * |
| 96 | 0 | 100.00 | .00 | * |
| 95 | 0 | 100.00 | .00 | * |
| 94 | 0 | 100.00 | .00 | * |
| 93 | 0 | 100.00 | .00 | * |
| 92 | 0 | 100.00 | .00 | * |
| 91 | 0 | 100.00 | .00 | * |
| 90 | 0 | 100.00 | .00 | * |
| 89 | 0 | 100.00 | .00 | * |
| 88 | 0 | 100.00 | .00 | * |
| 87 | 0 | 100.00 | .00 | * |
| 86 | 0 | 100.00 | .00 | * |
| 85 | 0 | 100.00 | .00 | * |
| 84 | 0 | 100.00 | .00 | * |
| 83 | 0 | 100.00 | .00 | * |
| 82 | 0 | 100.00 | .00 | * |
| 81 | 0 | 100.00 | .00 | * |
| 80 | 0 | 100.00 | .00 | * |
| 79 | 0 | 100.00 | .00 | * |
| 78 | 34 | 99.74 | .26 | ** |
| 77 | 75 | 99.16 | .84 | **** |
| 76 | 82 | 98.53 | 1.47 | **** |
| 75 | 150 | 97.37 | 2.63 | ******* |
| 74 | 405 | 94.25 | 5.75 | ****************** |
| 73 | 578 | 89.79 | 10.21 | ********************************* |
| 72 | 687 | 84.50 | 15.50 | ************************************ |
| 71 | 830 | 78.10 | 21.90 | ******************************************* |
| 70 | 919 | 71.01 | 28.99 | *********************************************** |
| 69 | 1179 | 61.93 | 38.07 | **************************************************************** |
| 68 | 1122 | 53.78 | 46.72 | ************************************************************* |
| 67 | 1001 | 45.56 | 54.44 | ******************************************************** |
| 66 | 879 | 38.78 | 61.22 | ***************************************************** |
| 65 | 713 | 33.29 | 66.71 | **************************************** |
| 64 | 759 | 27.44 | 72.56 | ******************************************* |
| 63 | 665 | 22.31 | 77.69 | ************************************* |
| 62 | 525 | 18.26 | 81.74 | ****************************** |
| 61 | 519 | 14.26 | 85.74 | ***************************** |
| 60 | 350 | 11.56 | 88.44 | ****************** |
| 59 | 390 | 8.56 | 91.44 | ******************** |
| 58 | 237 | 6.73 | 93.27 | ************ |
| 57 | 223 | 5.01 | 94.99 | *********** |
| 56 | 242 | 3.15 | 96.85 | ************ |
| 55 | 194 | 1.65 | 98.35 | ********* |
| 54 | 139 | .58 | 99.42 | ******* |
| 53 | 39 | .28 | 99.72 | ** |
| 52 | 21 | .12 | 99.88 | * |
| 51 | 8 | .05 | 99.95 | * |
| 50 | 3 | .03 | 99.97 | * |
| 49 | 4 | 0.00 | 100.00 | * |
| 48 | 0 | 0.00 | 100.00 | * |
| 47 | 0 | 0.00 | 100.00 | * |

POOR ORIGINAL

12972 CELLS FROM 0 to 100 MEAN = 66.84 MINIMUM VALUE = 49.57 MAXIMUM VALUE = 78.26 STANDARD DEVIATION = 5.13

Figure 6. Frequency Distribution of Comparison Screening Utility Values--Utah

592 355

## Interpretation

Using the 10 site selection issues (criteria), both the exclusion screening and comparison screening methodologies were employed and a suitability evaluation to determine potential site areas in the regional area was undertaken. The result of these evaluations was a map that shows, in the case of the exclusion screening, those areas that satisfy all 10 criteria and, in the case of the comparison screening, those areas that are most suitable. These geographical regions are called candidate site areas and are shown in Figure 7.

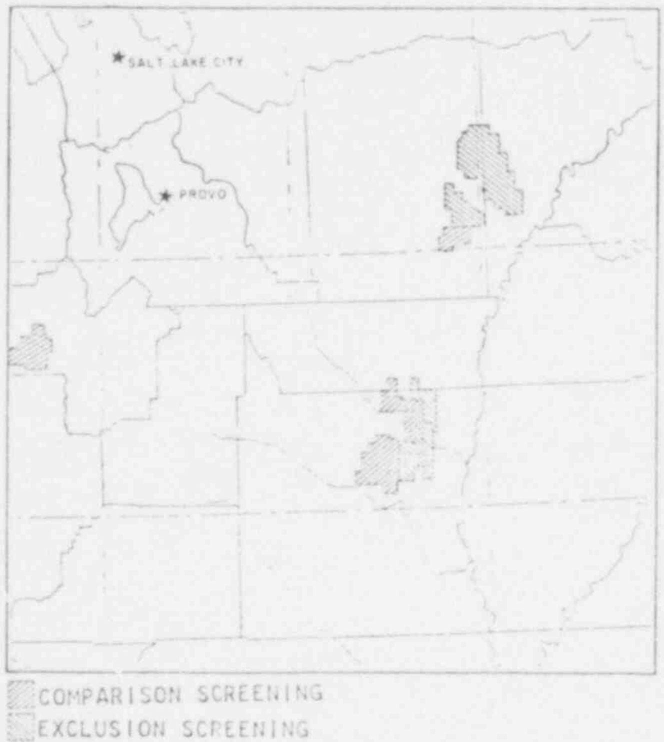




Figure 7. Candidate Siting Areas--Utah

It is apparent from Figure 7 that there is little actual overlap between the top areas identified by the exclusion screening and those identified by the comparison screening, although the areas identified by the two methodologies are close together (with the exception of the highly suitable area at the western boundary of the study area identified by the comparison screening). These differences between the results of exclusion screening and comparison screening can be explained by the different relative importance of specific issues.

The only overlap is in the southern portion of the study area, surrounding the Green River corridor. Even in this overlap, however, the exclusion-screened area is mostly on the right and the comparison-screened on the left. This distinction corresponds to the sharp vertical boundary shown in Figure 3, which, in turn, is due to the boundary of a highly suitable cooling area (see Figure A-10).

Cooling has a high importance ratio (Table II) so we might expect the border to show up most strongly on the comparison screening map. However, the threshold for exclusion screening on the cooling issue has been set so low (excluding most of the cooling categories) that the highest suitability cooling area stands out quite strongly.

The air hazard and electric power transmission issues are less determining for comparison screening than for exclusion screening because of their low importance ratios. It should be remembered that for exclusion screening all issues carry the same weight.

The highest-ranked areas of Figure 3, exclusion screening, cover a much smaller geographical area than those of Figure 5, comparison screening. This is because the large number of issues (10) means that relatively few areas will be able to satisfy the cutoff for every one.

## Illinois Example

### Illinois Data Base

The northern Illinois data base was abstracted from an ANL report.[14] The study area is depicted in the map in Figure 8. The origin was taken at a point on the border of Henderson and McDonough Counties, located in the southwestern portion of the map. Data were encoded in a grid of 130 horizontal divisions and 95 vertical divisions, 2 km per division, within the Illinois state boundaries. This represents a total of 11,022 sites. Most nuclear plants occupy at least the approximately 1,000 acres represented by the 2- by 2-km cell. In order to allow for accurate interpretive map values at the border of the grid (i.e., proximity to waterways, etc.), data were entered in a region 15 divisions farther out in each direction. This resulted in a total of 160 by 125 (20,000) divisions, covering 80,000 $km^2$. It must be noted that accurate interpretive results are assured only in the inner rectangle of Figure 8, within the state borders. Although several of the maps contain values for all of the 20,000 cells, the values outside the state borders or the inner rectangle (130 by 95 divisions) may not be realistic.

Numerous assumptions and simplifications were made in generating the northern Illinois data base. Although they should not affect the usefulness for this study of siting methodologies, the assumptions definitely have an impact on the accuracy of the relative merits of the sites within the study area. If one were truly performing a siting study, rather than a methodology study, additional effort and accuracy would be required.

Several factors were not included in the Illinois data base, despite their importance in many siting studies. For example, there are known seismic faults in northern Illinois, but since these faults are inactive, seismicity was not considered in the study. As another example, northern Illinois is relatively flat.

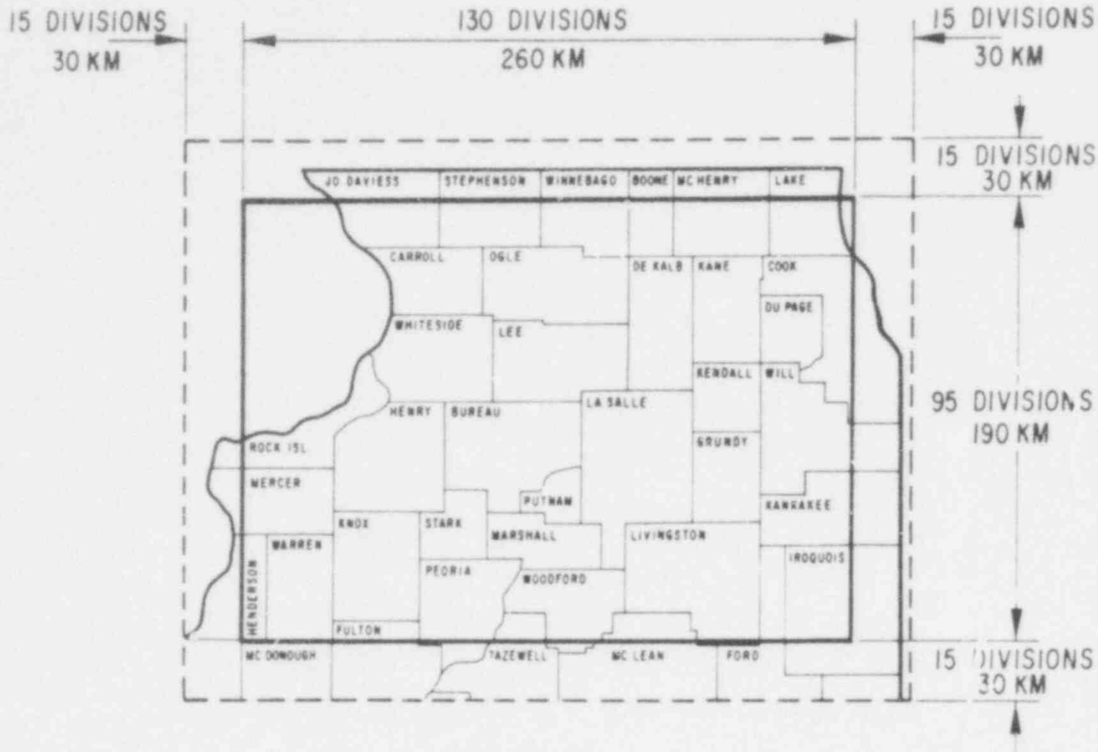


Figure 8. The Northern Illinois Case Study Area

Because the total range of elevation involved is only a few hundred feet, the importance of topography is minimal and it was, therefore, not considered. Due to the relative uniformity of northern Illinois, characterizing the ecological sensitivity on a regional level is somewhat meaningless. Areas such as state and national parks, wildlife ranges, and historical areas were eliminated from consideration on the basis of existing land use. Other than for these land use restrictions, ecological sensitivity needs to be considered on a site-specific basis and is, therefore, not included in the regional Illinois data base.

In addition to the data already present in the ANL report, several factors were encoded into a computerized format to provide a more complete data base. A total of seven site selection factors are included in the northern Illinois data base. A general description of these seven issues is presented in Appendix B.

All of the data used in the northern Illinois study were classified on a 0 to 5 scale as follows:

- 5 (*) = very favorable
- 4 (/) = favorable
- 3 (-) = acceptable
- 2 (:) = practical but difficult
- 1 ( ) = practical but very difficult
- 0 ( ) = unacceptable



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The scales for maps which were made by combining several data maps were based on the following system:

4.5 (*) = very favorable
3.5 (/) = favorable
2.5 (-) = acceptable
1.5 (:) = practical but difficult
0.5 ( ) = practical but very difficult
0 ( ) = unacceptable

The combined maps generated by this process include final results of the exclusion screening and comparison screening.

Illinois Exclusion Screening

To generate the exclusion screening case for Illinois, each of the seven siting issues was reviewed and two sets of threshold values were listed (see Table III). The cells which met each of the minimum values listed for Set I are indicated by an asterisk on the map in Figure 9. The cells which met the minimum values listed for Set II are indicated by a period on the same map.

TABLE III

Exclusion Screening Criteria for Northern Illinois

| Issue | Minimum Criteria Set I | Minimum Criteria Set II |
|---|---|---|
| Power Network Considerations | $\geq$ 4* | $\geq$ 3* |
| Proximity to Major Waterways | $\leq$ 15 km | $\leq$ 25 km |
| Population Density Within a 78-km Radius | $\leq$ 150 | $\leq$ 300 |
| Land Usage | $\geq$ 3* | $\geq$ 3* |
| Foundation Suitability | $\geq$ 4* | $\geq$ 3* |
| Transportation Accessibility | $\geq$ 4* | $\geq$ 3* |
| Tornado Frequency | no threshold | no threshold |

*These numbers refer to suitability ratings.

Some of the features of the map in Figure 9 can be interpreted in terms of the individual issue maps in Appendix B. For example, the circular sector border in the northeast part of Figure 9 reflects the boundary between the 300 persons per 4 $km^2$ area and the 500 persons per 4 $km^2$ area on the population issue map (Figure B-5 in Appendix B). Since the highest population density threshold (for Set II) is 300, the 500 persons per 4 $km^2$ areas is excluded and, therefore, left completely blank in Figure 9. Just to the left of the 300 to 500 border is another circular arc boundary, between asterisks and dots, which results from the boundary between the 150 and 300 persons per 4 $km^2$ areas on the population map.

Figure 9. Exclusive Screening Case for Northern Illinois

Illinois Comparison Screening

To generate the comparison screening case for northern Illinois, importance ratios were assigned for each of the seven siting issues. Using the importance ratios listed in Table IV and the suitability ratings shown in Appendix B, a suitability value was computed for each cell in the study area. Since the suitability maps in Appendix B are already expressed in terms of a common suitability scale (from 0 to 5), there was no need to develop separate suitability functions, as was done for the Utah example. This streamlined comparison screening technique is easier to apply than the one used for Utah, but it also presents a greater difficulty in keeping track of the technical analysis supporting the determination of suitability functions. Figure 10 shows the final cell-suitability ratings.

The map in Figure 10 consists of three symbols: diagonal and horizontal lines, which represent favorable and acceptable areas, respectively, and asterisks, which indicate very favorable areas.



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TABLE IV

Importance Ratios for Comparison Screening
(Illinois)

| Issue | Importance Ratio |
|---|---|
| Power Network Considerations | 2.0 |
| Proximity to Major Waterways | 1.5 |
| Population Density | 1.7 |
| Land Use | 2.0 |
| Foundation Suitability | 1.5 |
| Transportation Access | 1.3 |
| Tornado Frequency | 0.0 |

Figure 10. Comparison Screening

The population density map (Figure B-5 in Appendix B) is responsible for the circular arc border in the northeast corner of Figure 10, as well as blank pockets contained within the map itself. These pockets are also present in the exclusion





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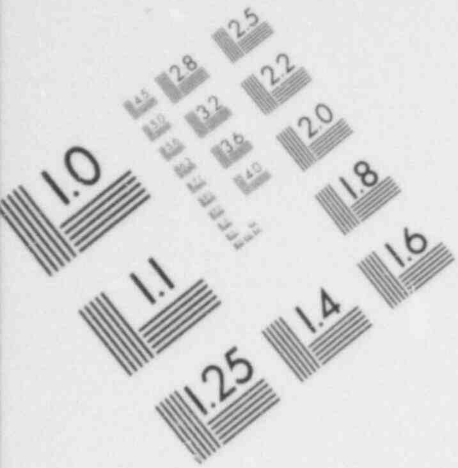
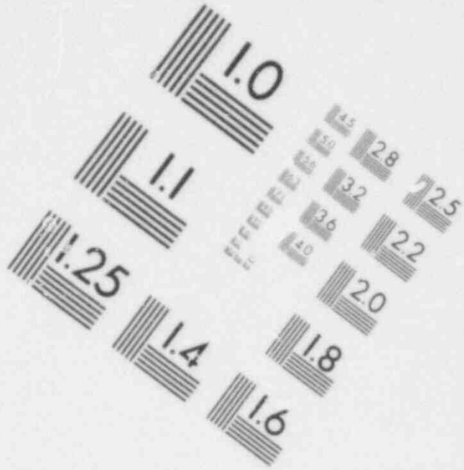
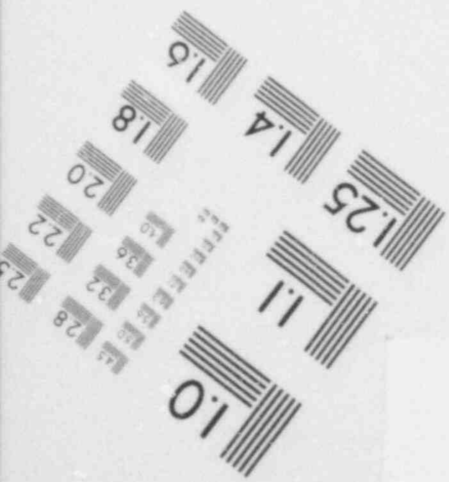
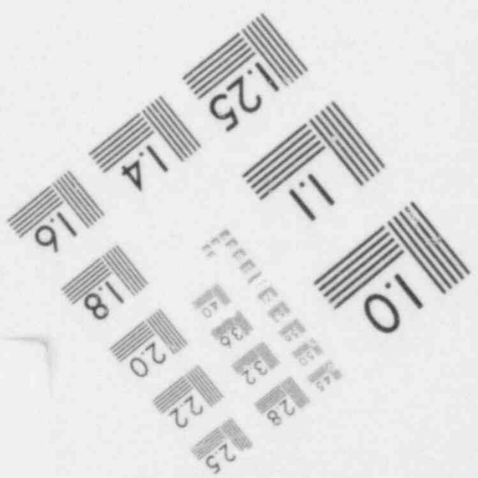




# IMAGE EVALUATION TEST TARGET (MT-3)



screening map (Figure 9) but are not so pronounced because the immediately surrounding area is indicated with very light shading.

In the middle portion of Figure 10 is a pocket of acceptable area (horizontal lines) which falls in the middle of a favorable area and extends into the northeast. This acceptable area corresponds to some areas designated favorable in the transportation issue map (Figure B-10) which happen to fall in the midst of a very favorable transportation area and therefore really only looks poor by comparison. Furthermore, the relatively poor transportation showing is due primarily to the distance from waterways, which also shows up as a separate issue (Figure B-4) to further emphasize the relative unsuitability.

In the northwest corner of Figure 10 is a short vertical boundary between favorable areas (on the left) and acceptable areas (on the right). This is the manifestation of a boundary in the foundation suitability map (Figure B-9) separating very favorable from favorable areas.

## Variation and Sensitivity

### Alternative Evaluation Methodologies

The results of any comparison screening process will always depend on the ways in which the issues are selected, parameterized, converted to suitability values, and assigned importance weights. Analysis done thus far has provided some insight into the manner in which the most suitable areas will be affected by changes in the major importance weights for individual issues. The quantification of such changes is known as sensitivity measurement.

An additional variation measure of interest concerns the overall contribution of the features of individual issue maps to the features of the final comparison screening map. For the entire map, the extent of features is best characterized by geographical variance (or standard deviation). Adding the individual map variances to the covariances between maps produces a measure of the overall contribution of the individual issue to the comparison screening suitability. This is also called the true issue weight. The methodology for this process has been described where it applies to the Utah data base. Time did not permit the application of the statistical techniques to the Illinois data base.

### Weighting Sensitivity--Utah

The general sensitivity of a weighting structure can be estimated from the statistical distribution of the evaluation (suitability scores) that results from applying a specific weighting structure. This is accomplished by plotting a histogram of the individual suitability scores for all cells within the study area and then reviewing the general form of the histogram. In general, such a histogram can range in shape from a broad distribution to a highly peaked shape.

In a broad distribution, the statistical population is fairly heterogeneous in character (having a wide variety of values). In such cases, it is assumed that the weighting system will have some sensitivity but will not significantly affect the rank ordering of those few sites (cells) that score at the high end of the distribution. When the curve is very peaked (and the values are homogeneous), a great deal more sensitivity in the weighting system must be assumed. In that event, the suitability scores are so tightly bunched together that the rank ordering (determined by very small differences between suitability scores) of specific cells at the high end of the distribution could change significantly.

The nominal comparison screening analysis of the Utah study area produced the fairly broad histogram of suitability value distribution already shown in Figure 6. An alternative importance weighting structure was generated by substantially decreasing the seismic risk and air traffic hazard. The remaining 8 issue weights were all increased by an identical factor, chosen so that the sum of all 10 importance values remained equal to 10.00. The resulting alternative list of importance values is given in Table V, with the nominal values also listed for comparison. The resulting histogram of suitability value distribution is shown in Figure 11; this distribution is just as broadly spread as the distribution in Figure 6.

TABLE V

Alternative Weighting Structures

| Issue | Importance Value Nominal | Importance Value Alternative |
|---|---|---|
| UTAH | | |
| 1 Seismic Risk | 1.82 | 1.14 (-37%)* |
| 2 Ecology | 0.88 | 1.00 |
| 3 Population Density | 1.36 | 1.55 |
| 4 Transportation Access | 0.78 | 0.89 |
| 5 Landform | 0.88 | 1.00 |
| 6 Transmission Access | 0.76 | 0.88 |
| 7 Land Use | 0.73 | 0.83 |
| 8 Foundation Capability | 0.70 | 0.80 |
| 9 Air Traffic Hazard | 0.50 | 0.23 (-54%)* |
| 10 Cooling System Suitability | 1.49 | 1.70 |
| | 10.00 | 10.00 |

*The importance values for seismic risk and air traffic hazard were deliberately reduced by the percentages indicated, thus changing the ratio relationship with all other values. While the values shown for the alternative case are different from the nominal case for all other values, this is only a result of renormalizing to a sum of 10. The ratio relationship between all other values remains the same for both cases.

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SUMMARY OF MAPS

| VALUE | FREQ * | LESS THAN | EQUAL GREATER | 0 : 240 : 480 : 720 : 960 : 1200 : |
|---|---|---|---|---|
| 100 | 0 | 100.00 | .00 | * |
| 99 | 0 | 100.00 | .00 | * |
| 98 | 0 | 100.00 | .00 | * |
| 97 | 0 | 100.00 | .00 | * |
| 96 | 0 | 100.00 | .00 | * |
| 95 | 0 | 100.00 | .00 | * |
| 94 | 0 | 100.00 | .00 | * |
| 93 | 0 | 100.00 | .00 | * |
| 92 | 0 | 100.00 | .00 | * |
| 91 | 0 | 100.00 | .00 | * |
| 90 | 0 | 100.00 | .00 | * |
| 89 | 0 | 100.00 | .00 | * |
| 88 | 0 | 100.00 | .00 | * |
| 87 | 0 | 100.00 | .00 | * |
| 86 | 0 | 100.00 | .00 | * |
| 85 | 0 | 100.00 | .00 | * |
| 84 | 0 | 100.00 | .00 | * |
| 83 | 0 | 100.00 | .00 | * |
| 82 | 0 | 100.00 | .00 | * |
| 81 | 0 | 100.00 | .00 | * |
| 80 | 99 | 99.24 | .76 | ***** |
| 79 | 82 | 98.60 | 1.40 | *** |
| 78 | 630 | 93.75 | 6.25 | ****************************** |
| 77 | 625 | 88.92 | 11.08 | ****************************** |
| 76 | 983 | 81.34 | 18.66 | *********************************************** |
| 75 | 1199 | 72.10 | 27.90 | *********************************************************** |
| 74 | 1137 | 63.34 | 36.66 | **************************************************** |
| 73 | 1180 | 54.24 | 45.76 | ******************************************************** |
| 72 | 886 | 47.41 | 52.59 | ******************************************** |
| 71 | 721 | 41.85 | 58.15 | ********************************** |
| 70 | 737 | 35.17 | 63.83 | *********************************** |
| 69 | 634 | 31.28 | 68.72 | ****************************** |
| 68 | 534 | 27.17 | 72.83 | ************************* |
| 67 | 588 | 22.63 | 77.37 | *************************** |
| 66 | 507 | 18.72 | 81.28 | ************************ |
| 65 | 409 | 15.57 | 84.43 | ********************* |
| 64 | 466 | 11.98 | 88.02 | *********************** |
| 63 | 426 | 8.70 | 91.30 | ********************** |
| 62 | 347 | 6.02 | 93.98 | **************** |
| 61 | 268 | 3.95 | 96.05 | ************** |
| 60 | 221 | 2.25 | 97.75 | ********** |
| 59 | 164 | .99 | 99.01 | ****** |
| 58 | 67 | .47 | 99.53 | *** |
| 57 | 16 | .35 | 99.65 | * |
| 56 | 19 | .20 | 99.80 | * |
| 55 | 10 | .12 | 99.88 | * |
| 54 | 1 | .12 | 99.88 | * |
| 53 | 7 | .08 | 99.94 | * |
| 52 | 7 | .01 | 99.99 | * |
| 51 | 0 | .01 | 99.99 | * |
| 50 | 1 | 0.00 | 100.00 | * |
| 49 | 0 | 0.00 | 100.00 | * |

MEAN = 71.23 MINIMUM VALUE = 50.86 MAXIMUM VALUE = 80.15 STANDARD DEVIATION = 5.20

Figure 11. Comparison Screening Sensitivity Alternative

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The effects of the changed importance weights are best demonstrated by comparing the changes of relative ranking of specific sites. For this purpose, a set of candidate sites is shown on Figure 12. The corresponding suitability values and rank ordering of the suitability values is given in Table VI, for both the nominal and alternative comparison screening examples. The row and rank ordered scores for the exclusion screening case are also given.

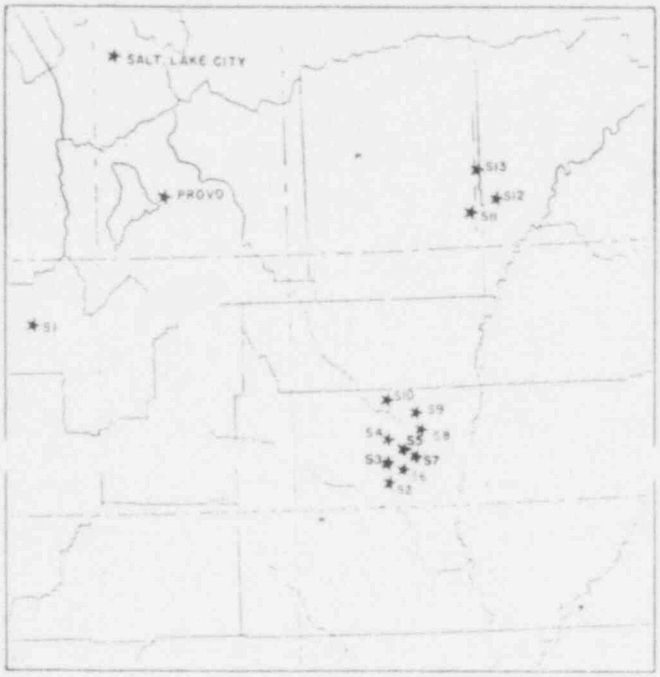


Figure 12. Candidate Sites--Utah

TABLE VI
Rank Ordering of Selected Sites--Utah

| Site No. | Suitability | | Number of Criteria Satisfied Exclusion | Rank Ordering | | |
|---|---|---|---|---|---|---|
| | Nominal | Alternative | | Nominal | Alternative | Exclusion |
| UTAH | | | | | | |
| 1 | 78 | 72 | 7 | 3 | 4 | 3 |
| 2 | 80 | 74 | 9 | 1 | 2 | 2 |
| 3 | 80 | 74 | 9 | 1 | 2 | 2 |
| 4 | 80 | 74 | 9 | 1 | 2 | 2 |
| 5 | 78 | 74 | 10 | 3 | 2 | 1 |
| 6 | 78 | 74 | 10 | 3 | 2 | 1 |
| 7 | 80 | 76 | 10 | 1 | 1 | 1 |
| 8 | 80 | 76 | 10 | 1 | 1 | 1 |
| 9 | 80 | 74 | 9 | 1 | 2 | 2 |
| 10 | 80 | 71 | 9 | 1 | 5 | 2 |
| 11 | 76 | 72 | 10 | 5 | 4 | 1 |
| 12 | 75 | 73 | 10 | 6 | 3 | 1 |
| 1[illegible] | 74 | 71 | 10 | 7 | 5 | 1 |

Examination of Table VI reveals several interesting features. First of all, the exclusion screening case appears to be closer to the alternative comparison screening case than to the nominal. This is largely because the strong decrease in seismic risk importance value gives the alternative case a more uniform distribution of importance values. Sites 1 through 9 appear to be relatively robust, differing by no more than one rank from one case to the next. Sites 10 through 13 appear to change quite significantly. They all lie quite close to the boundary between categories 1 and 2 on the seismic risk map (Figure A-1). Site 10 lies in the first category so the decrease in seismic importance (going from the nominal to the alternative) drops one of its major strong points. On the other hand, sites 11, 12, and 13 lie in the second seismic risk category, which gives them a poor ranking for the nominal case but allows them to move up significantly when the seismic importance weight is lowered for the alternative case.

Weighting Sensitivity--Illinois

For the Illinois case, four alternative importance weighting structures were defined, as indicated in Table VII, with the nominal weighting values also shown for comparison. The comparison screening maps generated by the four alternative weighting structures are shown in Figures 13 through 16. The resulting variations in areas of highest suitability are described in the paragraphs following the figures.

TABLE VII

Alternative Importance Weightings--Illinois

| Issues | Importance Weight (IW) | | | | |
|---|---|---|---|---|---|
| | Nominal | Alt. A | Alt. B | Alt. C | Alt. D |
| Power Network Considerations | 2.0 | 2.2 | 3.0 | 3.0 | 1.9 |
| Cooling Water Proximity | 1.5 | .5 | 1.0 | 1.0 | 1.4 |
| Population Density | 1.7 | 2.0 | 2.5 | 1.0 | 1.6 |
| Land Use | 2.0 | 2.2 | 3.5 | 1.5 | 1.9 |
| Foundation Suitability | 1.5 | 1.7 | 0 | 1.7 | 1.4 |
| Transportation Accessibility | 1.3 | 1.4 | 0 | 1.4 | 1.2 |
| Tornado Frequency | 0 | 0 | 0 | .4 | .6 |

The top 1 percent of the sites was a fairly consistent set except for Alternative B (Figure 14). For Alternative A (Figure 13), the importance ratio for proximity to major waterways was decreased by 66 percent. This was done to illustrate the differences in the choices of alternative cooling systems. If once-through cooling were assumed, the proximity of a site to a major waterway would be much more important than if the use of cooling towers were assumed. Ground water would then be capable of supplying the necessary makeup water. The choice of assumptions made very little difference in this case. The top 30 sites were identical for both cases. Only 10 of the top 1 percent of the sites in the nominal case were not included in the top 1 percent of the sites for Alternative A.

* Very favorable, / favorable, - acceptable

Figure 13. Alternative A, Illinois Comparison Screening Sensitivity

Figure 14. Alternative B, Illinois Comparison Screening Sensitivity

The elimination of two of the criteria for Alternative B (Figure 14) caused substantial changes. The top five sites from the nominal case still ranked highest, but there were numerous changes in listings for the top 1 percent. Half of the sites in the top 1 percent of the nominal case run were not in the top 1 percent of the Alternative B run. It is also interesting to note that those sites which made the top 1 percent of the Alternative B run, but not the nominal case run, did not meet the Set I exclusion criteria (see Table VIII). This is probably the result of low threshold values for transportation access, foundation capability, or cooling.

Alternatives C (Figure 15) and D (Figure 16) represent the possible changes caused by the addition of an extra siting criterion. The particular siting criterion addition, tornado frequency, had a relatively large standard deviation. Each of the six criteria weights used in the nominal case were decreased by 1 percent in order to include a seventh criterion. Although this change caused only 15 different sites to appear in the top 1 percent of the 2 cases, the rankings of the top 1 percent of the sites changed significantly.

A number of these variations can be interpreted in terms of the individual issues which have importance values changed from one alternative to the next. The most striking feature is the acceptable area near the middle of the maps which shows up most strongly in Alternative D (Figure 16). The source of this relatively poor suitability has already been discussed in connection with the nominal case (Figure 10) where it also shows up strongly. The primary reason for this poor suitability is distance from a major waterway; this affects two issues: transportation access and cooling water proximity. The nominal case and Alternative D have the highest importance weights for the cooling and transportation issues. Alternatives A and B have the lowest importance weights for the cooling and transportation issues, respectively.

Table VIII compares the rank ordering of the top 1 percent of the sites for each case. Only one representative site is listed for each of the various rank ordering combinations. The site listing consists of the x and y coordinates of the site which define the southwest coordinate of the map, i.e., (95,55). The Y and N listings for Set I and Set II indicate whether the site passed (Y for yes) or did not pass (N for no) the exclusion criteria listed in Table III. The sites listed under the alternative cases are those which were included in the top 1 percent for that particular case and not included in the top 1 percent for any preceding case.

Many more runs would have to be made for the Illinois study area to determine the actual confidence intervals of the various importance ratios. However, the runs that were made do indicate that a fairly wide range of weighting structures results in the same top-rated sites.

* Very favorable, / favorable, - acceptable

Figure 15. Alternative C, Illinois Comparison Screening Sensitivity

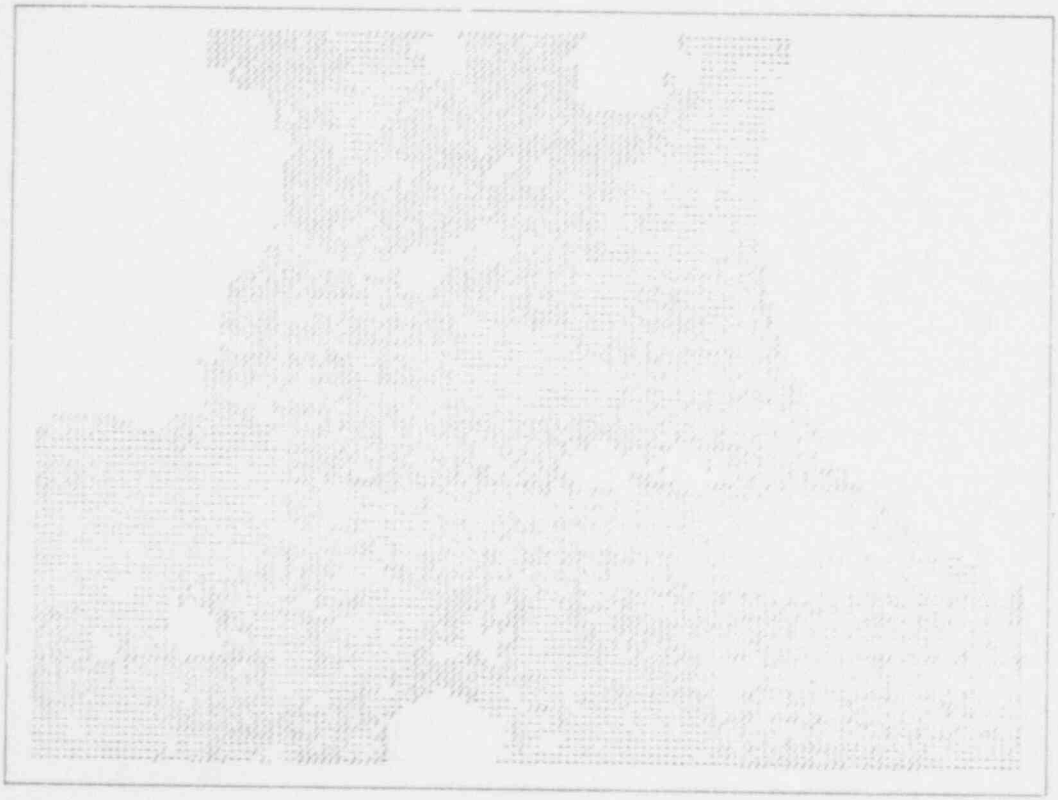

Figure 16. Alternative D, Illinois Comparison Screening Sensitivity



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TABLE VIII

Sensitivity of Selected Candidate Site Rankings--Illinois

| Selected Site (Δx,Δy) | (Number of Identically Ranked Sites) | Ranking Nominal | Alt A | Alt B | Alt C | Alt D | Set I | Set II |
|---|---|---|---|---|---|---|---|---|
| Nominal | | | | | | | | |
| 96,55 | (3) | 1 | 1 | 1 | 10 | 1 | N | Y |
| 99,46 | (2) | 1 | 1 | 1 | 27 | 7 | N | Y |
| 33,59 | (2) | 6 | 6 | 12 | 216 | 33 | Y | Y |
| 95,50 | (12) | 10 | 10 | 72 | 10 | 21 | Y | Y |
| 113,30 | (9) | 10 | 10 | 72 | 1 | 9 | Y | Y |
| 38,110 | (1) | 31 | 35 | 307 | 54 | 4 | Y | Y |
| 102,45 | (2) | 31 | 37 | 1 | 133 | 35 | N | Y |
| 60,55 | (4) | 34 | 10 | 12 | 307 | 75 | - | - |
| 95,52 | (14) | 38 | 81 | 72 | 114 | 101 | Y | Y |
| 104,52 | (6) | 38 | 81 | 72 | 62 | 40 | Y | Y |
| 95,58 | (9) | 58 | 39 | 72 | 29 | 50 | Y | Y |
| 99,51 | (2) | 58 | 102 | 311 | 128 | 467 | Y | Y |
| 100,48 | (3) | 58 | 102 | 311 | 128 | 123 | Y | Y |
| 94,46 | (26) | 58 | 39 | 72 | 62 | 123 | Y | Y |
| 139,30 | (2) | 58 | 39 | 72 | 25 | 35 | Y | Y |
| 112,29 | (17) | 58 | 102 | 311 | 95 | 50 | Y | Y |
| 142,29 | (1) | 58 | 102 | 311 | 56 | 35 | Y | Y |
| Alternative A | | | | | | | | |
| 42,36 | (1) | 165 | 35 | 8 | 490 | 354 | N | Y |
| 39,110 | (2) | 133 | 76 | 307 | 133 | 18 | Y | [illegible] |
| 94,31 | (3) | 962 | 76 | 8 | 911 | 467 | N | Y |
| 51,34 | (1) | 165 | 81 | 12 | 858 | 354 | Y | Y |
| Alternative B | | | | | | | | |
| 36,45 | (11) | 962 | 102 | 12 | 911 | 467 | N | N |
| 115,50 | (1) | 451 | 102 | 32 | 340 | 301 | N | N |
| 115,49 | (2) | 451 | 102 | 32 | 490 | 467 | N | N |
| 124,40 | (2) | 962 | 102 | 32 | 802 | 467 | N | N |
| 34,58 | (3) | 172 | 102 | 37 | 911 | 467 | N | N |
| 90,37 | (4) | 962 | 107 | 37 | 911 | 467 | N | N |
| 51,38 | (1) | 172 | 102 | 44 | 490 | 467 | N | N |
| 86,58 | (8) | 962 | 102 | 45 | 911 | 467 | N | N |
| 84,50 | (1) | 172 | 102 | 45 | 911 | 467 | N | N |
| 125,48 | (5) | 167 | 102 | 45 | 56 | 79 | N | N |
| 57,51 | (1) | 177 | 102 | 59 | 738 | 467 | N | N |
| 57,50 | (12) | 962 | 102 | 59 | 911 | 467 | N | N |
| Alternative C | | | | | | | | |
| 106,58 | (16) | 117 | 102 | 311 | 29 | 79 | N | N |
| 108,74 | (1) | 450 | 102 | 311 | 54 | 123 | N | N |
| 96,69 | (1) | 438 | 102 | 311 | 94 | 277 | N | N |

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TABLE VIII (Continued)

| Selected Site ($\Delta x, \Delta y$) | (Number of Identically Ranked Sites) | Ranking | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Nominal | Alt A | Alt B | Alt C | Alt D | Set I | Set II |
| Alternative D | | | | | | | | |
| 38,109 | (1) | 133 | 102 | 311 | 292 | 18 | Y | Y |
| 39,108 | (4) | 136 | 102 | 311 | 218 | 46 | Y | Y |
| 39,109 | (1) | 437 | 102 | 307 | 431 | 100 | Y | Y |

Individual Issue Contributions (Map Sensitivity)

One of the most important cha acteristics of each issue map is the geographic variation of parameter values or category numbers assigned to each cell. The essence of a consistent and comprehensive site evaluation methodology is the careful analysis of the complexities of this geographic variation. As a first step in this analysis, the mean and standard deviation can be computed for the appropriate parameter for each issue map. The greater the standard deviation, the greater the variety contained in the issue. It is generally expected that those issues with the greatest variety will contribute most strongly to the variety (or standard deviation) of the composite screening map, be it exclusion, comparison, or combination. However, this measure of contribution from individual issues is complicated by the fact that the individual issue maps may have similar geographic variations. Similarities between two maps are characterized quantitatively by the correlation coefficient, which gives the net fraction of the total area over which the two maps have the same variation (area positively correlated minus area negatively correlated).

The value of the correlation coefficient ranges from +1 to -1, with +1 indicating that the two maps vary in exactly the same manner and -1 indicating that the two maps vary in exactly the opposite manner The following paragraphs provide a brief description of these relationships and illustrate the with discussions of the exclusion and comparison screening of the Utah data base. (Time and resources did not permi imilar illustrations with the Illinois data base.) Only the general explanations and results of greatest significance are presented; the mathematical basis for the analysis is explained more fully in the WIEB report.[15]

The two-valued variables used for the exclusion screening methodology provide the simplest example. Any particular issue map is characterized by a variable whose values are specified for each cell of the map. The value is 0 if the cell does not satisfy the exclusion criteria and 1 if it does. The mean value of this variable gives the fraction of cells which satisfy the exclusion criteria. For any such two-valued variables, the mean and standard deviation are related by the following formula:

$$\text{standard deviation} = \sqrt{\text{mean (1-mean)}}$$

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It is most convenient to describe the relationship between the individual issue maps and the composite screening map in terms of the variances. If the geographic variations of the individual issue maps were independent of each other, the variance of the composite screening map would simply be the sum of the variances of the individual issue maps. In actual fact, the geographic variations may be quite strongly correlated; the matrix of correlation coefficients for the Utah study area is given in Table IX. The large correlation coefficients are between the seismic and transmission issues (which is a negative correlation) and between the seismic and cooling issues (which is a positive correlation); the only remaining significant correlation is between the transmission and cooling issues.

Examination of the maps in Appendix A shows that the strong positive correlation between the seismic and cooling issues arises from the eastern half of both these maps (Figures A-1 and A-10). It is purely accidental that the areas of low seismic risk are also areas of fairly abundant cooling water and moderate temperatures. The best areas on the transmission issue map surround the cities of Salt Lake and Provo in the northwest corner of the map; since this is the poorest section of the cooling and seismic maps, the source of the negative correlation becomes clear. However, the negative correlation between transmission and cooling is surprising since population centers tend to locate near reasonable sources of water. (When interpreting the correlation coefficients in terms of the issue maps, it should be remembered that the exclusion screening maps would look somewhat different from those given in Appendix A; they would have only two shades, but the dark and light areas would generally be as pictured.)

The variance of the composite screening map is equal to the sum of the variances of the individual issue maps plus the covariances between all the pairs of issue maps. Each covariance is the product of the correlation coefficient between the two issue maps multiplied by the standard deviation of each map. The covariance matrix for the exclusion screening in the Utah study area is given in Table X. The elements along the diagonal are the variances which are squares of the standard deviations. The covariances are the products of the correlation coefficients given in Table IX multiplied by the corresponding standard deviations. For example, the covariance between the seismic and the transmission issues is -0.1761, which is simply the product of the corresponding correlation coefficient (-0.729) multiplied by the standard deviation or the seismic issue (0.489) and the standard deviation for the transmission issue (0.494).

The elements of each row of the covariance matrix (Table X) are tabulated in the contribution column. Summing the elements of this column gives the variance of the composite screening map; the numbers in the column represent the relative contribution of the individual issues to the composite screening map. To emphasize the role of the individual issue contributions, the elements of the contribution column can be expressed as fractions of the total sum of all the elements in the column (the composite screening map variance); these numbers are given in the fractional contribution column of Table X. It should be noted that the covariance matrix is symmetric about the diagonal, so the issue contributions could be computed by summing each column instead of each row.

TABLE IX

Issue Correlation Coefficients Exclusion Screening

| | Std. Dev. | 1 Seismic | 2 Species | 3 Population | 4 Transportation | 5 Landform | 6 Transmission | 7 Land Use | 8 Soils (Foundation) | 9 Air Corridors | 0 Cooling |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 Seismic | 0.489 | | 0.2854 | 0.08959 | -0.2824 | 0.1914 | -0.7290 | 0.3109 | 0.08901 | -0.05705 | 0.7220 |
| 2 Species | 0.313 | | | -0.03874 | -0.2230 | 0.2516 | -0.1254 | 0.2152 | 0.02644 | -0.08270 | 0.2357 |
| 3 Population | 0.109 | | | | -0.07836 | -0.02598 | -0.09518 | 0.09793 | 0.002851 | 0.0379 | -0.07397 |
| 4 Transportation | 0.485 | | | | | -0.1746 | 0.2959 | 0.03474 | -0.05638 | 0.1398 | -0.2391 |
| 5 Landform | 0.223 | | | | | | -0.2027 | 0.00778 | 0.0135 | -0.05232 | 0.1580 |
| 6 Transmission | 0.494 | | | | | | | -0.1410 | -0.07683 | 0.1060 | -0.5736 |
| 7 Land Use | 0.434 | | | | | | | | 0.3670 | 0.03963 | 0.1409 |
| 8 Soils (Foundation) | 0.432 | | | | | | | | | 0.00433 | 0.09585 |
| 9 Air Corridors | 0.347 | | | | | | | | | | -0.0633 |
| 0 Cooling | 0.463 | | | | | | | | | | |

TABLE X

Issue Contributions Exclusion Screening

| | Std. Dev. | 1 Seismic | 2 Species | 3 Population | 4 Transportation | 5 Landform | 6 Transmission | 7 Land Use | 8 Soils | 9 Air Corridors | 0 Cooling | Contribution | Fractional Contribution |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 Seismic | 0.489 | 0.2391 | 0.0437 | 0.0048 | -0.0670 | 0.0209 | -0.1761 | 0.0660 | 0.0198 | -0.0097 | 0.1635 | 0.3084 | 0.18 |
| 2 Species | 0.313 | 0.0437 | 0.0980 | -0.0013 | -0.0339 | 0.0176 | -0.0194 | 0.0292 | 0.0036 | -0.0090 | [illegible] | 0.1635 | 0.09 |
| 3 Population | 0.109 | 0.0048 | -0.0013 | 0.0119 | -0.0041 | -0.0006 | -0.0051 | 0.0046 | 0.0002 | 0.0014 | 0.0037 | 0.0155 | 0.01 |
| 4 Transportation | 0.485 | -0.0670 | -0.0339 | -0.0041 | 0.2352 | -0.0189 | 0.0709 | 0.0073 | -0.0118 | 0.0235 | -0.0540 | 0.1445 | 0.09 |
| 5 Landform | 0.223 | 0.0209 | 0.0176 | -0.0006 | -0.0189 | 0.0497 | -0.0223 | 0.0008 | 0.0013 | -0.0040 | 0.0163 | 0.0611 | 0.04 |
| 6 Transmission | 0.494 | -0.1761 | -0.0194 | -0.0051 | 0.0709 | -0.0223 | 0.2440 | -0.0302 | -0.0164 | 0.0182 | -0.1312 | -0.0714 | [illegible] |
| 7 Land Use | 0.434 | 0.0660 | 0.0292 | 0.0046 | 0.0073 | 0.0008 | -0.0302 | 0.1884 | 0.0688 | 0.0060 | 0.0283 | 0.3851 | 0.23 |
| 8 Soils | 0.432 | 0.0198 | 0.0036 | 0.0002 | -0.0118 | 0.0013 | -0.0164 | 0.0688 | 0.1866 | 0.0006 | 0.0192 | 0.2609 | 0.15 |
| 9 Air Corridors | 0.347 | -0.0097 | -0.0090 | 0.0014 | 0.0235 | -0.0040 | 0.0182 | 0.0060 | 0.0006 | 0.1204 | -0.0102 | 0.1374 | 0.08 |
| 0 Cooling | 0.463 | 0.1635 | 0.0342 | 0.0037 | -0.0540 | 0.0163 | -0.1312 | 0.0283 | 0.0192 | -0.0102 | 0.2144 | 0.2886 | 0.17 |

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The issues which show the largest contributions in Table X are land use, soils, seismic, and cooling. The discussion of the Utah exclusion screening identified the seismic and transmission issues as contributing most sharply to the definition the boundaries of the areas which passed all 10 screening criteria. In Table X the transmission issue shows a small contribution (a negative sign) while still managing to sharply define a boundary of the area which passes all 10 screening tests. This is because this selected area covers only a small fraction of the study area, while the issue contributions given in Table X represent behavior over the entire map. The concept of issue contribution is not necessarily appropriate for selecting the few best cells which satisfy all the screening criteria. Since the issue contributions described the behavior of the map as a whole, they are probably most suited for analyzing the top 20 or 30 percent. In order to rely upon the issue contribution concept, for actual siting decisions, the study area over which it is applied would first have to be narrowed. Such a strategy is discussed further in Chapter IV.

The above issue contribution analysis can also be applied to the comparison screening, with similar results, but the process is more complex. The suitability parameter for each issue map ranges from 1 to 9 (continuous or discrete, depending upon the particular issue map chosen), instead of the simple, two-valued (zero or one) parameter used for the exclusion screening.

The standard deviations and correlation coefficients which result from the analysis of the comparison screening issue and composite screening maps are shown in Table XI. The correlation coefficients are approximately the same size as those for the exclusion screening case (Table IX) because the correlation coefficient is a normalized statistic, which is not affected by the difference in parameter size between the two cases. The standard deviations, on the other hand, are much larger for the comparison screening than for the exclusion screening case. This is primarily due to the larger parameter size, but it is interesting to note that the variation among the standard deviations for the various issues is much greater also. For comparison screening, the air corridors issue has the highest standard deviation, 3.12, which is more than five times the standard deviation for population (0.62). The ratio of largest to smallest standard deviations for the exclusion screening case is only slightly larger than 2.0.

In order to compute the individual issue contributions, the covariance matrix is constructed in the same manner as was the exclusion screening, but the individual covariances must now be multiplied by the corresponding issue weights. The resulting issue contribution calculation is shown in Table XII. The diagonal elements represent the squares of the standard deviations multiplied by the squares of the issue weights. For example, the seismic-variance element (9.1276) is equal to the product of the square of the seismic standard deviation (2.76) multiplied by the square of the issue weight (3.31). Taking the seismic-transmission element as an example, the product of the correlation coefficient (-0.8571) is multiplied by the seismic issue weight (1.82), the seismic standard deviation (1.66), the transmission issue weight (0.76), and the transmission standard deviation (2.41).

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TABLE XI

Issue Correlation Coefficients Comparison Screening

| Issue | Weight | Std. Dev. | 1 Seismic | 2 Species | 3 Population | 4 Transportation | 5 Landform | 6 Transmission | 7 Land Use | 8 Soils | 9 Air Corridors | 0 Cooling |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 Seismic | 1.82 | 1.66 | | 0.02067 | 0.2401 | -0.2451 | -0.02174 | -0.8571 | 0.2353 | 0.07539 | -0.1008 | 0.6913 |
| 2 Species | 0.88 | 2.4 | | | -0.1422 | -0.1511 | -0.1088 | 0.1832 | 0.1309 | -0.00125 | -0.1228 | -0.2587 |
| 3 Population | 1.36 | 0.62 | | | | -0.1031 | 0.06779 | -0.3470 | 0.01960 | 0.01623 | 0.1180 | 0.2771 |
| 4 Transportation | 0.78 | 1.55 | | | | | 0.3326 | 0.2708 | 0.1116 | -0.08813 | 0.2399 | -0.2540 |
| 5 Landform | 0.88 | 2.28 | | | | | | -0.09868 | 0.2922 | -0.03377 | 0.1889 | -0.05105 |
| 6 Transmission | 0.76 | 2.41 | | | | | | | -0.1486 | -0.07588 | 0.08797 | -0.7482 |
| 7 Land Use | 0.73 | 1.72 | | | | | | | | 0.1312 | -0.00777 | -0.01537 |
| 8 Soils | 0.70 | 1.35 | | | | | | | | | -0.01972 | 0.1224 |
| 9 Air Corridors | 0.50 | 3.12 | | | | | | | | | | -0.09138 |
| 0 Cooling | 1.49 | 1.82 | | | | | | | | | | |

TABLE XII

Issue Contributions Comparison Screening

| Weight | Std. Dev. | 1 Seismic | 2 Species | 3 Population | 4 Transportation | 5 Landform | 6 Transmission | 7 Land Use | 8 Soils | 9 Air Corridors | 0 Cooling | Contribution | Fractional Contributions |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 Seismic<br>1.82 | 1.66 | 9.1276 | 0.1319 | 0.6117 | -0.8953 | -0.1318 | -4.7427 | 0.8926 | 0.2153 | -0.4750 | 5.6639 | 10.3982 | 0.34 |
| 2 Species<br>0.88 | 2.4 | 0.1319 | 4.4605 | -0.2532 | -0.7958 | -0.4611 | 0.7086 | 0.3472 | -0.0025 | -0.4047 | -1.4817 | 2.6592 | 0.09 |
| 3 Population<br>1.36 | 0.62 | 0.6117 | -0.2532 | 0.7110 | -0.1051 | 0.1147 | -0.5359 | 0.0208 | 0.0129 | 0.1552 | 0.6337 | 1.3658 | 0.05 |
| 4 Transportation<br>0.78 | 1.55 | -0.8953 | -0.3858 | -0.1051 | 1.4616 | 0.8068 | 0.5997 | 0.1694 | -0.1006 | 0.4524 | -0.8328 | 1.1703 | 0.04 |
| 5 Land Form<br>0.88 | 2.28 | -0.1318 | -0.4611 | 0.1147 | 0.8068 | 4.0256 | -0.3627 | 0.7362 | -0.0641 | 0.5912 | -0.2777 | 4.9771 | 0.17 |
| 6 Transmission<br>0.76 | 2.41 | -4.7427 | 0.7086 | -0.5359 | 0.5997 | -0.[illegible]27 | 3.3548 | -0.3417 | -0.1313 | 0.2514 | -3.7162 | -4.9160 | -0.16 |
| 7 Land Use<br>0.73 | 1.72 | 0.8926 | 0.3472 | 0.0208 | 0.1694 | 0.7362 | -0.3417 | 1.5765 | 0.1556 | -0.0152 | -0.0523 | 3.4891 | 0.12 |
| 8 Soils<br>0.70 | 1.35 | 0.2153 | -0.0025 | 0.0129 | -0.1006 | -[illegible].0641 | -0.1313 | 0.1556 | 0.8931 | -0.0291 | 0.3138 | 1.26[illegible]1 | 0.04 |
| 9 Air Corridors<br>0.50 | 3.12 | -0.4750 | -0.4047 | 0.1552 | 0.4524 | [illegible].5912 | 0.2514 | -0.0152 | -0.0291 | 2.4336 | -0.3866 | 2.5732 | 0.09 |
| 0 Cooling<br>1.49 | 1.82 | 5.6639 | -1.4817 | 0.6337 | -0.8328 | -0.2777 | -3.7162 | -0.0523 | 0.3138 | -0.3866 | 7.3539 | 7.2180 | 0.24 |





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Summing the individual issue elements for each row gives the total issue contributions; in the fractional contributions column, these contributions are expressed as fractions of the total variance of the composite suitability map (which is the sum of the 10 individual cont ibutions).

Examination of the individual issue contributions in Table XII shows the largest to come from the seismic and cooling issues. The strong contribution from the seismic issue is quite consistent with the comparison screening map (Figure 5) where the boundaries of the highest suitability areas were found to be most strongly defined by the seismic issue. The species (ecology) issue was also responsible for sharply defining one small area in the extreme western part of the map (Figure 5); this can be reconciled with the rather small contribution of the species issue indicated in able XII because the western area is the only part of the seismic map that has a large amount of structure (Figure A-2).

One of the most interesting features of Table XII is the moderately large negative contribution from the transmission issue. In the exclusion screening issue contribution analysis, given in Table X, this issue was found to have a small negative contribution; for the comparison screening, however, the negative correlations with the seismic and cooling issues are stronger because of their larger issue weights and the overall contribution becomes sig ificantly negative. This means that, when the map variations are considered as a whole, areas of higher overall suitability will be areas of low transmission suitability and conversely, areas of low transmission suitability will be areas of higher overall suitability. This negative contribution indicates that, with the except n of a few isolated areas, an objective of short transmission distance will be inconsistent with the goal of highest overall suitability. Of course, as with the exclusion screening applications, the negative contribution from the transmission issue could be changed somewhat by concentrating the analysis on a smaller study area.

Policy Variations

Attribute Variation (Population Example) -- Safety is a major issue in nuclear powerplant siting. Several different attributes can be used to measure the relative suitability of a site with respect to safety. Radiation doses due to normal operating conditions and estimated doses from accidental releases can be considered. Current nuclear plants have had little difficulty meeting the established regulation limits for individual doses and total population doses resulting from normal operating conditions. This issue is, therefore, not likely to be a significant criterion in the selection of candidate sites.

Suitability ratings based on estimated doses from accidental releases can vary markedly for different sites in most regions, depending on meteorology and population distributions. Accident dose is, therefore, a usefu siting criterion at the regional level; however, it is not specific enough for a unique measure. Suitability ratings can be assigned to sites based on the dose at the site boundary, total population dose within the low population zone, maximum population dose for one cell within

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the low population zone, total population dose, or maximum population dose for one cell. Figures A.7 to A.10 in Reference 14 show these doses calculated from input based on the Dresden site (Morris, Ill.) meteorological data. Figures A.12 and A.13 in Reference 14 show a calculation of the total population dose and the maximum population dose for one cell, assuming that the dose is inversely proportional to the square of the distance from the site. References 14 and 23 contain the details of the assumptions used in calculating the various doses. A review of the six figures reveals that different suitability patterns would result, depending on which attribute was chosen to represent accident dose. Although the site population factor is presently one of the accepted attributes for measuring safety, the different suitability patterns illustrate the importance of choosing the proper attribute for any site selection issue.

Alternative Suitability Function Selection (Utah Cooling Example) -- A suitability function is used to define impact levels on a relative scale for all the possible parameter values of an individual siting issue. Development of the suitability function is a two-step process: (1) defining the issue and its attributes (categories or scale of measurement) and (2) assigning suitability values to those attributes. The perspective or purpose of the issue must be established prior to the selection of attributes. Guidelines have been developed for defining each of the more traditional siting issues. For example, concepts such as public safety are well-defined through guidelines pertaining to acceptable levels of seismic hazard and proximity to concentrations of population. For other issues, however, the conceptual approach to an issue may vary between regions or may be directly related to the technical specifications of the powerplant to be sited. For example, the definition of the suitability for cooling systems is partially dependent on the geographic region under study and the type of cooling system to be used.

It can be assumed that the operation of a cooling system is technically feasible at almost any site; individual site differences are manifested by differences in construction and operating costs. To estimate costs for a given site, however, some assumptions concerning cooling technology must be made. The following four options are available for classifying present and expected future cooling technology:

1. Once-through system--This is the simplest and cheapest system. Heat transfer is accomplished by increasing the water temperature. Because of the large quantities of water required and limited supplies of water available (particularly in the west), this option is permitted only at coastal sites.
2. Evaporative (wet) systems--In these systems most of the heat dissipation comes from water evaporation. Less water is required than with the once-through system but cooling towers must be constructed and operated.
3. Dry Systems--With these systems all of the heat transfer is between the working fluid (usually water) and the air. No water is required, but the large heat transfer surfaces make dry cooling towers expensive to construct.
4. Wet-dry systems--These are combinations of wet and dry systems and are designed so that water is used only when the cooling load is heaviest

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(high summer temperatures). This system is more expensive to construct and operate than a totally wet system. However, it can be operated in areas where little water is available.

Cooling ponds and spray systems can be considered variations of options 1 and 2.

Given these four basic types of systems, a policy must be defined before the evaluation of cooling system suitability can be undertaken. From the descriptions given, it is apparent that options 2 and 4 are the most likely ones for Utah. Furthermore, if little data are available on water availability (quantity and water rights) or if little water can actually be used, a policy that stipulates the use of a wet-dry system will result in an analysis that adequately differentiates among alternative sites (using realistic scales of suitability). If enough water is known to be available, an evaporative system policy can be selected. Such a policy would also provide adequate variety among sites. The actual costs resulting from the wet-dry and evaporative policies, however, may be different in value and geographic distribution.

Both types of cooling systems can be used to discriminate among potential plant sites; however, one policy must be selected to run the suitability analysis. (Both could be tested experimentally but one must eventually be identified as the assumed policy.) Selection of the proper policy for the Utah case was based on the assumption of limited water, thereby dictating the use of a wet-dry system.

Once the conceptual approach (policy) has been established, suitability ratings are assigned to the attributes of the issue. In the cooling system example, the attribute measured to assess suitability was cooling system cost. An analysis of the entire study area showed that for the wet-dry policy, costs ranged from approximately $140 per kW to over $260 per kW. To assess suitability, the least cost was assigned the highest suitability rating of 9 and the highest cost was assigned the lowest rating of 1. This relationship of cost and suitability is shown on Figure 17 as a linear function (line bc). However, composite suitability could also be computed using a totally evaporative system (line ac on Figure 17). A third alternative would be to evaluate all sites using the least cost resulting from the use of either system. In the present example, an evaporative system (line ac) has the lowest cost because of the low cost of water. If the cost of water were inflated, a wet-dry system might reflect the least cost.

For illustrative purposes, an evaporative system was analyzed as the least cost alternative; the composite suitability score was computed for the selected sites and rank ordering was established. This was compared to the original comparison screening evaluation and the resulting rankings were compared (see Table XIII).

The rankings of the selected sites evaluated on the basis of the least cost cooling system policy are different than the rankings of those same sites evaluated on the basis of the wet-dry system policy. Specifically, sites S5, S6, S7, S8, and

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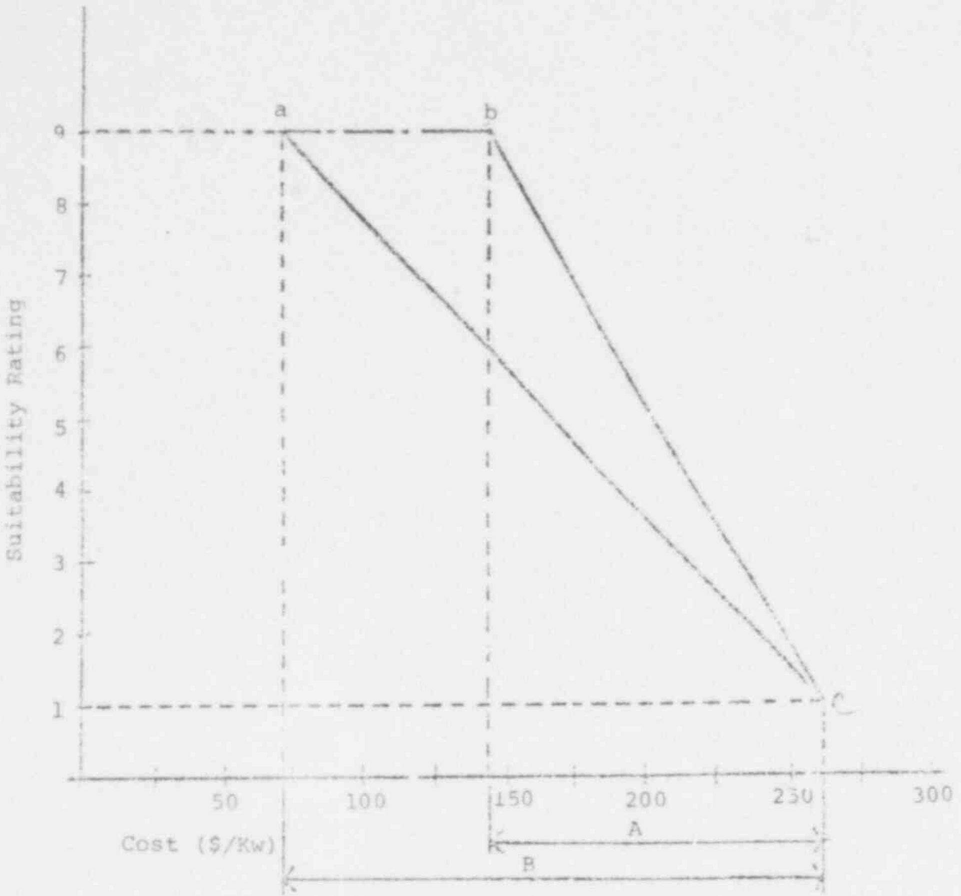


A - Range of Values for Wet-Dry    B - Range of Values for Evaporative

Figure 17. Alternative Cooling System Suitability Functions

TABLE XIII

Comparison of Suitability Rankings for Two Cooling System Policy Alternatives

| Site | Wet-Dry | | Least Cost | | Actual Cost | |
|---|---|---|---|---|---|---|
| | Suita-bility | Ranking | Suita-bility | Ranking | Wet-Dry $/kW | Least Cost $/kW |
| S1 | 78 | 8 | 81 | 8 | 215 | 125 |
| S2 | 80 | 1 | 83 | 1 | 187 | 103 |
| S3 | 80 | 1 | 83 | 1 | 188 | 104 |
| S4 | 80 | 1 | 83 | 1 | 190 | 107 |
| S5 | 78 | 8 | 80 | 9 | 184 | 98 |
| S6 | 78 | 8 | 80 | 9 | 183 | 97 |
| S7 | 80 | 1 | 82 | 5 | 178 | 90 |
| S8 | 80 | 1 | 82 | 5 | 183 | 96 |
| S9 | 80 | 1 | 83 | 1 | 186 | 100 |
| S10 | 80 | 1 | 82 | 5 | 192 | 110 |
| S11 | 76 | 12 | 80 | 9 | 179 | 91 |
| S12 | 75 | 13 | 76 | 13 | 170 | 78 |
| S13 | 78 | 8 | 78 | 12 | 144 | 70 |

S10 ranked lower for least cost than for wet-dry. The change in the rank ordering of S11 and S13 was even more dramatic. However, given even significant changes in rank ordering, the 13 sites represent (with high probability) the most acceptable sites available. The changes in rank ordering do serve to emphasize the importance of careful consideration of the definition and assignment of a suitability function to any specific site selection issue.

## CHAPTER II

## COMPARISON OF ALTERNATIVE SITING EVALUATION METHODOLOGIES

### Introduction

In the previous chapters of this report, alternative methodologies for evaluating site suitability for nuclear powerplants have been defined. Two of these methodologies (exclusion screening and comparison screening) have been applied to specific data sets to illustrate their characteristic features. The remaining methodologies have been discussed in terms of their utilization in siting studies which have preceded the actual development of nuclear powerplants. The purpose of this chapter is to compare these methodologies, with particular emphasis on their applications to the identification of the most suitable areas within a defined region of interest (Phase I of the siting process). The comparison criteria will generally be consistent with the basic objectives of siting studies. These objectives are to identify the best site areas and to provide documentary support for siting decisions as part of the regulatory approval process.

The exclusion screening and comparison screening methodologies are the most quantitative among all those considered; they have thus far been given the most extensive discussion in this report. This chapter is devoted to discussing the characteristics, advantages, and disadvantages of these two methodologies and to comparing them with the other methodologies.

### Characteristics of the Exclusion and Comparison Screening Methodologies

Both the exclusion and comparison screening methodologies are quite appropriate for the selection of suitable site areas from an RCI. Both are readily adaptable to map systems for the storage, manipulation, and display of data in a manner which is geographically comprehensive. The two methodologies can be used for studying any specific geographical area to any level of detail, limited only by the extent and resolution of the site-related data available.

The exclusion screening methodology requires two basic steps: (1) the identification of the crucial issues to be screened and (2) the establishment of threshold values for the parameters characterizing these issues. The exclusion screening methodology most naturally fits those situations in which the siting decisionmakers are primarily concerned with issues for which screening thresholds have been established by regulatory rulemaking. This is already the case with the population issue and will soon be the case with the seismic issue. In areas where regulatory criteria have not been strongly applied (such as cooling or transmission system costs), the responsible decisionmakers would need considerable analytic support before reasonable threshold criteria could be established. The threshold criteria applied to these types of issues in the examples of the previous chapter were somewhat arbitrarily chosen; a good deal more justification would be required for their use in any practical siting exercise.

The comparison screening methodology generally requires more analytic and decisionmaking effort than the exclusion screening methodology. The following four steps are typical for comparison screening: (1) identifying significant issues, (2) developing the suitability function for each issue, (3) determining the importance weight for each issue, and (4) selecting the threshold composite suitability score (or percentile rank). Considerable technical analysis by the study team may be required to develop suitability functions, and the results may be particularly vague and unsatisfying in those areas involving heavy socioeconomic impacts. The issue weights are determined by a voting majority or consensus process involving the solicitation of opinions and judgments from individuals representing all the major interests in the siting process. One type of decision process for determining the importance weights is a Delphi meeting of experts and interest group representatives. A Delphi meeting was held to determine the importance weights used for the WIEB study;[15] these importance weights also formed the basis for the importance weights used for the Utah study area in the present report. The threshold composite suitability score serves to define the candidate areas identified for further investigation. However, the boundaries of these candidate areas may be subsequently modified in response to special political or economic considerations.

## Advantages of the Exclusion and Comparison Screening Methodologies

Both methodologies produce maps with shading to represent the relative ranking of each geographic location. Examination of the maps and comparisons drawn with the individual issue maps show the influence of individual issues in defining the boundaries of the most highly suitable candidate areas. Examples of such analyses for both exclusion and comparison screening have been given in Chapter I. The computer programs which generate the issue maps and composite screening maps can also be used to compute statistics which summarize the overall variation of each issue map and the contribution of that overall variation to the composite screening map. The significance of the standard deviations and correlation coefficients arising from the simplest types of statistical analyses have also been described in Chapter I.

From the previous discussions and from the examples presented in Chapter I, the following advantages of the exclusion screening methodology become apparent:

1. It generally requires much less data than other evaluation methodologies, particularly comparison screening, and is, therefore, cheaper.
2. It always requires much less analysis than comparison screening and is, therefore, faster and allows less opportunity for error.
3. It provides clear distinctions between the selected areas and the rest of the ROI (in statistical language, a significant discrimination).

It provides a result which is easy for the decisionmakers to understand, be they regulators, industry officials, politicians, or the general public; the layman is more easily convinced by absolute concepts, such as safety, than by relative concepts (or a continuum of possibilities), such as risk.

5. The sharp boundaries greatly facilitate the identification of issues most responsible for defining the selected areas.

Similar analysis and consideration of the examples suggest the following advantages for comparison screening:

1. It provides for complete flexibility when considering the relative importance of the various possible values of each issue parameter (through modifications of the suitability function) and the alternative importance weights for the separate issues are considered.
2. The large number of different suitability values in the composite comparison screening map provides a great deal of detailed information to the decisionmakers; in particular, even the selected highly suitable area will have several hierarchies of rank within it.
3. The technical analysis required to develop the utility functions assures an explicit consideration of the technical assumptions (which are not explicitly expressed but are implicitly contained in any decision involving threshold criteria for exclusion screening).
4. It incorporates diverse opinions of experts and decisionmakers determine the importance weights (through the Delphi or another group decision process).
5. While the identification of a selected area is not as decisive as it is with exclusion screening, the selected areas are always sensitive to small variations in any of the parameters, suitability functions, or importance weights; as a corollary, this process also provides a valid ranking mechanism for all areas of the map, not only the most suitable ones. This sensitivity property also permits more flexibility when moving the boundary of a selected area in response to subsequently discovered nonquantifiable issues, such as political concerns.

### Disadvantages with Exclusion and Comparison Screening Methodologies

The following paragraphs describe shortcomings and difficulties with the exclusion and comparison screening methodologies. The shortcomings should be recognized when selecting the situations most appropriate for application of the methodology, and the difficulties should be recognized when applying the methodology to cases in which it is appropriate. The following discussion serves as a basis for the methodology application guidelines presented in Chapter III.

The illustrations and analysis of the exclusion screening methodology suggest the following disadvantages:

1. All of the issues must be given equal weight; some features of a system of unequal weights could be simulated by raising or lowering the threshold screening criterion for a single issue, but that would confuse the basis for analysis.
2. One poor issue param ter can eliminate a site which ranks very high on all the other issues; this problem could be somewhat alleviated by using only those issues which are absolutely essenti..l.
3. If there are too many issues, the area passing all of the issue screens is likely to be quite small. For example, if there are 10 independent issues, if the exclusion thresholds are set so that 50 percent of the cells pass each individual issue exclusion criterion, and if the cells which pass the screen are randomly distributed, then statistically, less than 0.1 percent of the cells would be expected to pass all 10 exclusion criteria.
4. The sharp definition of the selected area boundary may present severe difficulties as future influences and political concerns develop. For example, an individual cell might barely fail one particular issue and be just beyond the border of the selected highly suitable area, but local concerns might strongly favor locating in that area. If the exclusion screening results were announced, it would be much more difficult to convince the local public and decisionmakers that the supposedly hard and fast exclusion screening criteria could be partially violated.
5. It is impossible to distinguish the better cells within the selected candidate area since all cells have passed all the screenings.
6. This methodology does not provide significant rankings among the non-selected areas (which will be quite large unless the individual issue screening thresholds are set low enough to pass most of the cells on each issue). There is no natural way to rank the issues for which the thresholds have failed; for example, there would be no way to determine whether a cell whi... had failed a seismic screening criterion was better than a cell which had failed both the ecology and air corridor criteria.

The formal analysis and greater flexibility of the comparison screening methodolog, enable the user to overcome most of the difficulties inherent in the exclusion screening system. There are no unsolvable problems (or disadvantages) associated with the comparison screening methodology, but the following difficulties may increase cost or decrease acceptability:

1. It is difficult to develop universally acceptable suitability functions for nontechnical or noneconomic issues; this is particularly difficult when dealing with sociopolitical issues. Alternative methodologies for developing such suitability functions should be explored as part of a follow-on study.

2. It may be difficult to convince the local public and decisionmakers that the importance weights assigned by a particular Delphi panel would have been obtained by any other group constituted by a similar process. This difficulty may be alleviated if the sensitivity analysis shows the extent to which the determination of the selected areas can tolerate changes in the importance weights.

## Comparison of Alternate Site Evaluation Methodologies

Three factors have an effect on the final suitability ratings (rankings) for the sites under consideration: (1) the choice of attributes for measuring site issues, (2) the assumptions used in developing the suitability scales for the attributes, and (3) the importance ratios assigned to those attributes.

The qualitative comparison and favorability selection methodologies do not clearly address these three factors during the site selection process or during the documentation of it. Both methodologies are, therefore, less able to withstand a critical review of quantitative aspects of the siting choice.

None of the procedures classified as site rating methodologies in Chapter II of Part I use issue importance ratios; therefore, these procedures do not eliminate the subjectivity associated with weighting structures. The importance ratios for all the attributes are equal; consequently, the importance ratio for a particular siting issue (safety, environmental impact, etc.) is determined by the relative number of attributes used to measure it. These assumptions cannot be considered less subjective than any others. Several of the scales used for site rating procedures did not allow for any trade-off analysis. For example, the site rating scheme used in Reference 5 ranked each of the 3 candidate sites either 1, 2, or 3 on each of 10 siting criteria. This scale provides little useful information. The difference between a 1 and 2 ranking for one criterion could be minimal, whereas that difference for another criterion could be very significant. The appropriate method for combining or comparing the scales for the two different criteria is not apparent.

The cost-effectiveness analysis is essentially equivalent to the comparison screening methodology if all of the attributes which cannot be expressed in terms of dollar cost are equivalent at each of the candidate sites. However, it is unlikely that this would be the case. If such were the case, dollar cost would be as appropriate a suitability scale as any other for the analysis. The trade-off analysis is implicit ($1 = $1) and may be readily acceptable.

In order to perform a comparison screening, each attribute including its suitability scale and importance ratio must be defined. This allows for trade-off analysis and sensitivity analysis and provides important insight into the evaluation of the site selection procedure and, consequently, the selected site. Comparison screening was the only methodology evaluated which was able to provide documentation of the attributes, suitability functions (and the assumptions used in generating them), and importance ratios used for selecting the proposed site.

## CHAPTER III

## GUIDELINES FOR IMPLEMENTATION OF SITING METHODOLOGIES

### Introduction

This chapter presents guidelines for selecting and implementing a siting methodology. These guidelines are primarily concerned with the exclusion and comparison screening methodologies and are based upon analyses, examples, and discussions provided in the previous chapters of this report. Both methodologies can be applied and will provide similar answers when a significant portion of the ROI shows a high favorability rating on all the siting issues. Unfortunately, this situation is not likely to occur in future nuclear powerplant sitings; safety concerns are expected to increasingly dictate remote sitings, a situation which is undesirable from a transmission issue standpoint. The negative correlation between the transmission and the population issues given in Table XI clearly illustrates this point.

### Circumstances Favoring Selection of Exclusion Screening

Exclusion screening is best applied during the early portion of a Phase I evaluation, when the objective is to reduce the size of a very large ROI. In these circumstances, it should be possible to limit the number of issues with strong screening thresholds (passing a minority of the available cell areas); the remaining issues can either be neglected or treated with a weak exclusion criteria (passing a majority of the cell areas). Under any circumstances, exclusion screening would always be applied before comparison screening.

If a preliminary analysis of the major issues reveals significant gaps in the issue parameter values and if these gaps would be appropriate levels for screening thresholds, then exclusion screening would be the best methodology to apply. However, such clear-cut gaps have not been found in the most significant issue examined for the illustrations used in this report.

### Circumstances Favoring Selection of Comparison Screening

Whenever issue trade-offs are important, comparison screening is favored because in this methodology the effects of changes in assumptions and relative issue importance weights can be readily seen. Sensitivity studies performed within the comparison screening methodology provide valuable information for decisionmaking and for justifying decisions before a regulatory review.

Comparison screening is also strongly recommended when issue correlations are significant because the issues are negatively correlated and very little of the ROI is able to satisfy both issue threshold criteria simultaneously. Large issue correlations also imply that a significant degree of geographical shifting can be tolerated (since the issues have similar geographical variations) without drastically affecting the composite screening map.

### Special Implementation Considerations for Exclusion Screening

As mentioned in the previous analyses and discussions, the most important guideline for implementing exclusion screening is that of limiting the number of issues having strong screening thresholds. Unless there are natural gaps in the major issue parameters, it is advisable to seek opinions from recognized experts before setting the threshold criteria. This external decisionmaking process need not be as elaborate as the process used to determine issue importance weights, which must be done when implementing comparison screening; there certainly is no need to involve nontechnical people.

When the exclusion screening results are analyzed and reported, some interpretation should be made of the boundaries of the selected areas. This interpretation should be given in terms of the individual issue maps which contribute most strongly to the determination of such boundaries, especially if there are new considerations or political influences which might dictate a boundary shift. Although such shifting is extremely difficult to accomplish when applying exclusion screening, the feature interpretation may supply some justification for doing so.

### Special Implementation Considerations for Comparison Screening

Suitability functions must be developed in a fairly rigorous manner. This development is fairly straightforward for the technical issues, but there are not any good guidelines for the sociopolitical issues. In fact, this area is one which draws the greatest criticism of comprehensive regional screening procedures; skeptics often believe that a true site evaluation is not possible without an explicit consideration of the sociopolitical issues involved, particularly for the sitings of nuclear powerplants, an area which gives rise to extremely emotional issues. It should be possible to solicit advice from special interest groups which exert the strongest influence in this area, but they are often reluctant to approve any particular suitability function or procedure. The most promising approach would be to obtain meaningful participation from regional planning agencies.

The participants who determine the issue importance weights (by Delphi or some other systematic mechanism) should be suggested and/or approved by individuals who have regulatory responsibilities or by recognized independent authorities. Thus, a broad participation will be assured (including possible intervenors and other segments of the general public), and the credibility of the selected panel will be enhanced.

A thorough examination should be made of the issue correlation coefficients and the resulting individual issue contributions to the overall variation of the composite comparison screening map. In addition, sensitivity studies should determine the specific effects of changing importance ratios, particularly in relation to the location of boundaries and surrounding highly suitable selected areas and the relative ranking of candidate sites.

To identify specific contributions when determining suitable areas, the general features of the composite screening map should be analyzed and compared with corresponding features on individual issue maps. Even within the selected candidate areas, subareas of highest suitability can be identified and interpreted in this manner. Such interpretations are similar to those which would be undertaken in the exclusion screening methodology, but the more continuous nature of the suitability parameter in the comparison screening case permits the development of more detailed information; furthermore, this information provides a valuable guide for additional sensitivity studies.

There should be an overall assessment of data quality (accuracy) and resolution. Such an assessment can form the basis for a cost benefit analysis, which should be performed prior to making any decisions regarding additional data collection and subsequent refinement of the site evaluation process.

CHAPTER IV

RECOMMENDATIONS FOR FURTHER STUDY

This chapter describes possible follow-on studies. There are two fundamental objectives for these studies: (1) to refine the methodologies and develop their ultimate potential for practical usefulness and (2) to communicate the advantages of these methodologies to all potential users (regulatory bodies, political decisionmakers, and utility decisionmakers).

A formal development of suitability functions should be made; these suitability functions will serve as standards, or guidelines, for future site evaluation studies. The development of suitability functions for the technical issues will be fairly straightforward; much of this development has already been accomplished in the WIEB report.[15] The suitability functions should be circulated among experts in each field so that generally acceptable consensus modifications can be developed. The major cost issues (seismic, cooling, and transmission) are subject to some disagreement among experts, but agreement should be reached within some reasonable confidence interval. The sociopolitical issues, on the other hand, will be much harder to determine; therefore, efforts should be begun immediately. A survey of regional planning agencies should be conducted to determine their current approaches to this problem and to solicit suggestions for the appropriate suitability functions to be used. After preliminary definitions of these functions have been made, a group decision process should be determined for selecting the appropriate functions and proposing the needed modifications. The development of standard suitability functions should also include a forecast for changes expected to occur due to technological improvements and changes in social behavior and standards. For example, new construction techniques could significantly reduce the extra cost currently allocated to seismic hardening. In the sociopolitical area, a future decrease in concerns with the nuclear safety issue may occur if the nuclear industry continues its perfect safety record.

In light of current concerns with sociopolitical issues, a sample study area should be selected in which a number of these issues are clearly defined and quantifiable. An exercise similar to those presented in Chapter III should then be conducted, primarily emphasizing the sociopolitical issues. This study would utilize the suitability functions suggested in the previous paragraph and would also provide feedback for further refinement of those functions.

An issue correlation and contribution analysis should be performed for study areas approximately twice the size of the candidate areas identified in this study (and possibly also the WIEB study). Such an analysis would more sharply define the best candidate areas by identifying those with the best performance records on issues which make the greatest contributions to the screening map variations.

As the exclusion and comparison screening methodologies are developed, they should be properly organized and then described to appropriate regulatory agency personnel and decisionmakers (political and utility) to solicit their opinions on the current usefulness of the methodologies and suggested modifications. A manual explaining the use of the alternative methodologies (describing both guidelines and uncertainties) should be developed for planners, regulators, and decisionmakers.

The issue correlation analysis should be extended to determine which combinations of issues (principal component or factor analysis) make the greatest contribution to the composite screening map. For example, the strong correlation between seismic and transmission issues in the Utah study area implies that neither makes a major contribution alone; a linear combination is actually most responsible. This may be a rather abstract concept, but it can be explained to nontechnical people. Factor analysis has been used to identify major influences in the behavioral sciences for some time, so a portion of the public is used to thinking about them.

## APPENDIX A

## Utah Issue Analysis

The issues used for the Utah study area are described in this appendix. The included discussions are condensations of the issue descriptions used in the WIEB siting study for the 11 western states,[15] with the exception of the ecology, land use, and foundation suitability issues which were not considered in that report. The intent of these discussions is to be purely informative; they are not intended to convince the siting expert that they constitute a completely realistic and comprehensive evaluation of the study area. The purpose of this study is to illustrate and compare siting methodologies. The purpose of the WIEB study was to systematically and comprehensively evaluate on a very broad scale. To the extent that the broader criteria and larger cell size are applicable to this study, a fairly complete issue justification can be found in Reference 15.

The issue maps presented in this appendix are expressed in the units most suitable to the individual issues according to a categorization scheme most suitable to the actual data of the study area. Since many of the schemes were too large to fit conveniently on the maps themselves, each categorization scheme is described by a table preceding each issue map. Although the various maps have differing numbers of issue categories, on all maps the most suitable areas are the darkest, the least suitable areas are the lightest, and the restricted (or excluded) areas are completely blank.

The numbers actually assigned to each category have no physical significance. Before they can be used in any screening process, the numbers must be transformed to a common basis. For exclusion screening, cutoff levels which correspond to category boundaries are chosen for each issue. For comparison screening, suitability functions are used to transform each category number to a common suitability scale. For some issues, the suitability function is continuous so the transformation is actually made from the parameter values represented by the categories.

### Issue 1: Seismic Design

The following three major factors are generally considered in the seismic evaluation of a nuclear powerplant site:

1. Fault rupture hazard--primarily a siting problem,
2. Dynamic soil stability (liquefaction)--both a siting and a design problem, and
3. Strong ground motion (vibratory)--both a siting and a design issue.

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A detailed site qualification study would require the careful consideration of all three factors. The siting requirements are specified by the NRC, and the evaluation of the site (for design purposes) is based upon the additional cost imposed by these site-related conditions. The evaluation of all these factors generally requires effort far beyond the scope of this study. However, after careful consideration, a methodology has been developed for a coarse screening process which generally reflects the overall impact of these factors.

The fault rupture siting criterion is generally manifested by a minimum distance from the nearest capable fault (typically 5 miles). A detailed site evaluation should exclude areas in the immediate vicinity of such a fault. A review of sample data for the study area revealed that, in general, two major fault systems exist that could easily be mapped and that would have a significant impact on the area excluded from consideration. These two fault systems include the Wasatch and Sevier/Elsinore fault systems.

The dynamic soil stability siting criterion is considered part of the foundation suitability (Issue 8).

The remaining factor in seismic design is strong ground motion criteria determined by the postulated Safe Shutdown Earthquake (SSE). This is the largest possible event on the controlling seismogenic feature and could be a capable fault (not necessarily the closest one) or a tectonic province.

Although the SSE is specified by a deterministic process, it is nominally agreed that, viewed as random events, the typical SSE and OBE will have associated recurrence intervals of 10,000 and 100 years, respectively. The recurrence interval is the average time between occurrences of the specified earthquake in the source zone of strongest influence on the site. The differences between these typical recurrence intervals and those that would be calculated from the deterministically specified earthquakes at each cell are within the degree of approximation of the overall seismic risk procedure. Once these design earthquakes have been associated with recurrence intervals, they can be approximately related to probabilistic estimates of vibratory ground motion for the western states in general.

The seismic history (vibratory ground motion due to historical earthquakes) of the continental United States has been summarized by contour maps which give the peak horizontal accelerations expected over a 50-year time interval. The most recent of these is a map of Effective Peak Acceleration (EPA) prepared by the Applied Technology Council (ATC).[18] The ATC map contains four contour levels (0.05g, 0.1g, 0.2g, and 0.4g). This work is an adaptation of an analysis by Algermissen and Perkins for accelerations in bedrock; the modification reflects a propagation of seismic disturbances from the rock through soil characteristics of the general area but does not reflect specific local soil conditions at the site. The contours of the ATC map represent acceleration levels which have a 0.8 to 0.95 probability of not being exceeded in a 50-year time interval. Assuming random events, this probability range translates into a return period ranging from 224 to 975 years. (The return period is the average time between peak accelerations of a certain level at

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the site.) The 100-year recurrence interval normally attributed to the OBE refers to the occurrence of such events in the earthquake source region. Since not all such events will produce the maximum peak acceleration (which is what is calculated by ATC), the return period of the maximum peak acceleration corresponding to the OBE is assumed to be 3 to 10 times longer than the recurrence interval for the OBE itself in the source region. Therefore, the maximum peak acceleration produced by the OBE would have a return period of 300 to 1,000 years, which corresponds quite closely to the ATC range.

The above analysis suggests the seismic categories given in Table A-I. The application of these categories to the study area is shown in Figure A-1. The Wasatch and Sevier/Elsinore fault systems are shown as white in the figure, and the remaining categories are shown in shades of grey to black.

Issue 2: Ecology

The impacts of nuclear powerplants on local ecological systems stem from several sources. Depending on the quantities of water used for cooling, the aquatic environment may be disturbed. The aquatic environment may also be disrupted by discharges of cooling water or by erosion impacts during construction. Terrestrial plants and animals may be directly displaced from their natural habitats at the plant site, or they may be environmentally stressed by immediate-neighborhood effects such as the drift from cooling-tower plumes. These impacts are predominantly localized. In most cases, any area-wide effect will also depend on the specific site location that is selected.

To illustrate the siting methodology, the habitats of several ecologically significant species were mapped. One of the selected species was rare and endangered, and the other species were selected to allow discrimination among potential site areas over a large geographic area. The selected species are not necessarily representative of all of the species that inhabit Utah. The resulting classifications are listed in Table A-II. The application of these categories to the study area is shown in Figure A-2.

For the sake of simplicity, it is assumed that the plant will impact only the ecology of the grid cell in which it is located; therefore, the species map (Figure A-2) will be used directly as an issue map.

Issue 3: Population Density

The radiation hazard to the population from a postulated serious accident can be minimized by locating nuclear reactors in areas where population densities are lower. The NRC criteria treating population in relation to radiation hazard, which are discussed in 10CFR100, describe the following three general limitations: (1) an exclusion zone surrounding the facility, (2) a low population zone surrounding the exclusion zone, and (3) a minimum distance from the low population zone to the nearest population center. Specifically, 10CFR100 requires the following:

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1. An "exclusion area" surrounding the reactor in which the reactor licer has the authority to determine all activities, including exclusion or removal of personnel and property;
2. A "low population zone" (LPZ) which immediately surrounds the exclusion area in which the population number and distribution are ordered in such a way that "there is a reasonable probability that appropriate measures could be taken in their behalf in the event of a serious accident";
3. That at an point on the exclusion area boundary and on the outer boundary of the LPZ, the exposure of individuals to a postulated release of fission products (as a consequence of an accident) be less than certain prescribed values; and
4. That the "population center distance," defined as the distance from the nuclear reactor to the nearest boundary of a densely populated center having more than 25,000 residents, be at least 1.33 times the distance from the reactor to the outer boundary of the LPZ.

The three limitations mentioned previously are typically expressed in distances that are specific to site analysis. In order to treat the issue of radiation hazard to population on a regional scale, a more generalized measure, the Site Population Factor (SPF), has been developed. $SPF_x$ is expressed as an index of equivalent population density within a radius x. The base of the index scale is 1, which is equated to a population density of 1,000 people per square mile. Therefore, $SPF_{30} = 0.5$ is equal to an average population density of 500 persons per square mile within a 30-mile radius.

NRC guidelines suggest the following limitations:

1. $SPF_{30} = 0.5$ or less at the time of initial operation of the facility, and
2. $SPF_{30} = 1.0$ or less over the lifetime of the facility.

Regional SPF maps showing isocontours were obtained from WASH-1235[19] for use in the suitability analysis. The SPF map includes isovalue contours of 0.2, 0.4, 0.5, 0.7, and 1.0, with the resulting areas bounded by the upper and lower contours classified as a range of SPF indices. The SPF indices are shown for a radius of 30 miles in SPF and are based on population data from the 1970 U.S. Census. To modify the contours to reflect population growth for 1985 (a typical date for initiating construction) and 2020, which approximates a 30-year plant life, the OBERS[20] projections of economic activity and population were used. These population data, which were catagorized by Standard Metropolitan Statistical Area (SMSA), were used to determine population growth.

Based on NRC guidelines, those areas that were projected to be greater than 0.5 $SPF_{30}$ in 1985 or 1.0 $SPF_{30}$ in 2020 were restricted or excluded as potential NEC siting areas. Assuming that as future populations increase, the suitability of a specific site will decrease if it is close to an existing population concentration, the 2020 projected SPF values were used as a basis for determining suitability.

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The specific ranges of SPF are shown in Table A-III. These categories are applied to the study area as shown in Figure A-3. The restricted areas (Category 6) are primarily Salt Lake City and its environs. The remaining areas are represented by shades varying from grey to black according to the SPF categorization scheme indicated in the figure.

Issue 4: Major Transportation Access

Construction of a nuclear powerplant will involve the transportation of unusually large pieces of equipment. In addition, large quantities of materials, such as structural steel, concrete aggregate, mechanical system components, etc., must be transported to the site from diverse locations. If the site is not directly adjacent to a major transportation access system such as a railroad or major highway, a connection to such a system in the form of a rail spur line or access highway must be constructed. The cost of initial construction of such an access and its maintenance during the construction period is directly related to the length of the access.

In order to consider transportation access as a siting issue at the regional level, the access distance to the nearest major highway or rail line was determined for all potential site areas. This distance, measured in miles, was assumed in order to provide an index of a specific site area's suitability based on the cost of providing access. U.S. Department of Commerce[21] and U.S. Department of Defense[22] sources were used to determine the location of major highways and railroads. A computer program was used to determine the distance from all site areas (cells) to the nearest highway or railroad; no preference in the mode of transportation was assumed. The distance was modified when access through more rugged terrain (as shown on the landform map) was required in order to reflect the increased construction cost. The transportation access categories are listed in Table A-IV. The application of these categories to the study area is shown on Figure A-4.

Issue 5: Landform Suitability

A nuclear powerplant will require a land area of 1,000 to 1,500 acres, depending on the number of units and the cooling system design. An increase in slope or ruggedness of terrain translates directly into increased construction cost. This increased cost is due to difficulties that may be encountered when excavating for foundations and constructing access roads where minimal grades are required due to the extreme weight of components such as the turbine or pressure vessel. Difficulties may also arise due to measures such as control of runoff and erosion from cut slopes that must be taken to mitigate environmental disturbances. Furthermore, sections of transmission line forced to go through rugged terrain may be increased in cost up to 20 percent.

To evaluate the impact of landform (terrain) considerations over a large regional area, a general index that indicates both the steepness of slopes and the area of such slopes is needed. Such data were found to be available from the U.S. Geological Survey.[23]

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The index used for the landform map is the percentage of each cell classified as gently sloping. Although the gentle slope classification is defined here as general inclination less than 8 percent, this value is not strictly a critical threshold value for land utilization. Gentle slope does, however, fall within the range in which movement of vehicles becomes impeded and construction and operation become more difficult. Categories of general ruggedness were defined by applying the concept of a percentage area that has an 8 percent slope or less. For example, if less than 20 percent of an area is gently sloping, the terrain is considered to be very rugged and is assigned the lowest suitability rating. The remaining ruggedness categories were rated linearly, as shown in Table A-V. The application of these categories to the study area is shown on Figure A-5,

Issue 6: Electric Power Transmission Requirements and Costs

Transmission line requirements are a major cost factor when evaluating alternative power generation sites which are remote from load centers. A line carrying 1 GW typically costs $235,000 per mile; and an additional cost of up to 20 percent should be added for high altitude or rugged terrain. This cost increase may be necessitated by bottlenecks in mountain passes or geopolitical obstructions.

Considerable time and effort may be expended to secure the right-of-way (even for relatively undesirable terrain) because of conflicting local government jurisdictions. Aesthetic impact is also a major factor. Undergrounding has been an effective solution to aesthetic impact problems which are due to lower voltage transmission and distribution lines in urban areas. Unfortunately, undergrounding the highest voltage (500 kV and over) transmission lines is quite costly and has not yet been practically demonstrated because of excessive insulation and heat dissipation requirements. Additional arguments against high-voltage transmission lines are audible noise, possible ozone production, and biological effects.

To determine accessibility to the two major load centers, Salt Lake City and Provo, the distance in cell units from each cell to the nearest load center was computed. However, the specific route taken from each cell was modified by terrain (as represented by landform) and land use (excluded from national parks and monuments). The modification was accomplished by generating an augmented effective distance as a function of the steeper terrain and specialized land use. The resulting unit distances for all potential site locations were grouped into the interval categories in Table A-VI. The application of these categories to the study area is shown on Figure A-6.

Issue 7: Land Use

Locating a power generating facility in an area that is currently designated for some types of land use not only precludes the use of that land for any other purpose but also may impact (from a cultural or economic point of view) the region within which the site is to be located. Specifically, three classes of land use which could generate significant impacts are considered. These classes are protected lands, areas of potential coal development, and agricultural (arable) lands.

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Fo· the c     .eration of prote/ted lands, the Energy Reorganization Act (Sec-..ion .)7) of 19.. states that nat'.nal forests, national parks, national historic monuments, and national wilderness areas should be excluded from consideration as potential nuclear powerplant sites. The development of powerplants in thes. eco-logically and culturally important areas could signi...antly degrade their natural or cultural qualities.

There is a high probability that the coal reserves of this country will be increasingly utilized in the generation of electricity and as a general energy source. Coal reserves also represent a land resource that covers significant geo-graphic area within the western United States and, therefore, must be considered in the evaluation of siting areas.

Due to the foundation stability requirements of a nuclear powerplant, it is unlikely that the deep mining of coal could be conducted beneath, or in close prox-imity to, a nuclear powerplant. Coal deposit locations that have been strip mined could possibly be good powerplant sites provided the stripping excavation has not been too deep and that no valuable additional coal seams lay beneath.

In accordance with national energy policy, wherever conflicts between coal ex-traction and the development of a nuclear powerplant existed it was assumed that the area would be considered primarily for coal development.

In addition to protected lands and coal deposits, those lands shown as arable by the Soil Conservation Service were also considered. Due to limited agriculture in Utah, any existing agricultural area or potentially arable land is considered economically viable and important.

The land use considerations were mapped in categories that included all possi-ble combinations of the protected lands, coal development areas, and arable lands. These categories are indicated in Table A-VII. Since it would be difficult to map the 26 categories with different symbols, the land use issue has been mapped in terms of suitability (which is of more fundamental interest) on Figure A-7. The suita-bility value is given as a function of the category number and was determined from the suitability function given on Figure 4g.

Issue 8: Foundation Capability

The design and construction of a nuclear powerplant is highly dependent on soil type, depth, and typ  of underlying bedrock. Collectively, these factors form a major site-dependent cost component for a specific plant. However, data describing the engineering properties of soils and the bedrock depth were not immediately avail-able for the subject project. To simulate foundation capability, a general soils map, classified by soil properties based on agricultural considerations, was generalized and entered into the data base. These soil classifications were then correlated (by geographic pattern) to an area geology map to determine general foundation capability. This simulation provides a very generalized measure of foundation capability. How-ever, this measure was assumed to be adequate for comparing site selection method-ologies (the purpose of the subject study).

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The associated geologic descriptions given in Table A-VIII provide a general classification of soil data for the assessment of foundation capability. As with the land use issue, a decision was made to map the issue suitability rather than all 18 categories. The resulting suitability map is given on Figure A-8. The suitability values were determined from the suitability function given on Figure 4h.

Issue 9: Air Traffic Hazards

Air traffic hazards are becoming a significant issue for the siting of nuclear powerplants. The safety analysis report must contain a probability estimate of aircraft penetration of any safety-related structure on the plant site. If the probability is greater than one chance in 1 million per year for such an event, then further analysis or hardening is necessary to prove that the consequences of such an accident could not result in an operation impairment serious enough to produce a significant radioactive emission from the plant. For this reason, nuclear powerplants should be located several miles from any busy air traffic corridor.

To determine air traffic hazard, all air traffic corridors designated as such by the Federal Aviation Administration were mapped. The distance to the nearest corridor was then determined for each potential site location (grid cell). These distances were classified as shown in Table A-IX. The application of these categories to the study area is shown on Figure A-9.

Issue 10: Cooling System Suitability

Cooling system cost has become a major component of total powerplant cost. Increased environmental resistance to the thermal impact of once-through cooling has almost eliminated this relatively inexpensive cooling system. Evaporative cooling (wet) systems are presently being used for most powerplants under construction. Increased conflicting demands for dwindling water supplies in the West have led to the consideration of wet-dry and all dry cooling systems. As a result of these concerns, this report considers a wet-dry cooling system for all sites and concepts.

The relative portions of wet (evaporative) and dry cooling systems are determined for each site by minimizing total cooling costs (capital plus operating) within a fixed water budget. The resulting costs consist of the following three general components:

1. The cost of a wet system itself, including the cost of water (from surface or ground sources), the cost of operating the system, and the cost of power for auxiliary pumping functions;
2. Capital and operating costs of the water transportation and storage systems (over and above the nominal water cost considered in item 1); and
3. Dry system capital and operating costs.

A wet-dry system is optimized according to the following policy. During the hottest months, a major portion of the heat rejection load is carried by the wet system. A dry system is sized to carry the entire heat rejection load at cooler temperatures. 593 039 after the water has been depleted. Even if ample water is available for a wet cooling system, total consumption will be limited so that the overall system uses no more than 48 percent of the total water that would be consumed by a completely evaporative cooling system; the overall system is at least 50 percent dry. Within the constraints of limited water availability, the size (and cost) for both wet and dry cooling systems is determined by the distribution of local peak wet bulk temperature and dry bulk temperature. The resulting cost and performance figures are based upon a recent comprehensive wet-dry cooling system design study performed by United Engineers & Constructors.

The resulting costs range from $150 to over $250 per kW. The greater cost figure reflects very low water availability and high temperatures. For convenience of display, this cost range is divided into the nine categories shown in Table A-X. The application of these categories to the study area is shown on Figure A-10.

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Corresponding Tables and Figures for
the Utah Issue Analysis

(Note that the three blank rectangles in each map are an artifact required for printing city names.)

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TABLE A-I

Seismic Risk Categories

| Category | |
|---|---|
| Zone 1 | 0.05g |
| Zone 2 | 0.10g |
| Zone 3 | 0.20g |
| Zone 4 | Excluded by faults* |

*Includes a 5-mile exclusion zone on both sides of the fault system



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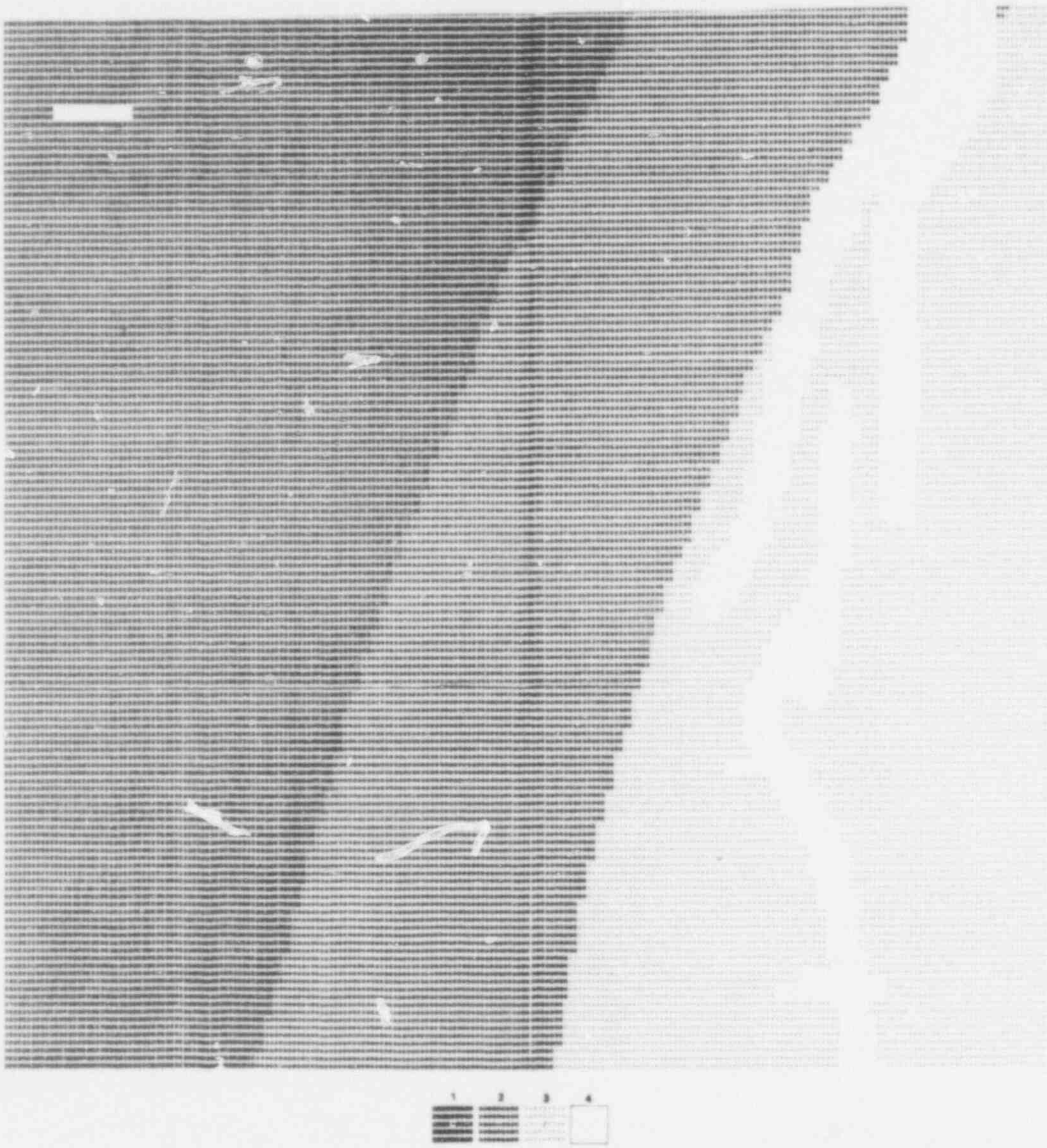


Figure A-1. Seismic Risk

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TABLE A-II

Ecology

| Category | Description |
| --- | --- |
| 1 | No species habitat |
| 2 | Utah prairie dog habitat (rare and endangered) |
| 3 | Other prairie dog habitats |

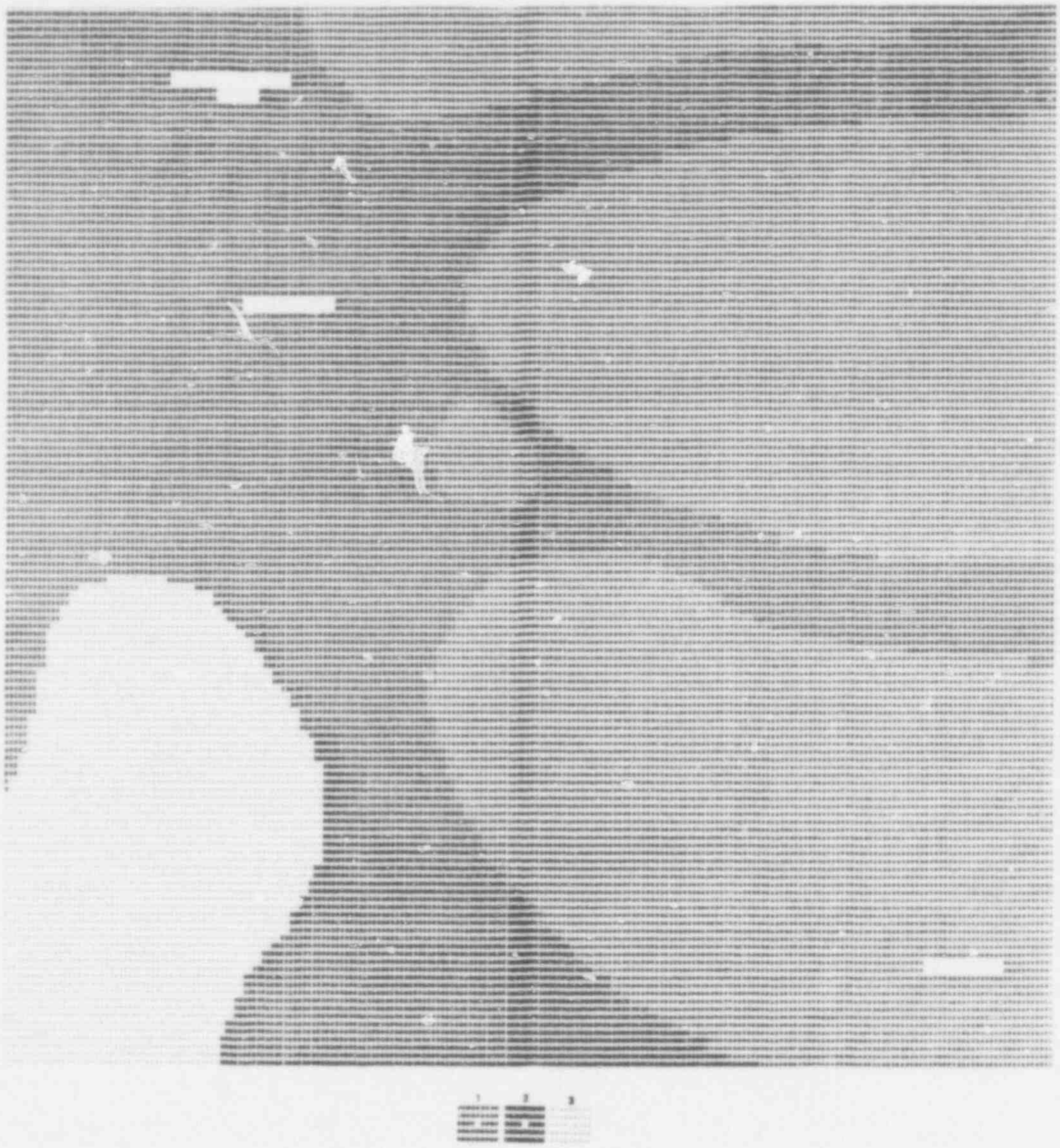

Figure A-2. Ecology

TABLE A-III

Population Density (SPF)

| Category | $SPF_{30}$ |
|---|---|
| 6 | $0.5_{to}$[a]<br>$1.0_{tu}$[b] |
| 5 | $0.71 - 0.99_{tu}$ |
| 4 | $0.51 - 0.70_{tu}$ |
| 3 | $0.41 - 0.50_{tu}$ |
| 2 | $0.21 - 0.40_{tu}$ |
| 1 | $0.0 - 0.20_{tu}$ |

[a] to = time at initial plant operation

[b] tu = maximum SPF during lifetime of the plant

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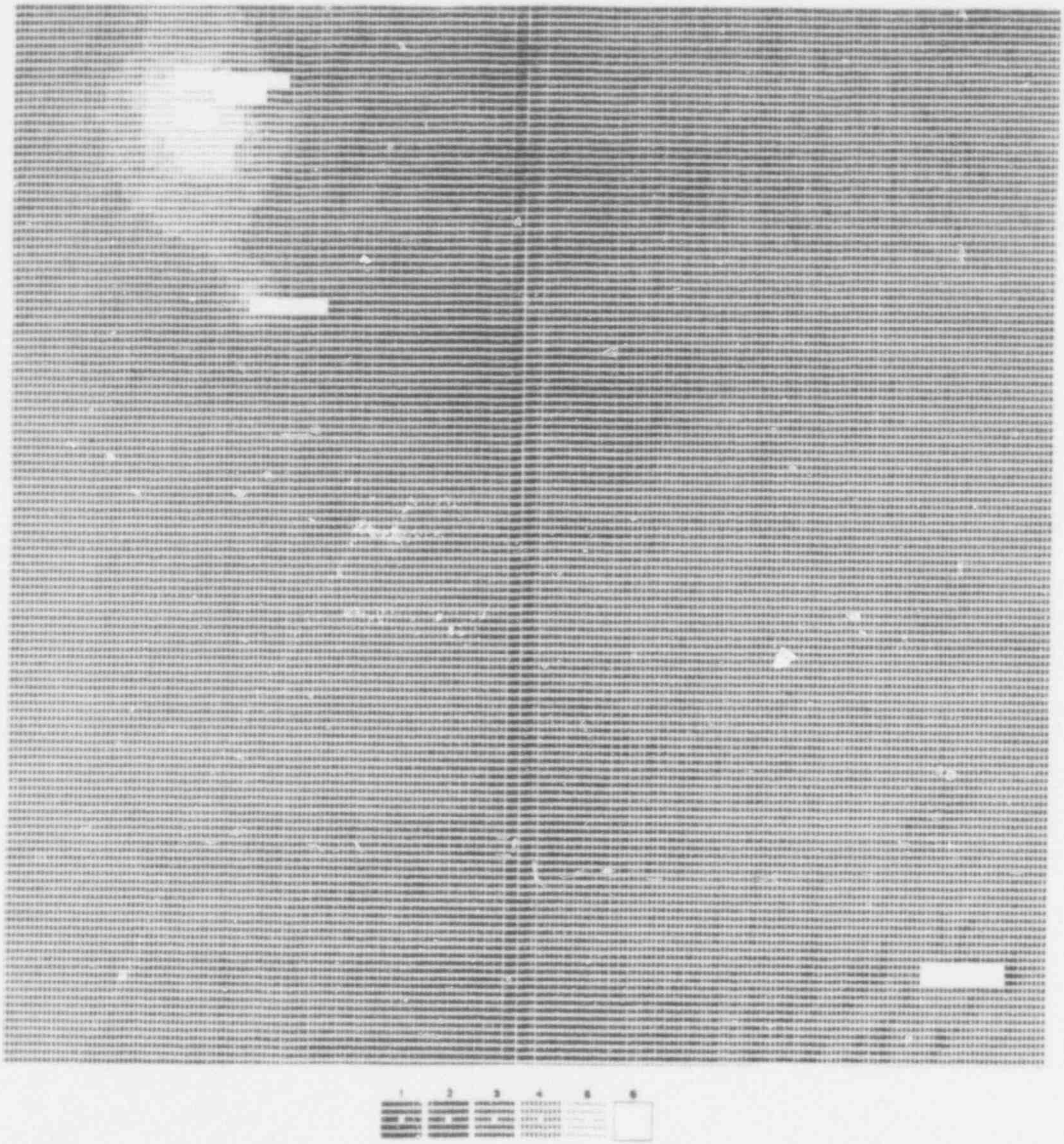

Figure A-3. Population Density

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TABLE A-IV

Transportation Access

| Category | Description |
|---|---|
| 1 | 0 to 10 miles |
| 2 | 10 to 20 miles |
| 3 | 20 to 30 miles |
| 4 | 30 to 40 miles |
| 5 | 40+ miles |

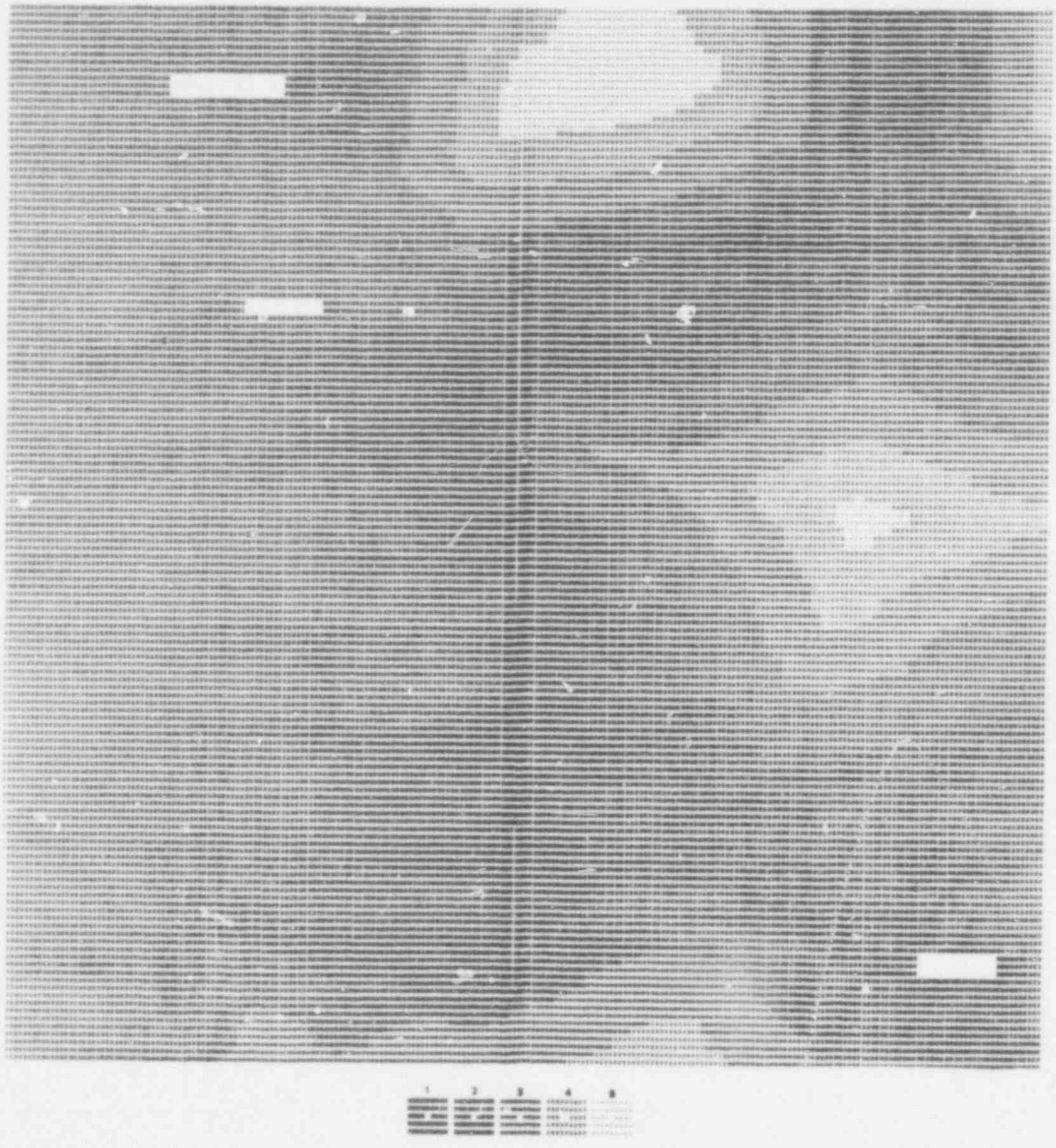

Figure A-4. Major Transportation Access

TABLE A-V

Landform Suitability

| Category | Description |
|---|---|
| 1 | 80 percent gentle |
| 2 | 50 to 80 percent gentle |
| 3 | 20 to 50 percent gentle |
| 4 | 20 percent gentle |


Figure A-5. Landform Suitability

TABLE A-VI

Electric Power Transmission Access

| Category | Description |
|---|---|
| 1 | 0 to 15 units* |
| 2 | 15 to 30 units |
| 3 | 30 to 45 units |
| 4 | 45 to 60 units |
| 5 | 60 to 75 units |
| 6 | 75 to 90 units |
| 7 | 90 to 105 units |
| 8 | 105 to 120 units |
| 9 | 120+ units |

*Units = cells. To convert to equivalent distance: units = cells x 1.5 miles

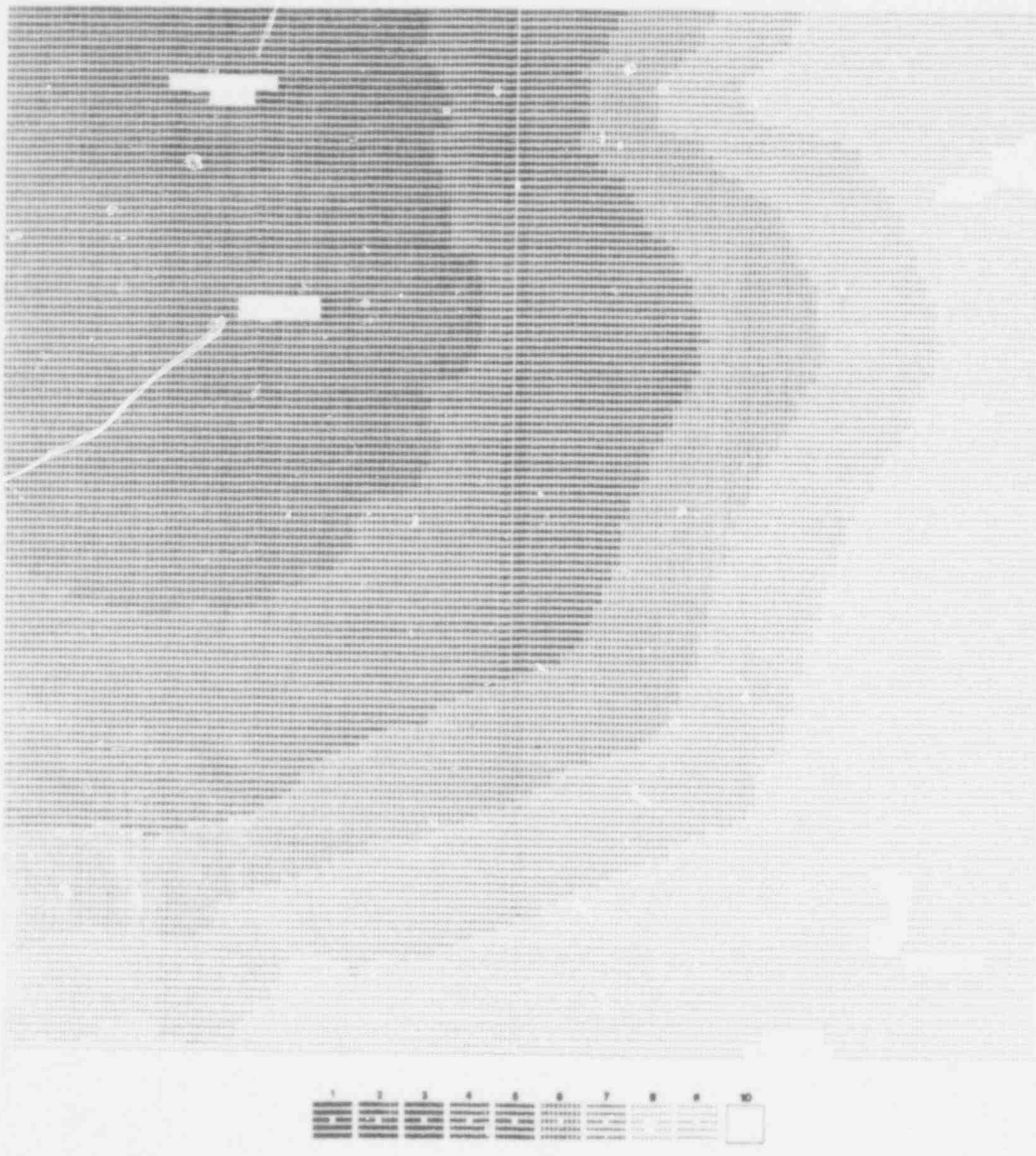


Figure A-6. Transmission Access





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TABLE A-VII

Land Use

| Category | Description |
|---|---|
| 1 | No preserve/protection/arable land |
| 2 | Coal development |
| 3 | National forests |
| 4 | National parks |
| 5 | National monuments |
| 6 | National wilderness areas |
| 7 | Coal development/forests |
| 8 | Coal development/parks |
| 9 | Coal development/monuments |
| 10 | Coal development/wilderness areas |
| 11 | Arable land |
| 12 | No. 2 w/arable |
| 13 | No. 3 w/arable |
| 14 | No. 4 w/arable |
| 15 | No. 5 w/arable |
| 16 | No. 6 w/arable |
| 17 | No. 7 w/arable |
| 18 | No. 8 w/arable |
| 19 | No. 9 w/arable |
| 20 | No. 10 w/arable |


Figure A-7. Land Use Suitability

TABLE A-VIII

Foundation Capability

| Category | Description |
|---|---|
| 1 | Qgm*--glaciated ground/moraines, includes base rock moraines of all types |
| 2 | Tgp/Tgp/Tc --Duchese formation, Parachute Creek formation |
| 3 | Similar to group 2 |
| 4 | The Knight conglomerate |
| 5 | Qzs--alluvial structures, mostly sloping, well drained |
| 6 | Not used |
| 7 | Not used |
| 8 | Kh--Hilliard shale |
| 9 | Pw--Weber formation |
| 10 | Not used |
| 11 | Pcf--Farmington Canyon complex |
| 12 | Qgo--Qgs glacial outwash |
| 13 | Not used |
| 14 | Qk--lakebed sediments |
| 15 | Qks--lakebed sediments, clay with flat surfaces, permanently moist |
| 16 | Tu, Tdr--Duchese formation (fluvial sandstones), Uinta formation |
| 17 | Pcm--Mutual formation (left section playas right) |
| 18 | Water |

*A lithologic classification from geology maps of Utah



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Figure A-8. Foundation Suitab'''ty

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TABLE A-IX

Air Traffic Hazard

| Category | Description |
|---|---|
| 1 | 0.2 miles from corridor |
| 2 | 2 to 5 miles from corridor |
| 3 | 5 to 10 miles from corridor |
| 4 | 11+ miles from corridor |

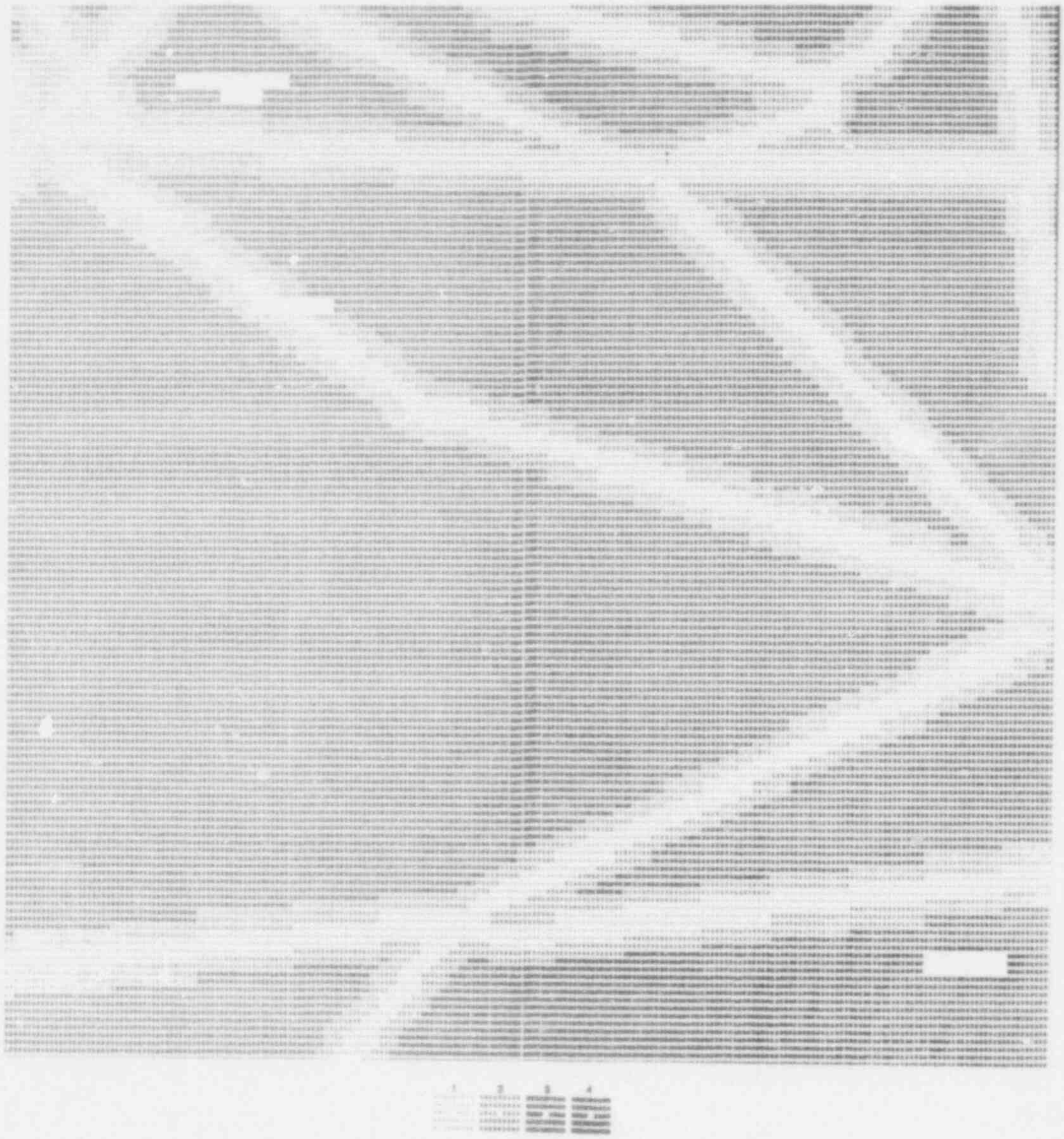


Figure A-9. Air Traffic Hazard

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TABLE A-X

Cooling System Cost

| Category | Cost (dollars/kW) |
| --- | --- |
| 1 | 0 to 155 |
| 2 | 155 to 170 |
| 3 | 170 to 185 |
| 4 | 185 to 200 |
| 5 | 200 to 215 |
| 6 | 215 to 230 |
| 7 | 230 to 245 |
| 8 | 245 to 260 |
| 9 | 260+ |

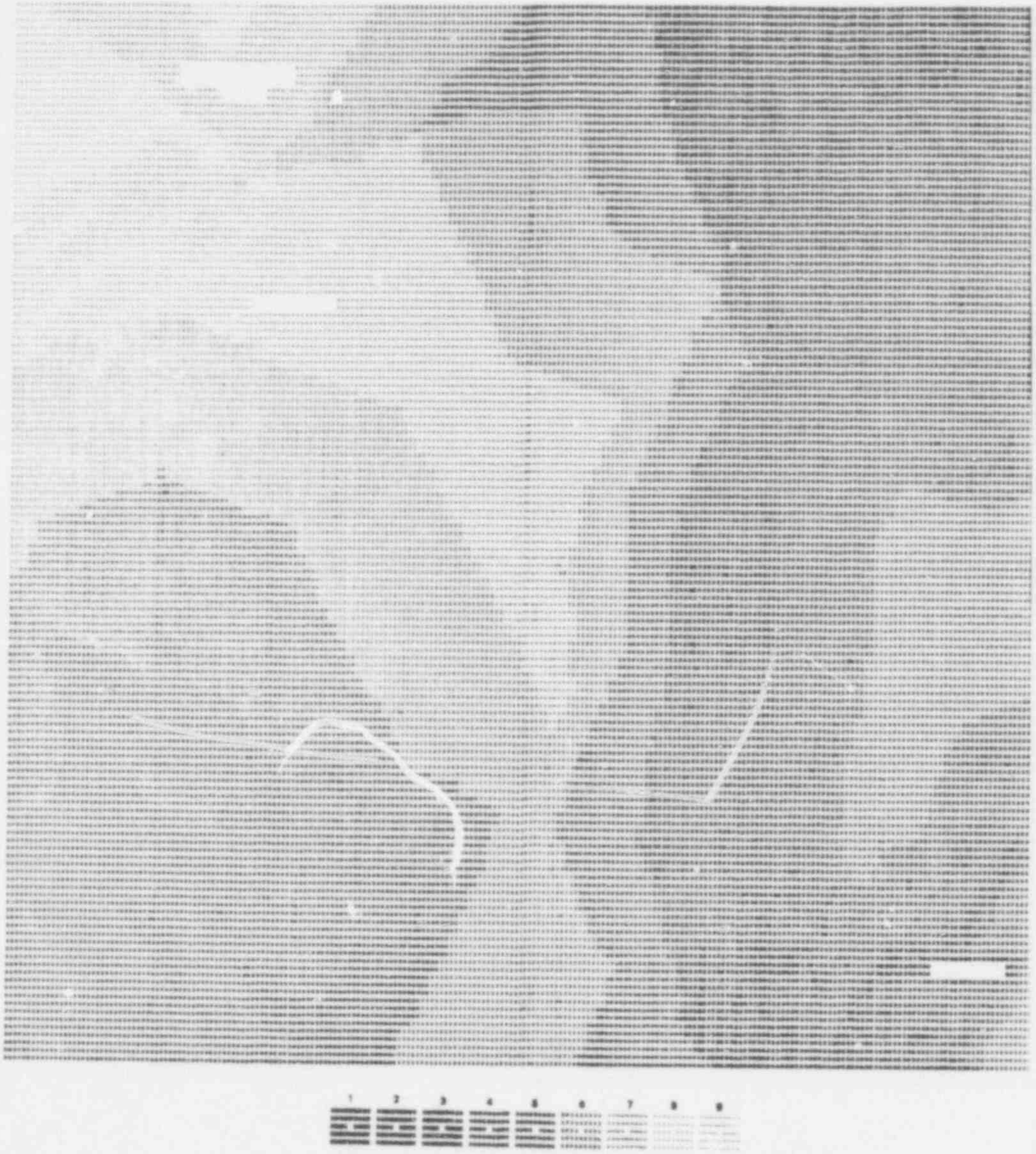

Figure A-10. Cooling Suitability

APPENDIX B

Illinois Issue Analysis

This appendix contains brief descriptions of the individual issues used to evaluate and compare the grid cells within the Illinois study area.

All of the data have been classified in terms of utility on a 0 to 5 scale, as shown in Table B-I.

TABLE B-I Rating Legend (Original)

| Rating | Symbol | Description |
|---|---|---|
| 5 | * | Very favorable |
| 4 | / | Favorable |
| 3 | - | Acceptable |
| 2 | : | Practical but difficult |
| 1 | . | Practical but very difficult |
| 0 | | Unacceptable |

The scales for maps (which were made by a weighted averaging of the utility numbers of two or more data maps) were based on the system shown in Table B-II.

TABLE B-II Rating Legend (Weighted)

| Rating | Symbol | Description |
|---|---|---|
| >4.5 | * | Very favorable |
| >3.5 | / | Favorable |
| >2.5 | - | Acceptable |
| >1.5 | : | Practical but difficult |
| >0.5 | . | Practical but very difficult |
| 0 | | Unacceptable |

This classification scheme provides utility values and map display categories simultaneously. Exclusion screening is accomplished by setting thresholds at category boundaries. Comparison screening is accomplished by a simple weighted averaging of the utility values for each issue.

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POOR ORIGINAL

Issue 1: Power Network Considerations

The first issue map, Power Network Considerations, is shown on Figure B-1. The suitability of each cell is developed as a weighted average (60 percent to 40 percent) of the suitability of the following two primary issues: (1) distance from the Commonwealth Edison load centroid for northern Illinois (Figure B-2) and (2) distance to existing transmission lines (Figure B-3). Actually, site selection would also be influenced by system reliability considerations and the proximity of the site to load centers of neighboring states.

The strongest determining feature is the load centroid south of Chicago. The major portion of the load of this region is in Chicago; however, the transmission distances from the western portion of the study area are not strongly affected by this displacement. In the eastern portion of the study area the distance differences are significant, but they produce little effect on overall suitability because the distances are small.

Issue 2: Cooling Water Availability

The availability of cooling water is a major concern in powerplant siting. Figure B-4 shows the suitability ratings for the proximity-to-major-waterways issue. For an actual siting study, the cell suitability ratings might differ considerably for the following reasons:

1. Future acceptability of the once-through cooling system is uncertain. Emphasis, therefore, is shifting away from major waterways.
2. Smaller waterways and ground water can often be sufficient to meet the makeup water requirements of cooling ponds and cooling towers.
3. The ground water draw-down capabilities of any site in northern Illinois should be able to support a withdrawal of 1.5 cubic feet per second, an amount suitable for the use of dry cooling towers.

For the purposes of this analysis, however, proximity to major waterways will be used as an issue map.

Issue 3: Population Density

The population distribution data for northern Illinois were obtained from the 1960 census. All urban populations other than the city of Chicago were increased by 10 percent. For an actual siting study, more recent population data would be required and additional information would be needed to investigate the implications of future population distributions. Figure B-5 shows the suitability ratings for the average population density (persons per 4 $km^2$, which corresponds to the cell size) within a 78-km radius. Since the border data only provide for a 30-km radius, the population density values are calculated using a smaller radius for those cells near the study area boundary. Any cell which had a population density greater than 770 persons per 4 $km^2$ (averaged over any radial distance out to 78 km) was considered unacceptable. The conservatism of the large radius results in the exclusion of a large region around Chicago.

Issue 4: Land Use

Existing land use is a very important factor in selecting a site for a powerplant, in terms of both cost and environmental impact. Figure B-6 depicts the suitability rating for the present land use in northern Illinois. Wasteland was rated as a very favorable location for a site. Small airports were rated as practical but difficult to use for potential sites. Urban areas, public conservation and historical areas, mine areas, and major airports were excluded. All other areas were rated as acceptable. Obviously, a more detailed assessment would need to be made for the candidate site analysis phase.

Issue 5: Foundation Suitability

The foundation suitability of a particular cell was based on two factors. Data on distance to bedrock (Figure B-7) and information on moraine geology (classification scheme in Table B-II and application to study area in Figure B-8) were combined to determine the foundation suitability rating for the cell. These ratings are shown on Figure B-9.

TABLE B-III

Moraine Geology, Northern Illinois

| Category | Suitability Rating |
|---|---|
| Woodfordian, moraine<br>Illinoian, moraine & ridged drift front of moraine system | 5 |
| Driftless, loess | 4 |
| Holocene & Wisconsonian, alluvium, dunes & gravel terraces | 3 |
| Woodfordian, ground moraine<br>Altonian, till plain<br>Illinoian, ground moraine<br>Kansan, till plain | 2 |
| Wisconsonian, lake deposits | 1 |

Issue 6: Accessibility

The suitability of sites based on the availability of transportation routes and their proximity to the sites is depicted on Figure B-10. Transportation routes were defined as railroad lines (Figure B-11), major highways (Figure B-12) and major waterways (Figure B-4). A systematic study to determine the navigability of the waterways on Figure B-4 was not performed; therefore, some indications of transportation suitability may not be realistic. For example, the two lakes in the southwestern region of the study area would not be useful for transportation purposes.

Issue 7: Tornado Frequency

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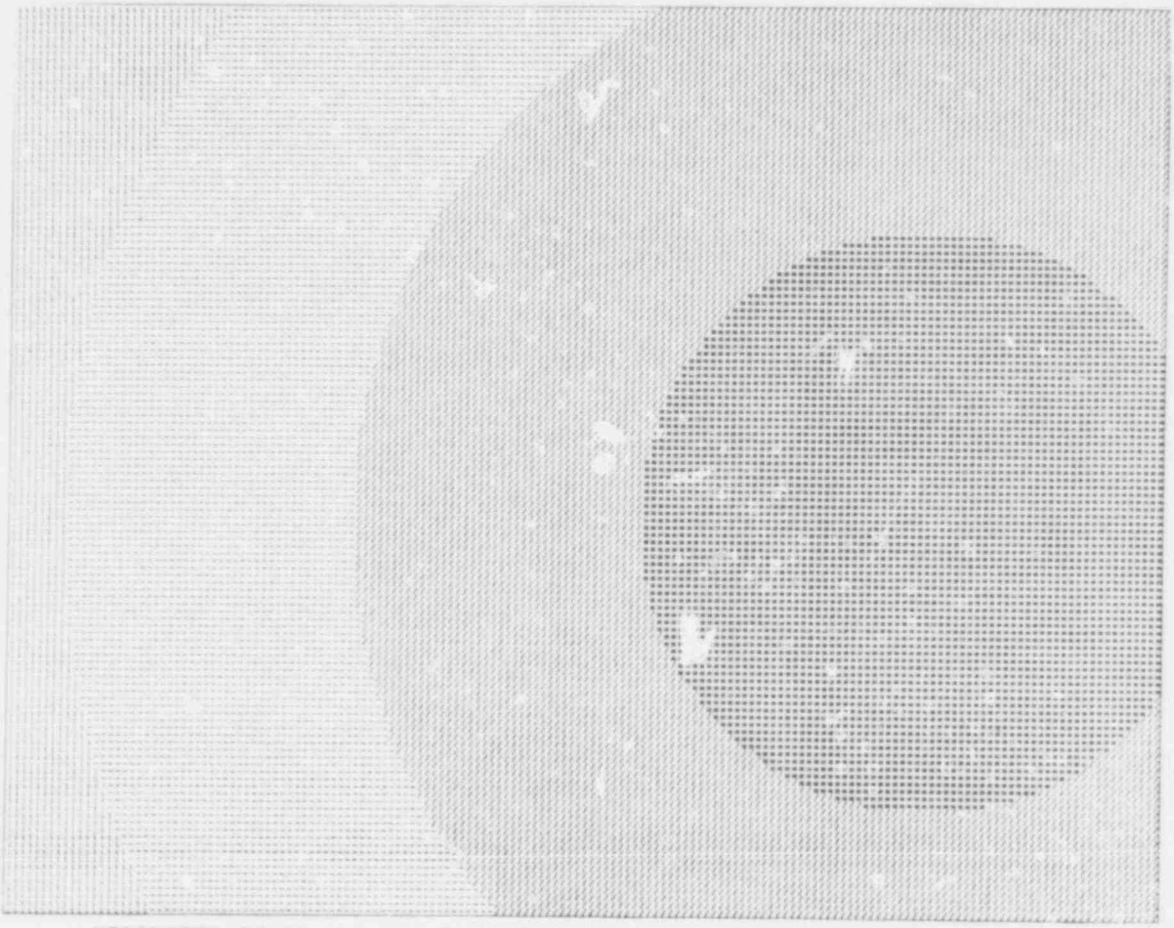
Figure B-13 shows the tornado frequency in northern Illinois. Although all powerplants in northern Illinois would probably have to meet the same tornado design requirements, the suitability ratings for the cells based on tornado frequency were included for illustration purposes.

Further information on the northern Illinois data base is contained in References 14 and 24.

Figures for the Illinois Issue Analysis

Figure B-1. Power Network Considerations: Corridors Approximately 40 Percent and Load Center Approximately 60 Percent



KILOMETER SCALE: * < 80 / < 160 - < 240 : < 320 . ≥ 320

Figure B-2. Proximity to Load Center

POOR ORIGINAL



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KILOMETER SCALE: * ≤ 5 / ≤ 15 - ≤ 25 : ≤ 50 . > 50

Figure B-3. Proximity to Major Transmission Lines in Northern Illinois

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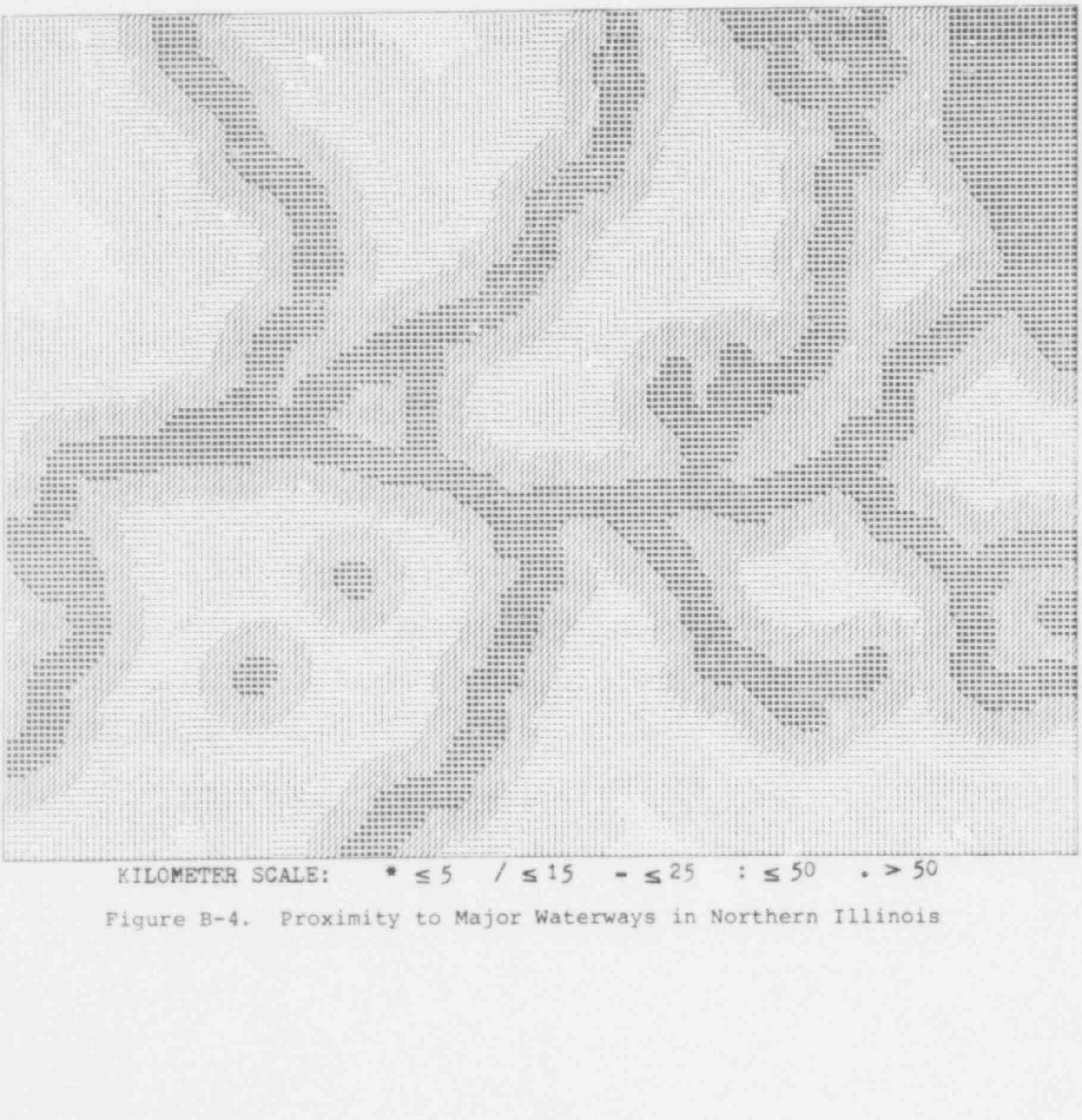

KILOMETER SCALE: * ≤ 5 / ≤ 15 - ≤ 25 : ≤ 50 . > 50

Figure B-4. Proximity to Major Waterways in Northern Illinois

POOR ORIGINAL

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SCALE: * ≥ 75 / ≥ 150 - ≥ 300 : ≥ 500 . ≥ 770
BLANKS DENOTE > 770 PER CELL WITHIN < 78 KM

Figure B-5. Population Density Within a 78-km Radius

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Figure B-6. Land Usage in Northern Illinois

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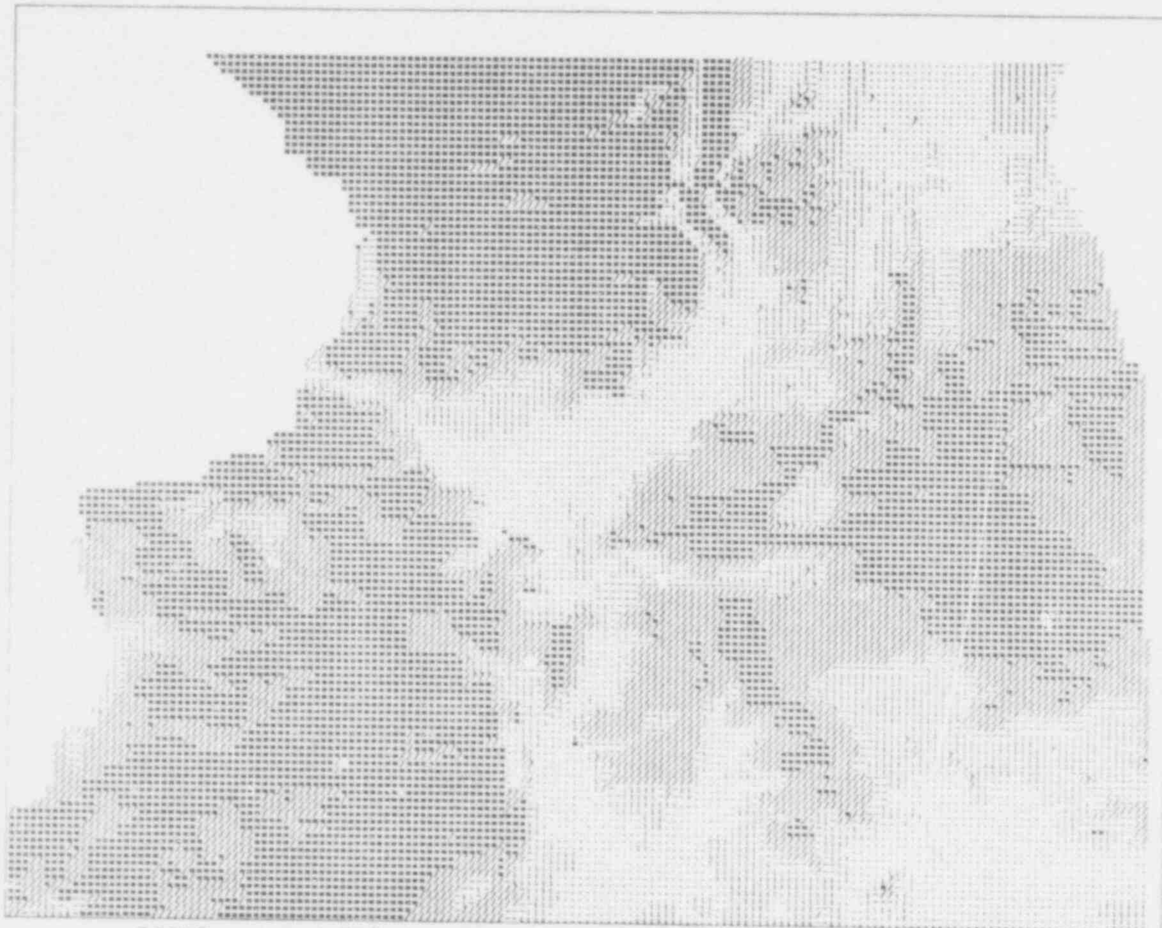

SCALE: * ≤ 50' / ≤ 100' - ≤ 150' : ≤ 200' . > 200'

Figure B-7. Distance to Bedrock

Figure B-8. Moraine Geology--Northern Illinois

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POOR ORIGINAL

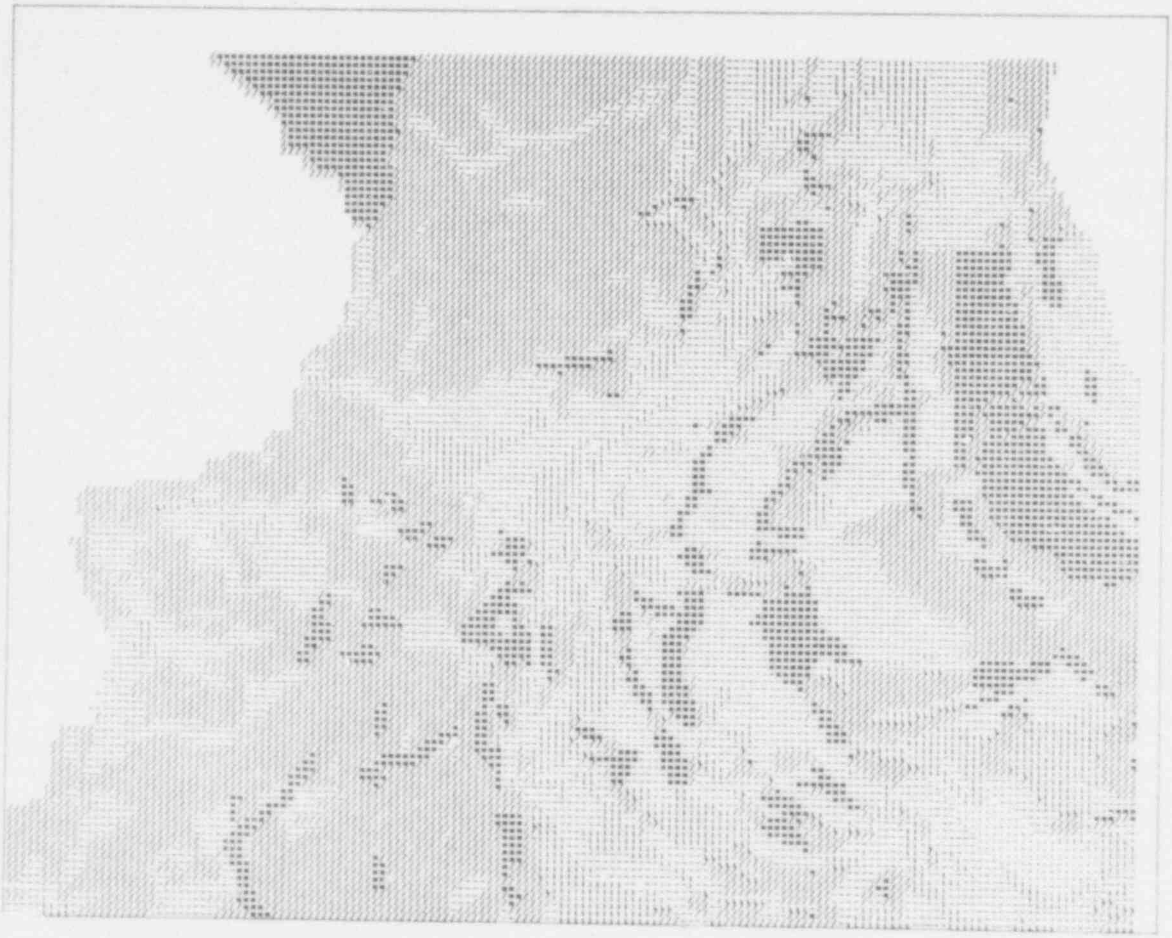

Figure B-9. Foundation Suitability: Bedrock Distance and Moraine Geology 50/50



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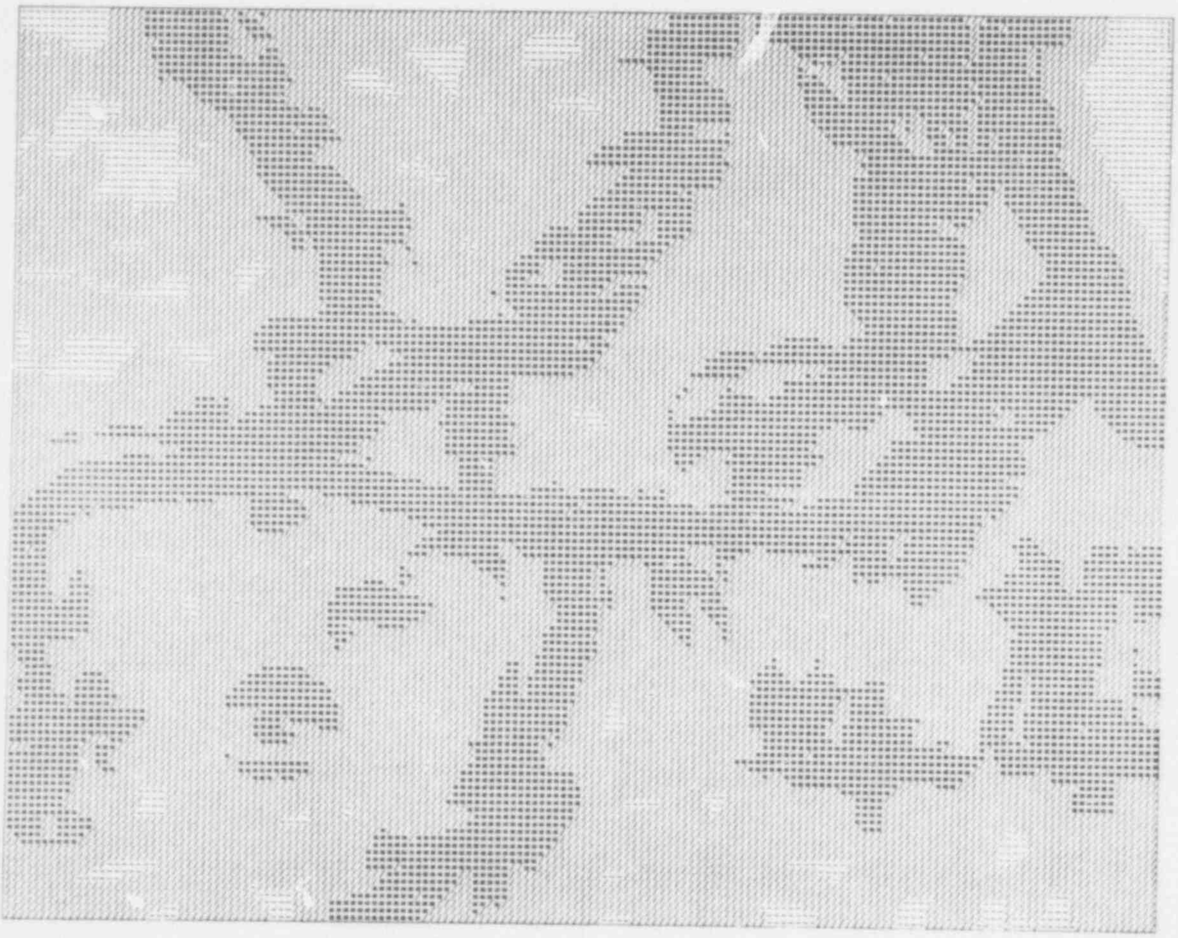
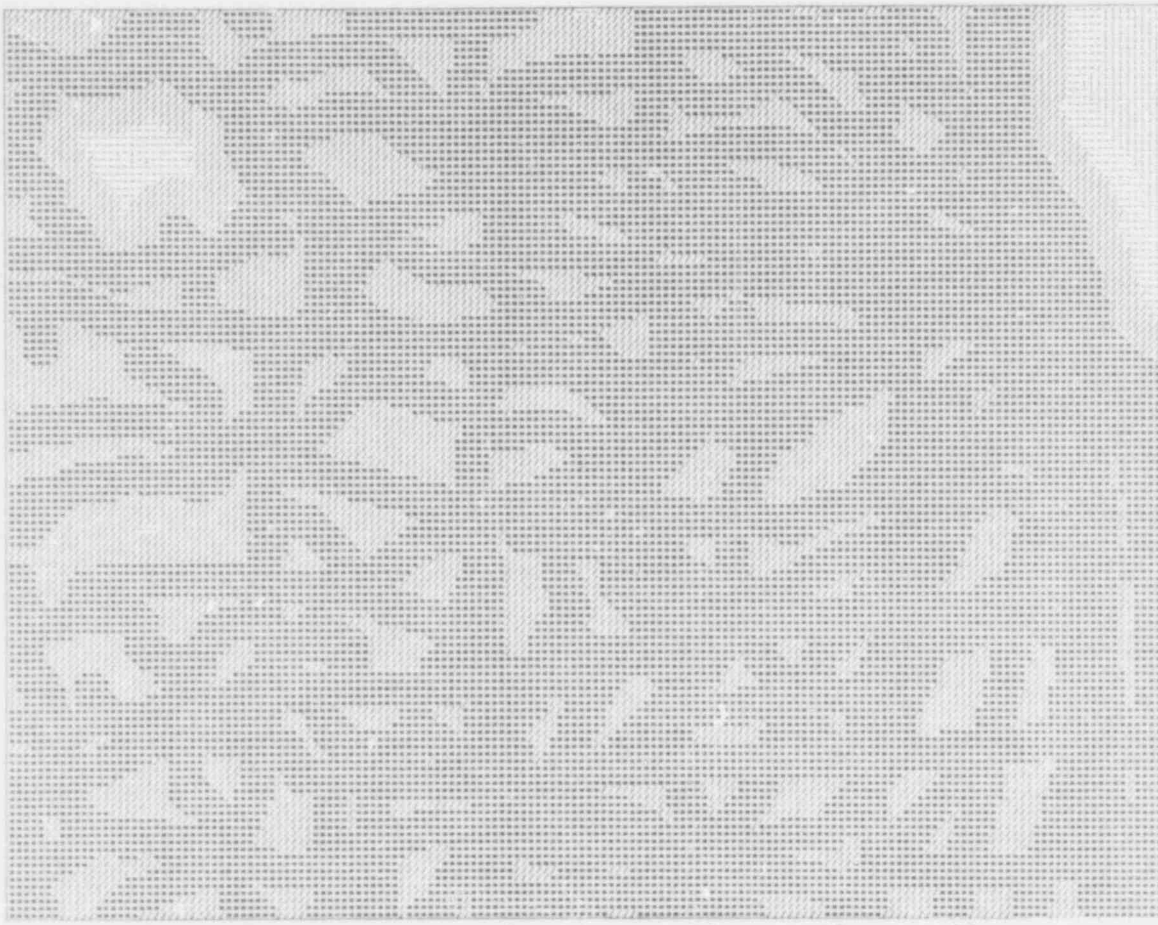


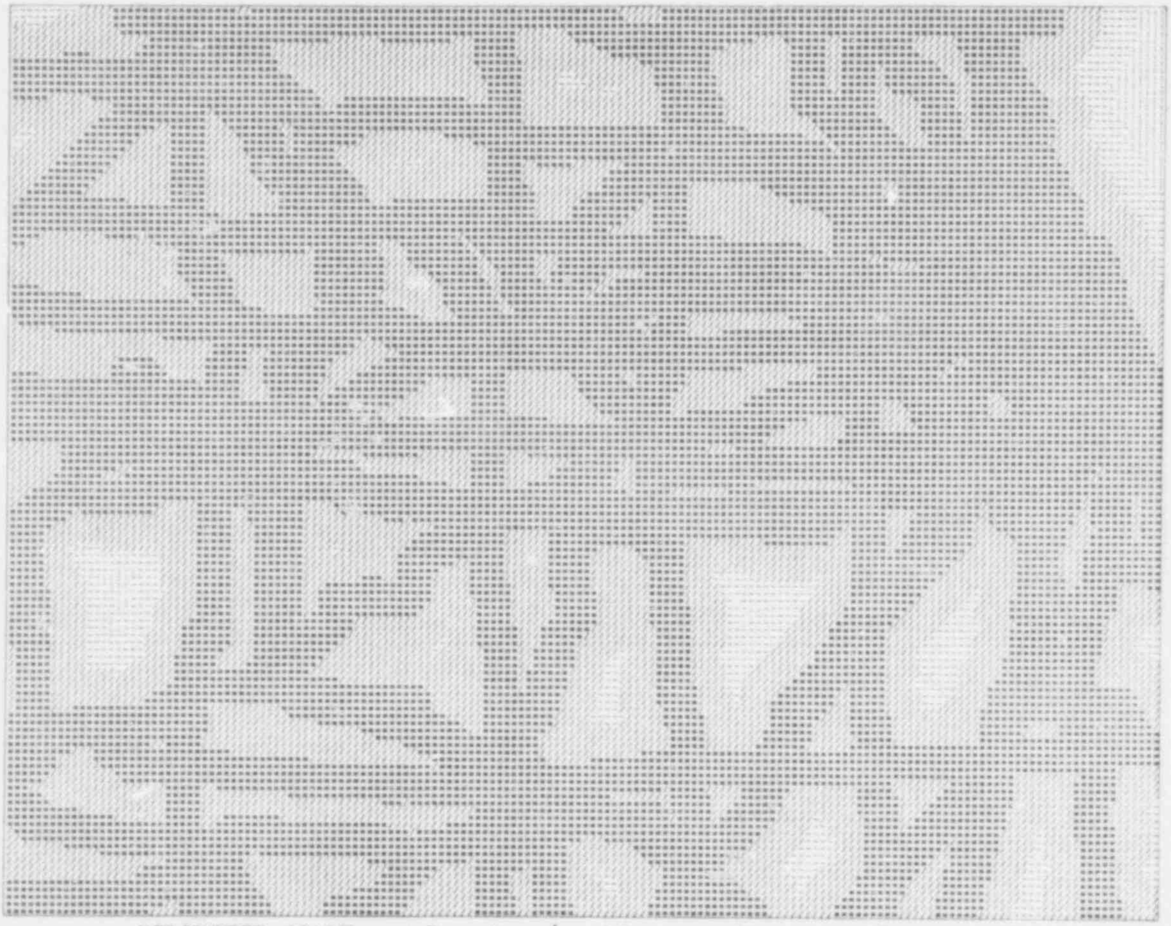
Figure B-10. Transportation Accessibility: Railroads Approximately 40 Percent, Highways Approximately 35 Percent, and Waterways Approximately 25 Percent

593 076



KILOMETER SCALE: * ≤ 5 / ≤ 15 - ≤ 25 : ≤ 50 . > 50

Figure B-11. Proximity to Railroads in Northern Illinois



KILOMETER SCALE: * ≤ 5 / ≤ 15 - ≤ 25 : ≤ 50 . > 50

Figure B-12 Proximity to Major Highways in Northern Illinois

593 078

NUMBER / 25 YRS / 100 SQ MI: * = 1 / = 2 - = 3 : = 4 . ≥ 5

Figure B-13. Tornado Frequency in Northern Illinois

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