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GEOGRAPHIC IMPLICATIONS OF PUBLIC POLICY: THE SITING OF NOXIOUS FACILITIES

DISSERTATION

Presented in Partial Fulfillment of the Requirements For the Degree Doctor of Philosophy in the Graduate School of The Ohio State University

By

Benjamin Gaylord Maiden, B.S., M.S.

* * * * *

The Ohio State University
1986

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To Jan
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CHAPTER I

STATEMENT OF RESEARCH PROBLEM AND OBJECTIVES

Statement of Research Problem

This dissertation study focuses on a contemporary location problem with significant long-term social welfare implications—the location of noxious public facilities. Specifically, the research problem is to examine the applicability of historical and contemporary location theory to the location of public facilities designed to handle the waste products of industrial activity. This examination will include a review of the key location questions in siting noxious public facilities; an evaluation of the influences that shape both the key location questions and the answers to those questions; and an assessment of the applicability of geographic thought and location theory to the spatial distribution of noxious public facilities. Where theory is found to be deficient in providing explanatory power, suggestions concerning how location theory might be augmented, refined, or redefined to address the noxious public facility location problem will be made.
Classical industrial location theory has focused attention primarily on private sector location decisions. Principal motivating forces for private sector location decisions have included profit maximization, revenue maximization, and cost minimization. Theorists, such as Weber, concentrated on such location factors as transportation costs, labor costs, the price of raw materials, the cost of capital, and proximity to markets in constructing theory designed to provide explanatory power in addressing the spatial distribution of industry. ¹ Such theory has relied primarily on classical economic theory to explain industrial location.

It is recognized, however, that there are significant differences in the character of public and private location decisions. The public sector location decision is typically driven by the desire to maximize the ability to provide a specific service rather than to maximize an economic objective, such as profitability. Secondary objectives in public facility location often include performing the desired service in a manner that minimizes negative environmental consequences or public disruption. Economic forces, such as minimizing the costs of facility development, are accounted for, but are often of tertiary significance. In addition, while public policy also may have some influence on the location of private sector facilities, such policy has a direct and substantial influence on the location of public
facilities. This is particularly the case where the public facility handles the waste products of our industrial society, what the economists term "externalities". In these instances, the spatial distribution of costs and benefits is such that a focused location is chosen to bear the costs (including health and safety risks, environmental impact, social disruption, etc.) so that a society-wide problem may be solved. Thus, the costs are often spatially focused and the benefits spatially diffused. The research reported by this study examines the differences between the private sector and the public sector location problem as they affect the formulation of theory that applies to the location of noxious public facilities, such as the siting of geologic repositories for high-level nuclear waste.

Statement of Research Objectives

This study was designed to achieve three primary objectives:

1) To summarize the location issues associated with the location of noxious public facilities, specifically the siting of geologic repositories for high-level nuclear waste,

2) To review the applicability of geographic thought and specific location theory to the noxious public facility location problem,
3) To extend location theory to explain more effectively the considerations in the location of noxious public facilities in space.

Each of these objectives is more fully discussed in the paragraphs that follow.

In examining the location issues important to siting noxious public facilities, the role of economic rationality is addressed, including a comparison of the roles of economic rationality in public and private sector location decisions. In addition, the role of non-economic issues is explored. Such non-economic issues have been a primary interest of behavioral research in geography, and include process-related considerations. The influence of what Cox has called "authority constraints" is assessed by examining a host of regulatory, institutional, and political factors. Other non-economic factors studied include health and safety, environmental, socioeconomic, and transportation considerations.

This summary of noxious public facility location issues provides the backdrop for the examination of the ability of location theory to accommodate such issues in explaining the spatial distribution of such facilities.

The second objective is to review the legacy of geographic thought, particularly location theory, and its applicability to the noxious public facility siting problem. In doing so, the various traditions of the discipline of geography are examined.
Specifically, the man-land tradition, the areal differentiation tradition, the spatial tradition, and the behavioral tradition are reviewed to extract geographic concepts, insights, and theories potentially applicable to the noxious public facility location problem. For each potentially applicable location theory evaluated, a series of key questions are asked and answered, as follows:

1) How does the theory structure the location problem? What are the theory's basic hypotheses? What are its fundamental assumptions?

2) Is the theory's structure useful in explaining the noxious public facility location problem? If so, how so? How is it not useful?

3) How is the theory operationalized?

4) What conclusions are drawn from operationalizing the theory? Are they valid and/or logically consistent?

5) Where is the theory useful in its explanatory power? Where is it deficient?

6) How might the theory be augmented or revised to better explain the noxious public facility siting problem?

The final research objective is to augment or refine location theory in order to enhance its ability to explain the location in space of noxious public facilities. This objective is the logical outgrowth of the previous two research objectives. The applicable elements of the location theories reviewed are utilized, along with extensions of previously developed theory and the formulation of new
theoretical concepts to develop a theory of noxious public facility location. In addition, research topics that warrant further research are identified in the hope that further research will extend the theory of public facility location in new and productive directions.

Overview of Subsequent Chapters

An inductive approach is taken in the conduct of this research. Inductive reasoning is characterized by the following five basic steps:

1) Gather a series of relevant but unordered facts,
2) Define key terms, measure/evaluate the facts, and classify the results,
3) Develop a set of ordered facts,
4) Develop one or more inductive generalizations (intermediate level location statements),
5) Construct or refine theory (in this case, enhance the explanatory power of location theory).

Primary inputs to this inductive approach to location theory development were derived from the study of the siting of a permanent geologic repository for high-level nuclear waste in crystalline rock formations. A high-level nuclear waste repository certainly fits within the class of public facilities designed to handle noxious waste, in this case waste from commercial nuclear reactors and
defense wastes from across the United States. The examination of key location influences and specific location factors in repository siting provided the unordered facts to start the inductive reasoning process. The development and application of a multi-state regional screening methodology provided the productive focus for defining important terms, for measuring key location factors, and for classifying regional screening decision inputs.* From the set of "ordered facts" or screening results derived from the application of this methodology, it was possible to develop a series of inductive generalizations regarding the location of noxious public facilities. These inductive generalizations, when coupled with the review and analysis of historical and contemporary location theory, resulted in the theoretical contributions documented herein.

The paragraphs that follow briefly outline the scope of each of the following chapters. Chapter II surveys relevant geographic literature by examining the traditions in geographic thought and several specific location theories. The intent of the chapter is to evaluate critically the applicability of the man-land, areal differentiation, spatial, and behavioral views in geography with an

* This multi-state regional screening methodology was developed under the researcher's direction at Battelle Memorial Institute subject to the terms of a contract with the U.S. Department of Energy to help direct the Department's effort on the Crystalline Repository Project, a project searching for the nation's second repository. This methodology is used as an example of a functional model of the noxious public facility location problem.
emphasis on the location problem posed by noxious public facilities. It provides the point of departure for the subsequent discussion of the augmentation or refinement of location theory to accommodate the noxious public facility location problem.

Chapter III introduces the specific location problem associated with the siting of geologic repositories for high-level nuclear waste. It describes the concept of geologic disposal, characterizes repository surface and underground facilities, and reviews the spatial distribution of suitable rock formations and the waste itself. Finally, it reviews the technical location factors that must be addressed in repository location decisions. These factors include health and safety, environmental, socioeconomic, transportation, and ease and cost of construction, operation, and closure.

Chapter IV looks at three types of authority constraints outlined in public policy that govern the location of geologic repositories. These three types of authority constraints are: 1) regulatory constraints, 2) institutional constraints, and 3) political constraints. The objective of this chapter is not a comprehensive review of regulations, institutional arrangements, and political considerations. Instead, it is an examination of each set
of authority constraints with a focus on how these constraints might be incorporated into inductive generalization, and ultimately into location theory.

Chapter V examines the experience of the development and application of the Crystalline Repository Project's regional screening methodology. The major influences on methodology development are described, including the influence of both technical location factors and authority constraints. The significance of value systems to the siting process is described, along with an approach for geographically capturing the implications of alternative values in site location. The focus throughout this chapter is the development of inductive generalizations that, in turn, provide inputs to theory building.

The final chapter outlines the implications of the previous chapters for location theory as applied to the spatial distribution of noxious public facilities. This chapter seeks to extend existing theory, to modify certain theoretical principles, and to formulate new theoretical concepts that enhance the explanatory power of location theory as applied to public facilities. It also suggests specific topics believed to warrant additional research related to public facility location theory and practice.
CHAPTER I REFERENCES


CHAPTER II

GEOGRAPHIC THOUGHT AND LOCATION THEORY:
A CRITICAL REVIEW AND EVALUATION

Chapter Overview

This chapter considers the applicability of geographic thought, and particularly location theory, to the noxious public facility siting problem. First, the legacy of geographic thought represented by the four twentieth century traditions in geography is reviewed. Specifically, the man-land tradition, the areal differentiation tradition, the spatial tradition, and the behavioral tradition are examined by drawing upon the writings of major geographers. In each case, the focus is on the relevancy of the tradition's concepts and theories to the siting of noxious public facilities. Given the pluralism of views in geography today, it is appropriate in the search to extend the applicability of location theory to noxious public facility location, that each major geographic
tradition be examined for its ability to provide a partial foundation for that effort.

In the second major section, the chapter outlines a comparative analysis of private versus public sector location problems. In doing so, key motivating forces are discussed, compared, and contrasted. The issue of optimizing versus satisficing in structuring the private and the public sector location problem is reviewed. Finally, a comprehensive survey of location factors and their respective applicability to private and public sector location problems is undertaken.

The third major section includes a review of the location theory literature. Both classical and neoclassical theory is examined. In addition, classical and contemporary tools, techniques, and models are summarized, including operations research applications, input-output applications, and multiobjective systems analysis techniques. The section ends with a discussion of the noxious facility siting problem, and the extent to which the location theory literature addresses those issues that are most important to successfully predicting the spatial location of such facilities.

It should be noted that throughout the chapter an attempt is made to characterize relevant geographic concepts and theory; to
discuss the operationalization or application of the theory; to evaluate the applicability of theoretical conclusions to the noxious public facility location problem; and to identify areas where location theory may need to be modified, extended, or reformulated to address this specific location problem.

Review of Major Geographic Traditions

The heritage of geographic thought since the turn of the century has included several major traditions that warrant examination in this study of the noxious public facility location problem. The man-land tradition dominated geographic thought from the founding of the American Association of Geographers until well into the 1920's. The area studies or areal differentiation tradition emerged in the late 1920's and dominated geographic thought through the 1940's. The spatial tradition gradually emerged out of the 1950's and prevailed during the 1960's with its emphasis upon scientific research methodologies, hypothesis testing, the use of mathematical models, and attempts to develop theory. The behavioral tradition also emerged in the 1960's. This tradition cuts across all of the other views of the discipline, but it has been particularly significant in stimulating a man-land/ecological view revival from the late 1960's through the 1970's.
While there has been an historical tendency to reject the other traditions of geography as each tradition (except the behavioral) enjoyed a period of dominance in the discipline, remnants of each tradition have influenced, and continue to influence, location studies. In fact, contemporary geography is perhaps best characterized by what Taaffe has termed "a cautious and pragmatic pluralism." The pages that follow look at this pluralistic legacy for concepts and theories relevant to noxious public facility siting.

The Man-Land Tradition

Early in this century the man-land view was the prevailing force in geographic thought. William Morris Davis, a physical geographer, was a major influence with his theory of "environmental determinism." Davis' focus was on physical process relationships between physiography (inorganic control) and ontography (organic response). Spatial distribution was relatively unimportant to Davis with his focus on the environment's controlling influence on man.

Ellen Churchill Semple was another prominent environmental determinist. Semple concentrated on the indirect effects of the environment, particularly remoteness and accessibility, as major environmental determinants of man's activities. She did not
ignore the effects of man on the environment, but emphasized environmental influences on man in her work on how the physical environment controlled man and his settlement of America.

Within the man-land view, however, environmental determinism was not without its detractors. Principal among them was Harlan Barrows, who attacked environmental determinism on the basis of the strength of the cause-effect relationship between inorganic controls and organic response. Barrows emphasized man's adjustment to the environment and ability to influence it, rather than being largely subject to its control. His definition of "environment" was broadened to include both physical and biological components, but interestingly, did not include man's cultural artifacts or institutions, or man himself. Barrows was also more concerned about spatial relationships in his work. His research was largely inductive in nature, consisting of the following steps he suggested as useful for geographers: 1) description, 2) analysis, 3) classification, and 4) interpretation.

There are some aspects of the man-land tradition that are relevant to the noxious public facility location problem. There are physical and environmental location factors (e.g., presence of certain rock types, faults, hydrologic conditions, threatened and endangered species) that have a direct affect upon the spatial
location of noxious facilities. However, environmental determinism in its pure form oversimplifies the problem by ignoring regulatory, institutional, socioeconomic, and political influences in the location of such facilities. Thus, even Barrow's definition of "environment" is too narrow to accommodate the major influences on such location decisions. In addition, man's ability to avoid and/or mitigate the effects of environmental influences through the application of technology is dramatically enhanced from the days of Davis, Semple, and Barrows.

The Areal Differentiation Tradition

The tradition of areal differentiation in geography developed, in part, as a reaction to environmental determinism and the man-land tradition. One key element of the areal differentiation view with applicability to contemporary location problems is the emphasis on integration or synthesis in geography. Fenneman, for example, stressed the need for the study of regions in their entirety, and viewed geography as an areal synthesizing discipline. Sauer also focused on synthesis in geography with his "landscape as the unit concept of geography." By "landscape" Sauer included both physical and cultural features. He emphasized the visible over the functional or behavioral. However, there was a heavy emphasis on mapping in Sauer's work.
James viewed the region as an "intellectual concept" that was designed for purposes of thought and customized to address the problem at hand in terms of the definition of relevant variables. This concept is applicable, along with his suggested "topical approach" to geographic study, when considering the variability in relevant location factors depending, in part, on the type of facility being sited. While recognizing complexity, it is less useful in the quest for extensions of location theory, however.

Richard Hartshorne was another principal actor in the areal differentiation tradition. In fact, he introduced the term "areal differentiation." He also emphasized synthesis and the study of complex interrelationships in geographic analysis. He strongly opposed the human-natural dualism of environmental determinism by arguing that man and nature are inseparable factors, with cultural or man-related activities commonly being causal. Hartshorne called for the development of new conceptual approaches and ways of measuring geographic interrelationships. Even though progress has been made in both areas, his call is still relevant to the challenges faced in locating noxious public facilities.

The areal differentiation tradition broadened the scope of geographic study beyond that of the man-land tradition to include cultural, technological, and functional relationships. This
broadened scope is consonant with the circumstances faced by location specialists today. In addition, the call for meaningful synthesis in geographic research, using cartographic techniques (among others), has directly influenced the development and application of location theory.

The Spatial Tradition

The emergence of the spatial tradition in geography was prompted, at least in part, by critical reactions to the man-land and areal differentiation traditions. The first strong programmatic statement of the spatial view was articulated by Schaefer. Schaefer criticized the areal studies proponents by arguing that geographers do not "synthesize" any more than is done in other disciplines. He contended that what was important in scientific inquiry is not individual facts, but rather the patterns they exhibit. Schaefer argued that the pattern-producing variables in geography are spatial. He also described the need for cumulative generalizations, theory building, and laws in geography, a hallmark of the spatial tradition. He categorized geographic laws as follows:

1) laws of physical geography - "specializations of laws independently established in the physical sciences"

2) laws of economic geography - "a whole group of deductively connected generalizations of general location"
3) process laws involving spatial variables – "systematic science."

He held that mature social science looked for process laws, and that should be the goal of geography. The above hierarchy of laws is useful in contemplating location theory relative to noxious public facilities because of linkages to each category.

Robert Platt contended that the physical environment was only one factor useful in providing spatial explanation, along with historical, cultural, and economic factors. Platt also differed from Barrows in holding that environmental factors did not give a topic geographic quality. His work was more complex in scope, including cultural and technological influences, and more spatial in character with his definition of geography as "the science of space occupied by man." Platt's functional region concept emphasized complex linkages (e.g., transportation flow maps) that included both visible features and functional activities with geographic expression. This concept is applicable to the complex world of noxious public facilities siting today, as is Platt's emphasis on field mapping of natural and cultural geographic variables.

In 1965, the National Academy of Sciences published The Science of Geography which took a strongly spatial view in defining the organizing concept of geography as "spatial distributions and space
relations. This organizing concept permeated the definitions of the major clusters of geographic research interest: 1) physical geography, 2) cultural geography, 3) political geography, and 4) location theory. It is not coincidental that location theory is the only category with "theory" in the title, because it was this research area where much of the theoretical-deductive work in the discipline was undertaken. It is important to note that another key element of the spatial tradition is the emphasis on theory development, often through the use of mathematical techniques.

King is a prominent name in the spatial tradition. He voiced a concern about the "geometric sterility" of some spatial work. King said that "a challenge for geography is to combine this interest in geometrics with the work on human behavior over space and to develop process theories from which spatial patterns can be deduced." This concern over the relevancy of "process" is applicable to the noxious public facility location problem. King has also been a critic of elegant but useless mathematical applications in geography. He contended that "we should lower our mathematical sights and aim at the target of operationally useful models rather than at that of formally providing existing theorems and the like." This concern must also be kept in mind as refinements to location theory to address the noxious public facility problem are contemplated. Finally, King was a critic of
the static character of neoclassical economic theory as a foundation for location theory.\textsuperscript{15}

The spatial tradition in geography has had considerable interaction with "regional science" over the last 35 years. People such as Walter Isard have contributed substantially to the development of quantitative methods and have had a significant influence on location analysis and location theory in geography.\textsuperscript{16} Britton Harris has been critical of regional science research.\textsuperscript{17} Harris' criticisms have included:

1) inappropriate use of existing tools to handle new problems,
2) overemphasis on static rather than dynamic systems,
3) too low an emphasis on theory building,
4) theoretical dicta untested by empirical research,
5) empirical rules accepted without theoretical question,
6) preoccupation with equilibrium work (need to address issues beyond a profit maximization framework).

While regional science has contributed much in the development and application of quantitative methods, the above criticisms apply directly in limiting the applicability of regional science tools to the noxious public facility siting problem. This is particularly the case because of the dynamic system that influences the problem, and because of the inappropriateness of an equilibrium framework in addressing the problem. A subsequent section of this chapter discusses this issue more fully.
The spatial tradition of the discipline has made significant contributions to geography that relate directly to the noxious public facility location problem, however. Kohn describes these contributions as follows: "The emergence of geography as an abstract, theoretical science appears to have been the most overriding development of geographic research in the 1960's," largely attributable to spatial research. Kohn held that "the role of the geographer is to understand the spatial structure and spatial interaction of the components of the several subsystems at a given time or through time." This focus on systems analysis is relevant to the multiobjective location problem discussed in this research. In addition, the spatial tradition's emphasis on theory development is desirable, although the spatial tradition highlights deductive reasoning as the path to theory development. This research attempts to contribute to the modification, refinement, or reformulation of location theory using a largely inductive approach.

In summary, the spatial tradition has made many contributions to geographic research that need to be kept in mind in addressing the noxious public facility siting problem. First, a principal focus of geographic study should be on contributing, however incrementally, to theory building. Second, in evaluating spatial patterns in location analysis, it is important to evaluate the applicability of quantitative methods and multiobjective systems analysis tools.
Third, there is a need to accommodate the dynamic character of the siting problem through a focus on process theories from which spatial patterns can be evaluated. Finally, care must be taken to avoid geometric sterility in the conduct of spatially-oriented research.

The Behavioral Tradition

The behavioral tradition in geography is not a separate subfield of the discipline, but rather cuts horizontally across work done in several geographic traditions. It is more accurately characterized as a way of approaching geographic problems than as a definitional paradigm. Such work generally focuses on obtaining explanatory power by examining the way individuals and/or groups of individuals perceive geographic phenomena. The behavioral tradition began to emerge in a significant way in the late 1960's, and is commonly associated with the ecological revival in geography. The paragraphs that follow discuss those contributions of the behavioral tradition which are relevant to the noxious public facility location problem.

First, it is important to understand some of the fundamentals of the behavioral tradition. Behavioralists emphasize cognition in defining the environment, that is there is no such thing as "objective reality", but rather it is defined by man's understanding
Another fundamental is that values are central to the perception of the environment, and that values are inseparable from facts. King recognized this when he said, "It is already clear that the so-called quantitative revolution changed mainly the research techniques employed by economic and urban geography, and did little, at least directly, to channel their attention away from a traditional concern for the static location patterns . . ., let alone analysis of the prevailing value systems, be they political, societal or individual." Another distinction of behavioral work is an emphasis on process which requires a focus on both the non-economic and the economic aspects of behavior.

The behavioral emphasis on cognition and on subjective rather than objective reality has a direct implication for multiobjective location problems. Values, as reflected in differential levels of importance ascribed to major location factors or variables, are key to exploring the geographic expression of subjective reality. The regional screening methodology described in Chapter V attempts to capture the geographic expression of values in siting noxious public facilities. Such values are a function of the way risks are perceived, of education and experience, and of individual basic life values.
The focus on process in behavioral research is also quite relevant to the noxious public facility location problem. Working with a broad definition of "environment," including economic, social, physical, political/institutional, and psychological considerations, Cox has devoted attention to how people make decisions, and to the constraints on the decision process. Cox's concept of "authority constraints" focused on the role of institutions in the decision process, and on how individual behavior is affected by and, in turn, affects institutions. This authority constraint concept is applicable to the complex array of regulatory, institutional, and political constraints that affect the siting of noxious public facilities. These issues are addressed in more detail in Chapter IV of this dissertation.

Golledge has been another important contributor to the role of process in behavioral work. He has been an advocate of theory building in geography and of the use of models "for illustrating theory, and as a way of summarizing complex relations of the real world." He also contends, "We are able to achieve an understanding of spatial patterns by focusing on the decision-making process itself rather than concentrating on the spatial manifestation of the choice act." His focus on process is prompted, in part, by recognition of the failure of classical economic theory to explain the locational choice decision.
influence of non-economic factors plays a pivotal role in the location of noxious public facilities. The process is typically not an optimization process driven by a single economic objective (e.g., cost minimization), but rather is a complex, multiobjective exercise involving both economic and non-economic factors in a satisficing process. Another section of this chapter discusses the optimizing versus satisficing issue in more detail as it relates to the noxious public facility location problem. However, Golledge has held that "The dominant theme in the search for higher explanatory levels in location theory seems to be related to the rebuilding of theory using assumptions other than economic and spatial rationality."\(^{22}\)

Finally, Golledge, Brown, and Williamson have done research regarding the perceptions of hazardous situations.\(^{23}\)* In this research, they concluded that, "Perceptions by occupants of hazardous situations vary with respect to three main factors:

1) Relation of the hazard to the dominant resource use,
2) Degree of personal experience with the hazard,
3) The frequency of occurrence of the threat."

Because noxious public facilities are, by definition, perceived as representing risk, this kind of behavioral research is relevant to the reformulation of location theory, as applied to such facilities.

* Early hazards work was done by Gilbert White and is documented in such publications as White's *Human Adjustment to Floods*, University of Chicago, Department of Geography, Research Paper No. 29 (1945)
In summary, the behavioral tradition of geography offers significant implications for the study of location theory applied to noxious public facilities. The cognitive focus on alternative subjective realities in siting is useful, particularly as a reference point in attempting to express values geographically. The focus on the importance of the decision process, and on the authority constraints that shape and influence that process, is also appropriate to consider in the context of the location of noxious public facilities. Finally, the significance of non-economic factors, as well as traditional economic factors, in the location decision in a multiobjective, satisficing context is also useful in evaluating the research problem of this dissertation.

**Comparison of Private and Public Sector Location Problems**

The similarities and differences between private and public sector location problems are relevant to addressing the theoretical implications of siting noxious public facilities. This section examines these similarities and differences.

First, the motivating or driving forces of the location decision are quite different in the private sector from those in the public sector. Economic forces are commonly held to be dominant in private sector decision-making. Such economic forces manifest themselves in
such private sector objectives as profit maximization, revenue maximization, and cost minimization. While economic forces also influence public sector location decisions (primarily through cost minimization-related objectives), such decisions are more often driven by non-economic considerations such as: 1) public service maximization, 2) risk minimization, 3) minimization of disruption/environmental and socioeconomic impact, and 4) maximization of accessibility. For example, a common goal of public sector location problems, such as the location of fire stations, is the minimization of average weighted travel time between demand centers and assigned supply centers.

Looking at private and public sector location influences in more detail, it is clear that both types of decisions are quite complex. For example, Table 1 summarizes a list of attributes applicable to private plant location decisions. This list includes quantitative, economic variables, as well as qualitative considerations related to functional impacts, public acceptance, and quality of life. However, as the subsequent review of location theory attests, most private sector location theory development has focused on classical and neoclassical economic formulations that seek to optimize location on the basis of economic considerations.
### Table 1
HEIRARCHY OF ATTRIBUTES FOR EVALUATING PRIVATE PLANT SITES

**ECONOMIC IMPACTS (LESS COST)**
- Capital/development cost
- Annual/operating costs
  - Labor
  - Transportation
  - Taxes
  - Fuel/utilities

**FUNCTIONAL IMPACTS (HIGHER PRODUCTIVITY)**
- Labor
  - Availability
  - Workers' attitude
  - Skill level
  - Extent of unionization
- Utilities
  - Availability
  - Reliability
- Transportation
  - Trucking service
  - Rail service

**PUBLIC ACCEPTANCE (BETTER COMMUNITY RELATIONS)**
- Attitude of local citizens
- Attitude of local government

**QUALITY OF LIFE (BETTER LIVING)**
- Climate and terrain
- Housing
- Health care
- Crime
- Public transportation
- Education
- Recreation

While the economic dimension is present in public sector location decisions, the significance of cost minimization is substantially outweighed by a complex array of factors such as: 1) technical considerations (for example the effects on physical, biological and chemical environments), 2) authority constraints such as regulatory compliance and licensing, 3) political/public acceptability, 4) engineering feasibility, 5) system reliability, and 6) risks of adverse consequences. It is the dominance of the non-economic factors over the economic in public sector location decisions that most clearly distinguishes the two, and most directly affects the tools and theories that enhance explanation for each.

While economic considerations dominate private sector location theory, the literature recognizes the influence of non-economic factors in the private sector also. For example, environmental regulations have had a significant impact, only in part through economic effects, on the location of major industrial plants in the U.S. The Clean Air Act, with its associated authority/regulatory constraints, has had a significant spatial impact upon the location of plants with substantial emissions in the U.S. In addition, state and local authority constraints can be significant factors in private location decisions. Bruce indicates that "Environmental regulations . . . are exceedingly complex. They can delay or even prohibit industrial development of an area. Unforeseen technical problems, such as soil conditions or ground-water contamination, can
make it impractical to develop a piece of property. The local
government's permitting process may be cumbersome if zoning changes
or conditional land use authorizations are needed, they often
require public hearings, legislative actions and other
time-consuming steps. Thus, technical, political, regulatory,
inengineering, and risk-related considerations can have a bearing on
private sector location decisions. Typically, however, these are
secondary to the economic considerations. This is in contrast to
the typical public sector location problem.

The driving forces of private and public sector location
problems have a direct effect upon the extent to which such problems
are best dealt with in an optimization or a satisficing model.
Optimizing models of the location decision have the virtue of unique
and consistent solutions, assuming the relevant conditions or
constraints can be tightly defined. This same reference
indicates that "The accuracy of programming (optimizing) approaches
depends centrally on the degree to which the explicit objective
function of the industrial system conforms to the function specified
in the model, the accuracy with which production and transportation
functions have been modeled, and the degree to which the evolution
of 'exogenous' components (notable resource constraints) can be
predicted." Such optimization model approaches have been
difficult to develop and validate in private sector applications
driven by economic forces. Developing and applying such models as a means of prediction in noxious public facility location decisions, driven largely by non-economic forces, has not been done.

Public sector location decisions are best conceptualized using a satisficing model because such decisions have diverse, multiple objectives, and these objectives commonly conflict with each other. Thus, the solution to such location problems is based upon trade-offs and compromise, and not on the concept of a unique optimization. Simon has argued for a departure from optimization models by asserting that decision-makers are concerned with evaluating and selecting from a set of satisfactory alternatives and not upon a quest for the optimum. Davis contends that the choice process itself requires "the replacement of the goal of maximizing with the goal of satisficing, of the finding a course of action that is good enough." Wolpert also addressed this issue. He concluded that optimization was introduced into economic geography on the assumption that economic activity is organized spatially to maximize economic objectives. He found the concept of the spatial satisficer to more accurately portray man's behavior than the normative concept of "Economic Man." The complexity of location objectives, and the difficulty of measuring these objectives meaningfully in an optimization context, make the satisficing process model more adaptable to the problem of locating
noxious public facilities. This is further reinforced by the behavioral notion that there is no such thing as objective reality in siting, and that a range of values expressed in geographic terms (subjective reality) is a more functional approach to the development of location theory.

Review of Location Theory

This section reviews major classical and neoclassical contributions to location theory, and their applicability to the noxious public facility location problem. It should be noted that the focus of theory formulation has been largely on the private sector location decision, and consequently, much of the discussion is concentrated on the relevance of private sector considerations to the location of noxious public facilities.

A report prepared by Arthur D. Little, Inc. summarized the distinction between classical and neoclassical approaches to location theory as follows: "Although the two schools share the standard assumptions that economic behavior is competitive (perfect competition) and that good information is generally available, they differ significantly in their treatment of the process of production. In the classical school the production functions of individual firms are characterized by fixed technical coefficients,
while neoclassical models allow for the possibility of substitution among inputs. This fundamental difference can lead to very different conclusions concerning optimal location even when most other underlying assumptions are identical. The paragraphs that follow review the work of major classical and neoclassical theorists beginning with the work of Weber.

Weber's work has been the foundation for classical location theory. His theoretical construct addressed industrial location change and was founded on the following major assumptions:

1) a single product at a fixed point in time,
2) raw material locations are given,
3) size and location of markets are known,
4) relatively immobile/fixed labor sources (although wage differences can exist),
5) labor is available in unlimited quantities,
6) capital is mobile and at fixed interest rates for all,
7) transportation costs are a linear function of weight and distance,
8) a uniform transport surface (transportation sufficient everywhere).

Weber concentrated on what he called "regional factors" as the forces that attract industry from one region to another. He defined the important regional factors as:
1) price of raw materials and power,
2) set of labor costs,
3) costs of transportation.

His theory then combined factors 1) and 3) into a single factor. He also introduced the concept of agglomeration as a key element of location theory. Agglomeration is a force driven by the desire to take advantage of either external and/or internal economies of scale which tends to result in industrial clusters or concentration. The order of importance of the regional factors was reflected in the order of their application. Weber contended that transportation should be looked at first in the quest for explanatory power followed by labor costs, and lastly agglomeration forces. In essence, Weber's idealized firm produced a single output with a classical, fixed coefficient production function, and attempted to maximize profits by locating to minimize total transport costs associated with both inputs and outputs. The concept of the "locational triangle" was the core of his initial analysis. Taking a single market and two input sources, Weber contended that the optimal location, given his assumptions, was represented using the balance of 'pulls' of unit transportation costs.
He also developed the concept of the Materials Index (MI) defined as:

\[ MI = \frac{\text{weight of localized raw material}}{\text{weight of the final product}}. \]

Based on the MI and his transportation emphasis, he classified firms into four classes, as follows:

1) Class 1, MI = 0, Firms locate at the point of consumption because you are dealing with ubiquities.

2) Class 2, 1 > MI > 0, Firms locate at the point of consumption. Raw materials are relatively light compared to the weight of finished products.

3) Class 3, MI = 1, Firms are locational indifferent (if terminal charges are ignored).

4) Class 4, MI > 1, Firms locate at the raw material site. Raw materials are relatively heavy compared to the weight of finished products.

In an attempt to take labor costs and agglomeration into account, Weber conceived of the isodapane concept. The isodapane was a graphical technique which was, essentially, a contour line representing "balance at the margin between transport costs (rising with divergence from the weighted balance point) and other advantages (i.e., declining wages or rising agglomerative advantages)." The "critical isodapane" was that contour where this balance of costs was the lowest.
Finally, Weber's major conclusions were as follows:

1) Transport-oriented industries tend to be concentrated at or near minimum transportation points (MTP).

2) Industries that deviate from MTP are oriented to labor or to economies of agglomeration.

3) Critical isodapanes tend to expand outward which promotes agglomeration.

4) High value-added industries tend to agglomerate. The higher the value-added, the more agglomeration.

5) Transportation cost savings account for an accumulation of sub-assembly sites (e.g., today's automobile industry).

How does Weber's theory relate to the noxious public facilities location problem? First, competitive market assumptions and private sector driving forces (e.g., profit maximization) do not drive the typical public sector location decision. Although transportation is a location factor in many public decisions, as Chapter III describes, it is typically not the overriding factor. Public health and safety, and risk minimization are the overriding factors. Labor costs associated with construction and operation of such public facilities are minor location factors. Finally, agglomerative forces are largely absent. In fact, the primary force is deglomeration. The location of such facilities is driven away from population concentrations (because of risk), and away from each other (because of need for dispersed, regionalized services).
Consequently, Weber's theory is largely inadequate to explain the location of noxious public facilities.

Hoover also focused on transportation as key to explaining industrial location. He contended that firms looking for an optimal location seek to reduce "transfer costs," which include assembly and distribution costs. Assembly costs can be lessened by locating near the raw materials site, and distribution costs reduced by locating near the market. A balance must then be struck between assembly costs, distribution costs, and other relevant location factors (e.g., labor costs) in the siting decision. This model developed by Hoover shares the same problems of applicability to the noxious public facility problem as the Weber theory.

Von Thünen developed one of the earliest theories of location. He restricted himself to the location of agricultural products/activities around a central market. By assuming a plain with homogeneous characteristics surrounding the central market, he postulated that agricultural patterns were determined as a function of transport costs, measured by weight and distance. Here again, while transportation is a factor in explaining the location of noxious public facilities, it is not the dominant factor that Von Thünen described in the context of agricultural activity.
Lösch was the first to introduce the complete notion of profit maximization in location theory. To quote the Arthur D. Little, Inc. reference, "Lösch considered the demand for industrial products, not as a datum, but as a variable which was elastic with respect to prices and income. Thus he was the first to point out that the location outcome could differ considerably when full profit maximization was taken as the decision criterion of the firm." Even though this was a move toward neoclassical theory, Lösch's formulation, with profit maximization as the driver, is not applicable to the public facility location problem, which is driven by a maximization of public service objective. Lösch did add new complexity to the private sector location decision, however, that parallels somewhat the complexity of multiobjective public sector location decisions. A major difference between the two, however, is that private sector location decisions can be measured in dollar terms, according to Lösch, whereas public sector location decisions cannot be measured by a single dollar metric.

Neoclassical principles of production input substitution began to diminish the role of transportation in location analysis. Predöhl, for example, attempted to explain location decisions as a function of three groups of production inputs: land, capital and labor, and transportation. He held that the location problem was solved by arriving at the combination of these production inputs
that was most efficient in terms of cost. Transportation also is viewed more broadly in the contemporary context to include, in addition to rates, speed, convenience, safety, dependability, and frequency of service considerations. This additional complexity dilutes the dominance of transportation somewhat as a location factor.

Norcliffe takes a neoclassical perspective in further critiquing classical location theory. He finds classical location theory, with its emphasis on transportation, to have diminishing utility because:

1) Transport costs are no longer greatly important to a large number of relatively "footloose" industries, that is, there is more high value-added (market-oriented) industry today.

2) More efficient use of material inputs has tended to reduce the influence of raw materials on plant location.

3) There has been an improvement in the quality/purity of raw materials.

4) Substitution of material inputs has reduced transportation constraints.

5) There have been significant improvements in transportation technology.

6) With respect to labor costs, empirical evidence points to a reduction in regional wage inequalities.
It is important to note that Norcliffe ignores authority constraints (e.g., government regulatory effects) in his critique. However, such constraints pose additional complexity that compromise the utility of classical theory, even for private sector location decisions.

Factors that are increasingly important to contemporary industrial location include the availability of supporting infrastructure, internal/external economics of scale, and linkage/contact patterns. Linkage/contact patterns include those forces of agglomeration associated with the desirability of face-to-face contact with key actors in the business. Interestingly, this translates into a focus on large urban centers in location decisions. In contrast, noxious public facilities are sited to avoid such population concentrations (See Chapter III).

Neoclassical theory, while accounting for a more realistic level of complexity in the location decision, still does not provide a useful foundation for explaining the location of noxious public facilities. Principally, this is because of the focus on economic factors to explain the spatial location of industry. Non-economic factors, such as those described in the next chapter, tend to dominate in their influence on the location of noxious public facilities, even though economic factors still play a role. The
fundamental economic assumptions of classical and neoclassical theory do not apply to the public facility location problem, and the multiple objectives that public location problems must address cannot all be measured in economic (dollar) terms. Finally, the level of importance assigned to these multiple objectives reflects value judgements which are subject to greater variability than are factors that can all be measured in dollar terms.

Unfortunately, there has simply not been much attention in the literature devoted to public facility location theory, in general, to say nothing of the noxious public facility location problem. It is clear that the operation of competitive markets generates externalities (industrial waste/pollution) that need to be effectively managed. The disposal of such wastes requires the siting of public facilities viewed by many as noxious. Wingo has conceived a model of urban environmental quality that is designed to explain the quality of the environment at any point in space according to: 41

1) the valued features of the natural environment,
2) the output of public goods (and services) in the area,
3) a set of unsolicited externalities.

This model is so generic that it provides little that can be used to apply to the location of noxious public facilities. It does point out, however, that the presence of unsolicited externalities
is a negative factor in location analysis. This reinforces the problems associated with locating a public facility designed to manage externalities (e.g., waste products), where a local area is the hub for the disposition of wastes from a much larger area.

A host of techniques have been employed to explore location theory and the application of theory. These techniques have included operations research, input-output analysis, and multiobjective system analysis methods. The paragraphs that follow summarize the applicability of these techniques to the noxious public facility siting problem.

Most operations research techniques reviewed were deterministic, optimization models designed to extend the classic Weber location problem (private sector-oriented) to the location of multiple facilities, to the multiobjective minimax and minisum location problems, or the application of general assignment problem algorithms. In each case, the approach was highly mathematical, focused on economic variable optimization, and dependent upon the mathematical determination of constraints on the objective function. While such research has played an important role in the extension of location theory as applied to the private sector (operating within conventional economic driving forces), they do not lend themselves to the prediction of public sector location decisions for the reasons outlined previously.
There have been attempts in operations research to address more fully the complexity of forces in the location decision. For example, Nijkamp and Spronk proposed the use of interactive multidimensional programming models in an iterative process to facilitate location decisions. In this approach multiple objective functions (monetary and non-monetary) were employed in an iterative mode to define trade-offs for location decision-makers. While an improvement over other operations research applications, this approach is still optimization-oriented and constrained by the ability to mathematically portray the non-monetary objective functions. It also does not lend itself to the incorporation of alternative value systems in the decision process.

It was concluded, for purposes of the research documented herein, that operations research techniques were not useful in capturing the multiobjective complexity of the noxious public facility siting problem.

Input-output techniques have also been employed to address the location problem. Such applications have even included the use of input-output to examine the tradeoffs between economic and environmental factors in the location decision. Richard Davis used input-output to assist with the selection of target industries for regional economic development programs. These uses are
designed to link physical mass flows (e.g., effluents and emissions) with production, just like dollars are linked to production in conventional input-output applications. This input-output mass flow/dollar flow accounting system is not well adapted, however, to addressing authority constraints, risk considerations, or value systems in location analysis. Consequently, input-output techniques were not employed in the subject research.

Multiobjective decision methods were also reviewed for their applicability to the noxious public facility location problem. Hobbs states that "Analytical siting methods have their proponents and detractors. Persons favoring their use contend that only systematized methods can explicitly and rigorously account for all siting considerations. They assert that unassisted human judgment is incapable of balancing risk, multiple objectives, and interest groups, while fulfilling legal mandates. Others, however, accuse multiobjective methods of being impractical, simple-minded, and misleading numbers games that only obscure important tradeoffs and information." The objective of such methods is to account for relevant economic and non-economic location factors in the identification of the most suitable locations for a given type of facility utilizing different value systems in the process. Such techniques may or may not incorporate risk into the analysis. It is this multiobjective decision methods framework that was selected as
the most appropriate approach to the extension of location theory that addresses the noxious public facility location problem. This framework was selected because:

1) It allows for the integration of economic and non-economic location factors.
2) It is a systematic approach that lends itself to the formulation of theory.
3) It allows for the incorporation of authority constraints into the location problem.
4) It affords the opportunity to look at location decisions from different value system perspectives.

It is this decision methods framework that offers the best hope of extracting theoretical implications for noxious public facility location.

The next chapter introduces the location factors important to the siting of a specific type of noxious public facility, a geologic repository for the disposal of the high-level nuclear waste. The next three chapters (Chapters III-V) look at the repository location problems in detail with the intent of extracting cumulative generalizations from which location theory might be modified, refined, or reformulated.
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CHAPTER III
DESCRIPTION OF LOCATION FACTORS FOR A
HIGH-LEVEL NUCLEAR WASTE REPOSITORY

Chapter Overview

This chapter introduces the siting problems associated with the location of a specific type of noxious public facility—a mined geologic repository for high-level nuclear waste. The Department of Energy Siting Guidelines (10 CFR 960) define high-level radioactive waste to mean: "1) the highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations and 2) other highly radioactive material that the Nuclear Regulatory Commission (NRC), consistent with existing law, determines by rule requires permanent isolation."\(^1\) This type of facility provides an excellent focus for the search for cumulative..."
generalizations applicable to the modification, extension, or reformulation of location theory as it applies to the noxious public facility location problem.

This chapter provides background on the high-level nuclear waste disposal issue. It then describes the concept of geologic disposal, which is the cornerstone of the Nation's program to dispose of high-level radioactive material. The nature of a repository, both surface and underground facilities, is then described. Finally, the important location factors that help drive the repository location decision are reviewed by major category of location variables. These location factors include health and safety, environmental, socioeconomic, transportation, and ease and cost of construction considerations.

Background on the Repository Location Problem

Nuclear power represents a significant, and controversial, share of the Nation's total energy budget. The Department of Energy indicates that in 1984, domestic nuclear power plants generated in excess of 13% of the total electricity produced in the U.S. Figure 1 illustrates the geographic distribution of existing, planned, or under construction nuclear plants at the end of 1984. At that time, there were 94 commercial plants in operation and another 35 plants planned or under construction in the U.S. From
Figure 1  Geographic Distribution of Existing, Planned and Under Construction Nuclear Power Plants in the United States

the dawn of the commercial nuclear age in the 1950's through 1984, approximately 10,000 metric tons of uranium (MTU) have been discharged by commercial reactors in the U.S. In volume terms, this quantity of waste is approximately equal to the volume of a football field about three feet deep (or about 150,000 cubic feet). Projections are that by the year 2000 commercial reactors will have produced approximately 50,000 MTU of waste, and by the year 2020, 130,000 MTU of waste. In addition to commercially generated high-level waste, high-level material has been, and will continue to be, generated by the Nation's atomic energy defense activities. This waste currently occupies a volume of about 1,000,000 cubic feet, which is almost seven times the current commercial waste volume. The Department of Energy expects this volume of defense high-level waste to stay about the same through the year 2000 because of an ongoing program to concentrate and solidify such waste. In any event, there are currently no facilities for ultimate waste disposal, and new quantities of waste are being generated daily at commercial reactors, through defense programs, by medical and research institutions, and in industrial uses.

Why is it so important to dispose of high-level nuclear waste? The Office of Technology Assessment (OTA) has addressed this question in a recent publication entitled Managing the Nation's Commercial High-Level Radioactive Waste. OTA points out, "Some atoms, known as radioisotopes, are unstable (radioactive) and
undergo a spontaneous decay process, emitting radiation until they reach a stable form. Called decay, this stabilizing process takes, depending on the type of atom, from a fraction of a second to billions of years. The rate of radioactive decay is measured in half-lives, the time it takes for half the atoms in a sample to decay to another form. Such radiation can penetrate matter, including human tissue, and result in damage or death to individual cells, tissue or even whole organisms. The actual impact of radiation depends upon such variables as type of radiation, distance from radiation source, length of exposure, and susceptibility of the exposed cells. OTA asserted that "The principal concern about radioactive waste is that it might be released into the environment and be taken into the body through drinking water or food supplies, thus placing a source of radiation very close to vulnerable tissues."  

The commonly used unit of measure for radiation exposure is the rem—a unit that indicates the amount received and the biological implications of the exposure. We all are exposed to natural background radiation levels in the U.S. annually approximating 160 millirems (thousandths of a rem) (See Figure 2). To put this exposure in perspective, OTA offers the following:

1) An acute radiation dose is generally considered to be 50 rem or more over a 24 hour period. Such a dose results in
Figure 2  Background Radiation Levels in the United States (Millirem per year)

radiation illness between one hour and several days from time of exposure.

2) Human death is a virtual certainty at doses exceeding 10,000 rems.

3) Exposure to 600 to 1000 rems carries with it a chance of death in excess of 90%.

4) There is a 50% chance of death from exposure to 400 rems.

5) Exposure to less than 200 rems means immediate survival is almost certain, but other significant consequences may be suffered. Such consequences may include gastrointestinal and circulatory system disorders, cancer, birth abnormalities, genetic defects, and poor general health.

6) Significant long-term effects are also possible from chronic exposure to much lower levels of radiation.

Consequently, the safe and effective disposal of high-level nuclear waste is a major social obligation attendant to the contemporary uses of nuclear energy.

It is important to draw the distinction between the concept of "waste storage" and "waste disposal" because, to date, waste management has concentrated on safe storage until permanent disposal becomes possible. "Storage" is isolation that allows easy access to the material after emplacement, and that requires continuous human control and maintenance to guarantee safety. Nearly all commercial spent fuel today is stored in pools of water at operating reactor sites all across the country under the control of electric
utilities. "Disposal" is waste isolation that is dependent upon natural/environmental and engineered barriers, and that does not offer easy human access or require continued human control and maintenance. Continued delay in solving the disposal problem both creates major problems for operating utilities related to the need for more storage capacity, and threatens the social viability of the nuclear option as a means of meeting national energy needs. One key element to solving the high-level waste disposal problem is the appropriate location of repository facilities in geographic space.

Concept of Geologic Disposal/Repository Description

The ultimate disposal of high-level nuclear waste is designed to limit or prevent the release of highly radioactive materials into the accessible environment for literally thousands of years (See Chapter IV for a detailed discussion of regulatory requirements). While such a facility has not yet been licensed anywhere in the world, the United States has been a leader in pursuing the location of such a facility. In doing so, a wide range of disposal options has been thoroughly examined. These options have included ice sheet disposal, subseabed disposal, outer space disposal, transmutation, and geologic disposal. Geologic disposal has been selected by the Federal government as the option of choice. This concept relies upon the emplacement of packaged nuclear waste in stable rock formations 1000 to 4000 feet below the earth's
A geologic repository, which will resemble a conventional deep mining operation in many respects, depends upon both natural and engineered barriers to ensure waste isolation. The paragraphs that follow describe this concept of multiple barriers in deep geologic disposal.

The Office of Technology Assessment described the natural barriers as follows: "The natural features of the site that contribute to (nuclear waste) isolation are the host rock (which can be selected to prevent or minimize contact between the waste and flowing ground water, the principal potential mechanism for bringing buried waste into contact with human beings), the chemical characteristics of the site and its environment (which can limit the rate at which the waste dissolves in ground water and is transported to the biosphere), and the time required for contaminated ground water to flow from the repository to the biosphere (which, along with the chemical characteristics of the media surrounding the repository, can delay the release of dissolved waste until many of the hazardous radionuclides have decayed). In addition, the location of the site can be selected to reduce the possibility of human intrusion (e.g., by avoiding proximity to valuable natural resources), and to provide for dilution of any contaminated ground water by large quantities of surface water before ground water is used by human beings." The natural barrier system must be considered of primary importance in ensuring the effective isolation
of the waste from the accessible environment. Rock types being evaluated for geologic disposal include: 1) both bedded and domed salt deposits, 2) tuff (compacted volcanic ash), 3) basalt (coarse-gained solidified lava), and 4) crystalline rock (intrusive igneous and high-grade metamorphic rocks such as granite). Figure 3 shows the geographic distribution of the various rock types being considered for the Nation's first repository, while Figure 4 illustrates the distribution of crystalline rocks being considered for the second repository.

The concept of engineered barriers is aptly described by the Office of Technology Assessment as follows: "The principal engineered features are the overall design of the repository, the waste form (e.g., solidified high-level waste or unprocessed spent fuel), and the waste package, which may include an overpack (e.g., a titanium container) designed to provide containment for up to 1000 years, and a packing material (e.g., bentonite) designed to prevent water from reaching the overpack and to limit the escape of any water that does come into contact with the waste." Figure 5 illustrates an artist's concept of what the waste package might look like after emplacement in the natural barrier of the repository. After all the waste packages have been emplaced, each mine tunnel or drift will be backfilled with impermeable packing material to seal the repository, and to inhibit the movement of ground water and
Figure 3  Location of Potentially Acceptable Sites for the First Repository By Rock Type

Figure 4  Location of Crystalline Rocks Considered for the Second Repository

Figure 5  Artist's Concept of High-Level Waste Package

waste. Figure 6 shows an artist's concept of the complete repository system with both natural and engineered barriers in place.

Now that the multiple barrier concept in geologic disposal has been briefly reviewed, it is appropriate to describe the fundamentals of a repository site, including the functions of both surface and subsurface facilities. This provides additional perspective and context for the discussion of important repository location factors to follow.

As mentioned previously, a repository will have many of the same characteristics of any large deep mining operation. Figure 7 provides a general schematic layout of a typical repository site. It is estimated that the surface facilities will occupy an area of approximately 400 acres. The surface facilities will include the following major components (See Figure 8):

1) waste receipt and handling buildings,
2) waste package facilities (assumes on-site packaging),
3) transportation cask storage area,
4) excavated rock storage area (including drainage collection and treatment systems),
5) ventilation shaft facilities,
6) administration/mine operation and maintenance facilities,
7) a security building,
8) a visitors' center.
Figure 6  Artist's Concept of Multiple Barriers in a High-Level Waste Repository

Figure 7  Schematic Layout of Areas at a Typical Repository

Figure 8  Artist’s Concept of a Working Geologic Repository

For purposes of conceptual design, it is assumed that the wastes are delivered to the repository by rail or truck in licensed, shielded shipping casks. These casks will be unloaded, inspected, sorted, and packaged at the surface facilities, in preparation for their emplacement underground.

Depending upon the final mode of waste package emplacement (e.g., vertical or horizontal and different package densities), the underground facility area is estimated to take up about 2000 acres. This underground area will consist of a network of shafts and tunnels that allow for ingress, egress and waste emplacement. Separate shafts will be used for transporting personnel and equipment, and for transporting waste canisters to the underground. Other shafts will be designed to provide ventilation.

A controlled area will extend horizontally no more than 6 miles in any direction from the boundary of the underground facilities. The purpose of this controlled area is to prohibit surface activities (e.g., mining or drilling) that might compromise the integrity of the repository. The specific size and configuration of the controlled area will ultimately be dependent upon the direction and rate of ground-water flow associated with a specific repository site. The government intends to maintain institutional control of this area in perpetuity. However, with a planning horizon of
literally thousands of years, government control cannot be counted upon. Consequently, a system of monuments, marking the boundaries and communicating the nature of the hazard, will have to be conceived to communicate for hundreds of generations to come.

**Review of Major Repository Location Factors**

Chapter II reviewed relevant location theory literature and concluded that the focus on economic determinants in most theory was not generally applicable to the noxious public facility location problem. This section looks at the major categories of location factors that drive repository location decisions. These categories include:

1) Health and safety factors,
2) Environmental factors,
3) Socioeconomic factors,
4) Transportation factors,
5) Ease and cost of construction factors.

Chapter IV discusses in some detail the origin of these categories in authority constraints or regulations.

**Health and Safety Factors**

The issue of paramount importance to the location of a geologic repository for high-level nuclear waste is the protection of public
health and safety at a high level of confidence. This includes protection during the period of repository operation, prior to closure (commonly termed preclosure radiological safety), as well as long-term safety after the repository has been closed (postclosure considerations). The paragraphs that follow describe both the postclosure and preclosure health and safety factors that are of primary importance to the repository location decision.

Postclosure location factors are defined to ensure that emplaced high-level waste is effectively isolated from the accessible environment for thousands of years. (Note: Chapter IV describes the applicable regulatory requirements in some detail). Key location factors that contribute to this objective are geohydrology, geochemistry, rock characteristics, climatic change, erosion, dissolution, tectonics, and human interference.

Geohydrologic considerations are of major consequence because ground water is the primary vehicle for the transport of waste to the accessible environment. Favorable geohydrology is defined to include very long ground water travel times from the repository disturbed zone to the accessible environment (in excess of 10,000 years); stability of geohydrologic conditions; relative ease of modeling geohydrologic flows with acceptable levels of confidence; low hydrologic conductivities with generally downward or horizontal hydraulic gradients; and the absence of major ground water users in
the vicinity of the repository. The geographic or spatial distribution of these characteristics is strongly correlated with the distribution of certain rock types. Ultimately, geohydrologic analyses require detailed subsurface data collection and complex modeling of repository performance incorporating a wide range of variables in a systems analysis framework.

Geochemistry is important because geochemical conditions could either compromise or enhance the waste containment and isolation objective, depending upon the chemical interactions among the radionuclides, the host rock, and the ground water. Desirable geochemical characteristics include stable and favorably predictable geochemical conditions for 100,000 years; and geochemical reactions (precipitation, sorption etc.) that retard/inhibit radionuclide movement.

Rock characteristics also play an important role because of the need for capability to withstand the thermal, chemical, mechanical, and radiation stresses associated with the construction, operation and closure of the repository. The intent is to avoid or minimize the creation of new fractures associated with these stresses which could constitute accelerated pathways to the accessible environment. Favorable rock characteristics include thick, laterally extensive and homogeneous rock; and high thermal conductivity, low coefficient of thermal expansion, and sufficient ductility to seal any fractures created.
Climatic change is another factor that could affect the ability of the repository to isolate waste. The concern here is the potential for significant, negative hydrologic changes (e.g., rising water tables, upward hydraulic gradients etc.) created by climatic change. Desirable location characteristics include a geologic system that is not susceptible to the impacts of climatic change and a relatively stable surface water system projected over 100,000 years.

Erosion is important to repository location because the waste emplacement depth should not be compromised by erosional forces to the extent that waste releases would be larger than regulatory limits. Favorable conditions are those where projected erosional processes and erosion rates are such that they will not adversely affect waste containment and isolation.

Dissolution relates to those rock types (e.g., salt) that are subject to dissolving in the presence of water, thus creating potential pathways for waste migration. Desirable location characteristics include no evidence of dissolution processes over the Quaternary Period of geologic time (the last one and one half million years).

Tectonic activity includes uplift, subsidence, faulting and folding of the geologic setting. Tectonics are important to
repository location decisions because they are potential disruptive processes or events that could create new pathways for waste or adversely affect the geohydrology in the vicinity of the repository. It is desirable that, based on the historical record, tectonic activity is not likely to compromise the integrity of the repository.

The final postclosure health and safety factor is human interference. The objective of this location factor is to avoid conditions that could lead to inadvertent loss of waste isolation. Desirable conditions for this location factor are the absence of historical extractive industry; absence of natural resources (including ground water) that could attract drilling or mining activity; and ability of the government to obtain all surface and subsurface ownership rights at the repository site.

Preclosure radiological safety is concerned with meeting all applicable regulatory requirements for radiological exposure during repository operation and closure. Key location factors associated with preclosure radiological safety are population density and distribution, site ownership and control, meteorology, and offsite installations and operations.11

The population density and distribution factor is designed to ensure that average expected radiation doses to the public will not
exceed a small fraction of the regulatory limitations, and that individual doses in the unrestricted area around the repository will not exceed regulatory limitations. Desirable population characteristics include remoteness from highly populated areas, and low population densities. This factor not only takes account of existing population conditions, but also future projections of population growth (including seasonal population fluctuations.) The need to address population density and distribution is a significant force for deglomeration in repository location decisions.

Site ownership and control are concerned with acquiring and maintaining the required surface and subsurface rights of ownership to conduct all repository activities during operation and closure. This includes the ability to control access to the repository site. The desired circumstance for this factor is the ability of the government to secure all such rights, including water rights, at candidate repository locations.

Meteorological conditions are a significant preclosure health and safety location factor because air movement is a potential vehicle for radionuclides that may be released during repository operation or closure. In addition, it is desirable to locate the repository where the risks of disruption of facility operations associated with extreme weather conditions (e.g., hurricanes, floods etc.) are minimized. It is also desirable to locate the repository
such that prevailing meteorologic conditions would lead to the dispersal of radionuclides and to transport away from population concentrations in the case of severe accident scenarios.

The final preclosure radiological safety consideration relates to offsite installations and operations. This factor recognizes the potential adverse effects of nearby industrial, transportation or military facilities on repository operation and closure. Specifically, it is desirable to avoid locations where other nuclear installations may contribute radioactive releases that could compromise the ability of the repository to meet regulatory requirements.

It is also considered desirable to avoid the presence of nearby hazardous installations such as munitions plants, bombing ranges etc.

**Environmental Factors**

Environmental factors also play a significant role in shaping the location decision for high-level nuclear waste repositories, and for that matter, other types of noxious public facilities. The generalized objective related to environmental quality is to adequately protect the environment by avoiding impacts where possible, and by mitigating those impacts where they are unavoidable. Mitigation decisions must balance
policy/programmatic, technical, social, economic, and environmental considerations. The paragraphs that follow describe these environmental factors in more detail.

The first environmental factor relates to the ability to meet, in a timely manner, all regulatory requirements that relate to the environment. Such requirements may be promulgated by either Federal or state authorities, although litigation is possible where there is a conflict between the Department of Energy's responsibilities under the Nuclear Waste Policy Act (See Chapter IV for details) and state environmental requirements. In any event, permits must be secured to manage the water effluents, air emissions, and solid/mine waste products associated with repository construction, operation, closure, and decommissioning. Additional possible environmental requirements relate to the issuance of state drilling permits, and to the preparation of environmental assessments mandated by a state prior to field characterization activities in the repository siting process. Failure to demonstrate a capability to meet air quality, water quality or solid waste-related permit requirements can jeopardize the feasibility of a candidate repository site. This capability to meet permit requirements is dependent, in part, upon the geographic distribution of other sources of environmental pollution.
Another environmental location factor addresses the issue of land use compatibility and potential irreconcilable conflict of use. Regulations preclude the location of a repository within the boundaries of components of the National Park System, the National Wildlife Refuge System, the National Wild and Scenic Rivers System, the National Wilderness Preservation System, and some portions of National Forest Lands. In addition, comparably significant state protected resources, dedicated to resource preservation, prior to the enactment of the Nuclear Waste Policy Act are also disqualified as potential repository locations. Beyond that, where proximity to such Federal and state protected lands constitutes an irreconcilable conflict of land use, the repository cannot be sited. This irreconcilable conflict of use concept also may penalize candidate areas where significant Native American cultural resources are present, or where there is critical habitat for threatened or endangered species of plants or animals.

The final environmental location factor is the ability to mitigate anticipated environmental impacts to an acceptable level, again given a complex array of policy/programmatic, technical, social, economic, and environmental considerations. Where it can be demonstrated that the protection of the environment is not possible, due to unavoidable and largely unmitigable environmental impacts, an area may be disqualified from consideration as a repository site.
All of the above environmental factors may have an effect upon the spatial location of high-level nuclear waste repositories in the U.S. Some of these effects are very clear and direct (e.g., the mandate to avoid National Parks). Others are much more subtle, indirect, and open to debate in terms of their significance to the location decision. The methodology described in Chapter V attempts to accommodate these differences. In any event, non-monetary environmental quality factors must be fully accounted for in repository location studies.

**Socioeconomic Impact Factors**

Socioeconomic location factors have the potential to shape the repository location decision in a manner quite similar to the environmental quality factors. The construction and operation of a repository has the potential to result in a wide range of social and economic impacts, particularly in the rural areas where siting is most likely to occur. Such impacts include both positive benefits and negative costs. Benefits might include increased direct and indirect employment, increased gross regional product, possible enhanced opportunity to retain the younger segment of the population, increased local government revenues, and expanded public services. Costs might include disruption of established regional economies (e.g., recreation-based economies); disruption attributable to in-migration of the repository labor force; stress
on local community services, and housing; and local resources conflicts (e.g., over water rights, construction materials etc.). It is desirable in repository location to maximize the beneficial impacts, and to minimize the costs by mitigation or, where mitigation is not possible, by direct monetary compensation.

Many of the above socioeconomic location factors can be quantified in dollar terms, but many others related to community disruption, lifestyle changes, and community cohesion cannot. This demonstrates the need for a multiobjective framework that allows for the exploration of different value systems in explaining the spatial location of repositories and other noxious public facilities.

Transportation

Given the spatial distribution of high-level waste generators and temporary storage facilities described earlier in this chapter, safe, effective transportation of the waste from the sources to the repository for final disposition is a key concern. This is particularly the case since it is conceivable, and even likely, that more of the Nation's population will be exposed to risk in the transportation process than after final waste emplacement. The development of reliable transportation cask technology, capable of sustaining major catastrophic events, is one way of minimizing this risk. Other transportation factors are taken into account to
further reduce this risk and to maximize the effectiveness and efficiency of the waste transportation network. These factors are described below.

Accessibility is a significant location factor. It is desirable to have ready access by both highway and rail to the repository, and to ensure that such access routes are in good physical condition. Any new construction of highway access or rail spurs is best kept to minimum lengths, without requirements for cuts, fills, tunnels or bridges. It is also desirable that transportation routes be free of sharp curves, steep grades, and landslide prone stretches. It is desirable to have good access with routes that bypass local cities and towns.

Total projected life-cycle cost and risk associated with transportation is another location factor. It is desirable to minimize both costs and risk in considering location options, but clearly tradeoffs are often required between cost and risk minimization objectives. Such analyses need to consider the geographic distribution of waste sources, the location of potential interim storage/waste processing facilities, and the location of the first repository in the case of the search for subsequent repository locations.
Institutional considerations must be taken into account. It is desirable to avoid legal impediments to compliance with U.S. Department of Transportation and Nuclear Regulatory Commission regulations. It is desirable to be able to develop relatively simple and implementable emergency response plans along transportation routes. Finally, it is desirable to avoid the need for Federal condemnation to acquire access route rights-of-way.

Here again, the transportation location factors are a complex array of considerations, some measurable in monetary terms and some not in monetary terms. In addition, transportation is yet another example of the need to balance often competing objectives to reasonably predict the eventual spatial distribution of repository sites. This complexity has implications for the development of tools to address the repository location problem, and for the formulation of location theory that addresses the location of noxious public facilities. Chapters V and VI consider these implications.

Ease and Cost of Siting, Construction, Operation and Closure Factors

Clearly, the location of a high-level repository for nuclear waste cannot ignore economic factors in the decision process. However, the regulations that guide this decision process mandate that cost considerations be the least important category of location
factors, after the health and safety, environmental, socioeconomic, and transportation factors (See Chapter IV for details). These ease and cost-related factors are related to surface characteristics, rock characteristics, hydrology, and tectonics.  

The nature of surface characteristics can have a substantial effect upon the ease and cost of repository construction, operation, and closure. Locations in hilly terrain require expensive earth moving and site preparation costs. Transportation and utility corridors are more difficult and expensive to construct and maintain. Consequently, relatively flat terrain is preferred. In addition, locations prone to flooding because of proximity to water bodies, or downstream from reservoirs subject to catastrophic dam failure could jeopardize the repository. Thus, well-drained land, not subject to flooding is also considered a significant cost and site location factor.

Rock characteristics also have a direct relationship to ease and cost location factors. For example, host rock that is thick, laterally extensive and homogeneous offers more flexibility in selecting the depth, configuration, and location of underground repository facilities. This flexibility is likely to be reflected in lower construction costs also. Similarly, it is desirable to have rock that exhibits characteristics that allow for minimal engineered measures for underground openings. Such characteristics
include stability under anticipated mechanical, thermal, chemical, and radiation induced stresses, and the absence of faults, shear zones and other stratigraphic or structural features that could complicate or compromise the safety and integrity of the repository. Developing and implementing engineered fixes for such problem features increases the difficulty, risk, and costs of repository construction, operation, and closure.

Hydrologic factors also can have implications for ease and cost. For example, if there are aquifers between the repository underground facilities and the surface, then expensive dewatering techniques must be employed to prevent repository flooding. Aquifer contamination over time also becomes a concern that is reflected in the costs of the repository. Consequently, an absence of such aquifers is a favorable location factor. Likewise, as previously discussed, an absence of surface water features that could cause repository flooding is also a favorable condition.

Tectonic location factors associated with ease and cost of repository construction, operation, and closure relate to the nature and rates of faulting, and to the seismic characteristics of the geologic setting under consideration. Active faulting runs the risk of creating new and accelerated migration pathways for the waste to the accessible environment. Faulting also is a focus of seismic or earthquake hazard. Engineering protection in the face of such
hazards is expensive and carries with it some measure of risk of failure. Consequently, it is desirable from an ease and cost standpoint to avoid locations where the geologic setting evidences active faulting, or historical or man-induced (e.g., underground bomb testing) seismicity.

In the end, total repository system costs (including repository support facilities such as transportation networks) will be considered in the selection of repository locations. However, cost minimization is not a primary location driver, and in fact, costs are likely only to be a discriminator where candidate sites have very similar health and safety, environmental, socioeconomic, and transportation characteristics. This situation stands in contrast to most location theory development to date which has concentrated on the economic forces driving private sector location decisions.

Implications of Location Factors for Theory

This chapter has described a particular type of noxious public facility, the geologic repository for high-level nuclear waste, and the location factors that shape the spatial location of such a facility. The intent was to describe the repository location factors in a manner that provides a vehicle for comparison with those factors that drive previously developed location theory. The paragraphs that follow provide such a comparison.
It is clear from the review of repository location factors that the location of such a facility is a complex multiple objective problem. It is also clear that any location theory developed to help explain such a problem must provide a framework for trading off the achievement of one objective in relation to other objectives. Optimization is not a workable framework because of the complex multiple objectives and the inverse relationships between objectives. That is, optimizing for one objective leads to suboptimal outcomes for other objectives. In addition, ascribing relative importance measures or weights to the various location factors is not possible in an optimization framework. Addressing the geographic implications of different views of the relative importance of the location factors is important to predicting the spatial distribution of such facilities. Consequently, a satisficing framework that accounts for different value system perspectives in the location decision is likely to provide the best avenue for revising location theory to better apply to the noxious public facility problem.

Another conclusion that can be drawn from this chapter is that the conventional economic driving forces are much less important to repository location than they are to private sector location decisions, and even to other kinds of less controversial public sector location decisions. Repository location decisions are driven primarily by health and safety (risk minimization) related factors,
and by environmental, socioeconomic, and transportation factors. Ease and cost of construction factors are mandated in Federal regulations (10 CFR 960) to be least important in the location decision, and are likely to be discriminators only where sites exhibit similar health and safety, environmental, socioeconomic, and transportation characteristics. This requires that models used in theory formulation be capable of addressing both monetary and non-monetary measures of location factors in predicting location outcomes.

The next chapter addresses the issue of the authority constraint in repository location, another significant influence in the examination and reformulation of location theory applicable to noxious public facilities.
CHAPTER III REFERENCES


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CHAPTER IV

REVIEW OF PUBLIC POLICY INFLUENCES ON REPOSITORY LOCATION

Chapter Overview

This chapter examines the role of public policy in shaping location decisions related to noxious public facilities, specifically high-level nuclear waste repositories. It takes the concept of "authority constraints" articulated by Cox, and reviews three categories of such constraints as they affect the repository location decision: 1) legal/regulatory constraints, 2) institutional constraints, and 3) political constraints. Each of these categories offers an opportunity to extract insights that can be utilized in considering the refinement, modification, or reformulation of location theory. It is this objective, and not simply a recitation of laws and regulations, that provides the focus
for this chapter. These categories of authority constraints have a material effect upon the nature and scope of the regional screening methodology described in Chapter V.

The section on legal/regulatory constraints reviews the significant location-related provisions of the major public policy instrument that directs the high-level waste program, the Nuclear Waste Policy Act of 1982. It reviews relevant Federal regulations promulgated by the U.S. Department of Energy, the Nuclear Regulatory Commission, and the U.S. Environmental Protection Agency that shape the repository location decision. State and local legal and regulatory influences are also briefly discussed. Implications for location theory development and inductive generalizations regarding legal/regulatory constraints are then summarized.

The section on institutional constraints describes the roles, responsibilities, authority, and accountability of the major Federal, state, tribal, and judicial actors in repository location. It describes the checks and balances involved in shaping location decisions, and reviews key institutional issues that contribute to the development of inductive generalization and location theory.
The section on political constraints attempts to characterize the political environment in which noxious public facility location decisions are made. Here, again, the emphasis is placed on repository location as an example of a noxious public facility. Political issues in repository siting are explored only to the extent that such exploration provides input to inductive generalization and the formulation of location theory that recognizes the need to accommodate major political constraints.

The chapter concludes with a summary of the major ways in which public policy influences manifest themselves in the location of noxious public facilities.

Legal/Regulatory Constraints

The final disposition of high-level nuclear waste suffered for decades from a lack of functional public policy guidance and direction. In fact, this lack of public policy impetus is, in part, responsible for the historical inability to locate a high-level waste repository. The public policy void was filled with the passage of the Nuclear Waste Policy Act of 1982 (hereafter NWPA), and with the promulgation of supporting regulations.2
Nuclear Waste Policy Act

The Nuclear Waste Policy Act was passed "to provide for the development of repositories for the disposal of high-level radioactive waste and spent nuclear fuel, to establish a program of research, development and demonstration regarding the disposal of high-level radioactive waste and spent nuclear fuel and for other purposes." As mentioned in Chapter III, disposal was to be in a mined geologic repository that has to be licensed as a safe facility by the Nuclear Regulatory Commission. This statement of public policy balances diverse social and political interests in attempting to achieve the following purposes:

1) establish a schedule for the location, construction, and operation of repositories,
2) articulate the Federal responsibility and a Federal policy for high-level waste disposal,
3) define Federal/state relationships for waste disposal,
4) establish a Nuclear Waste Fund to pay for the disposal of high-level waste.

The following paragraphs summarize those provisions of the NWPA that influence the repository location decision.

Section 112 (a) of the NWPA mandates the preparation of detailed guidelines for the location and selection of geologic
repositories. This section incorporated in law the technical scope of the location factors that must be taken into consideration in repository siting, while leaving the details to the mandated guidelines. Specifically, Section 112 (a) states that, "Such guidelines shall specify factors that qualify or disqualify a site from development as a repository, including factors pertaining to the location of valuable natural resources, hydrology, geophysics, seismic activity and atomic energy defense facilities, proximity to water supplies, proximity to populations, the effect upon the rights of users of water, and proximity to components of the National Park System, the National Wildlife Refuge System, the National Wild and Scenic Rivers System, the National Wilderness Preservation System or National Forest Lands." \(^5\)

This same section of the Act requires that, "Such guidelines shall specify population factors that will disqualify a site from development as a repository if any surface facility of a repository would be located: 1) in a highly populated area; or 2) adjacent to an area 1 mile by 1 mile having a population of not less than 1000 individuals." \(^5\) Thus, the origin of the location factors discussed in Chapter III are actually specified in Federal law. Clearly, this is a notable and direct example of a legal authority constraint having significant influence upon the spatial distribution of noxious public facilities.
Section 114 (a) in the NWPA also provides direction that has spatial implications for repository location.\(^6\) This section says, in part, that, "In making site recommendations and approvals subsequent to the first repository site recommendation, the Secretary (of Energy) and the President, respectively, shall also consider the need for regional distribution of repositories and the need to minimize, to the extent practicable, the impacts and cost of transporting spent fuel and solidified high-level radioactive waste."\(^6\) Consequently, the legislation requires the Department of Energy to consider regionalization of repository locations designed to minimize both the risks and costs associated with waste transportation from the source to the repository. This provision also tends to regionalize the political costs associated with the location of multiple repositories, a factor that Congress could not overlook. Thus, if the first repository goes in to a Western state, this provision places some pressure on the Department of Energy to look for an Eastern state for the second repository. This is another example of legislation having a direct, and a perhaps profound, spatial effect upon the location of noxious public facilities.

In addition to the specification of categories of location factors, the NWPA also outlines the framework of a process that must be followed in making the repository location decision. This
framework is significantly expanded in the guidelines mandated by Section 112 (a). This process requires the Secretary of the Department of Energy to nominate at least five sites that are suitable for detailed site characterization as the first repository, and to recommend three of those five sites to the President to proceed with site characterization. Site characterization includes the sinking of an exploratory shaft to support the conduct of substantial testing of rock characteristics at repository depth in order to support the requirements of repository licensing. Each nominated site is required to be accompanied by an environmental assessment that documents the following: 7

(i) an evaluation by the Secretary (of Energy) as to whether such site is suitable for site characterization under the guidelines established under subsection (a);

(ii) an evaluation by the Secretary as to whether such site is suitable for development as a repository under each guideline that does not require site characterization as a prerequisite for application of such guidelines;

(iii) an evaluation by the Secretary of the effects of site characterization activities at such site on the public health and safety and the environment;

(iv) a reasonable comparative evaluation by the Secretary of such site with other sites and location that have been considered;
(v) a description of the decision process by which such site was recommended; and

(vi) an assessment of the regional and local impacts of locating the proposed repository at such site."

After characterization of at least three sites, the Secretary of Energy then recommends one of the characterized sites for the Nation's first repository. This recommendation is to be fully documented and is to include a final environmental impact statement prepared pursuant to the National Environmental Policy Act of 1969. The recommendation must also be promptly communicated to the governor and the state legislature in the affected state, and as appropriate, to the governing body of any affected Indian tribe.

The next step in the legislated process is that the President submits the recommendation of a single site to Congress, along with a copy of the Department of Energy's supporting documentation. This step starts the clock on one of the most interesting provisions of the NWPA.

Section 115 (b) of the Act states that, "The designation of a site as suitable for a construction authorization for a repository shall be effective at the end of the 60-day period beginning on the date that the President recommends such site to the Congress under section 114, unless the governor of the state in which such site is located, or the governing body of an Indian tribe on whose
reservation such site is located, as the case may be, has submitted to Congress a notice of disapproval under section 116 or 118. 9 The NWPA provides for a state and/or tribal veto of the President's site recommendation. Section 115 (c) then provides, "If any notice of disapproval of a repository site designation has been submitted to the Congress . . . such site shall be disapproved unless, during the first period of 90 calendar days of continuous session of the Congress after the date of the receipt by Congress of such notice of disapproval, the Congress passes a resolution of repository siting approval . . . approving such site, and such resolution thereafter becomes law." 9 Consequently, the Act provides that a state or tribal veto may be overturned by a majority vote in both Houses of Congress. This is an attempt to balance all the interests in the location process, while avoiding the absolute ability of a given state or tribe to stand unreasonably in the way of a solution to a national problem.

It should be noted that the process for the selection of a second repository follows much the same process as outlined above. One major difference is that there are carry-over sites from the first repository decision process to be considered, along with newly nominated second repository sites. In any event, the process framework specified in the NWPA has the potential to affect the location decision depending upon the ability of participating
parties to point out flaws in the recommendation decision and sustain that position in the Congress.

The NWPA also makes specific provision for structuring the Federal/state/tribal relationship in the location decision. Section 116 (b) and 118 (b) of the Act authorizes state and tribal grants to ensure that these key actors are fully involved, after the identification of potentially acceptable repository sites, in the location decision. This funding may be used to review technical work related to public health and safety, environmental, socioeconomic, transportation, and other impacts; to develop requests for Federal impact mitigation assistance; to monitor, test, and evaluate site characterization activities; to provide public information and education materials; and to interact with the Department of Energy.

Section 117 (c) of the Act calls on the Department of Energy to seek to enter into a binding written agreement with affected states or tribes during the decision process. Such "consultation and cooperation agreements" are to specify procedures for such activities as:

1) state/tribal involvement in the study, review and recommendations related to the full range of repository impacts,
2) the Department of Energy's response to comments or inquiries (including a time period for response),
3) modification of the agreement,
4) submittal of impact reports and requests for impact assistance,
5) specific topical commitments on the part of the Department of Energy regarding such issues as State liability for accidents, emergency response, baseline health studies, follow-up health monitoring, transportation monitoring, public notification, information sharing, etc.
6) resolution of state/tribal objections at any stage related to planning, siting, development, construction, operation or closure of the repository through negotiation, arbitration or other appropriate mechanisms.

Here, again, these agreements provide a mechanism for influencing the repository location decision.

The Siting Guidelines (10 CFR 960)

The Department of Energy, per the NWPA, was charged with the responsibility of preparing implementing regulations subject to concurrence by the Nuclear Regulatory Commission. Such regulations were titled "General Guidelines for the Recommendation of Sites for the Nuclear Waste Repositories," and are contained in
They became effective in January 1985. The paragraphs below summarize those provisions of these implementing guidelines that relate to the repository location problem.

The Siting Guidelines expanded the description of the required location decision process beyond that framework established in the NWPA. This process was segmented into five distinct phases: 1) site screening, 2) site nomination, 3) site recommendation for characterization, 4) site characterization, and 5) site selection.

Site Screening. This phase applies only to the search for the second repository because the first repository screening decisions were largely completed prior to the passage of the NWPA. Site screening is intended to focus increasingly the geographic scope from a national survey (narrow to regions), to a regional survey (narrow to areas), to an area survey (narrow to locations), and finally to a location survey (which narrows to sites). Proceeding from the national scale the "data for comparing regions, areas, and locations become increasingly detailed as progressively smaller land units are considered and as exploration and testing concentrate on them." The sizes of areas, locations, and sites are not precisely specified. Areas may be hundreds to thousands of square miles in size, while locations are typically tens to hundreds of square miles in aerial extent. Sites that are identified in this stage are approximately ten square miles in size.
Site Nomination Phase. Site nomination takes the potentially acceptable sites from the site screening phase, examines them for the presence of disqualifying conditions, and performs a comparative evaluation of the sites to determine the most suitable site in each "geohydrologic setting." The guidelines define geohydrologic setting as "the system of geohydrologic units that is located within a given geologic setting." The guidelines definition of geologic unit is "an aquifer, a confining unit, or a combination of aquifers and confining units comprising a framework for a reasonably distinct geohydrologic system." This comparative evaluation within each geohydrologic setting is based on the location factors described in Chapter III, some of which do not require site characterization and some of which do. The result of this phase's comparative evaluations is the nomination of at least five sites for detailed site characterization. These nominations are documented in the environmental assessments described earlier.

Site Recommendation Phase. A subset (three) of the nominated sites is to be recommended to the President for detailed site characterization. The Secretary of Energy's recommendations are to be based upon: "1) available geophysical, geologic, geochemical, and hydrologic data; 2) other information; and 3) associated evaluations and findings in the environmental assessments." This phase ends with the President's final acceptance of the three recommended sites.
Site Characterization Phase. Detailed site characterization will be conducted at the three sites recommended in the previous phase. Site characterization will include detailed geologic, hydrologic, geophysical, and other tests to definitively determine compliance with Guidelines' requirements. This will require the excavation of an exploratory shaft to allow testing at repository depth. In parallel with this testing, more detailed environmental, socioeconomic, transportation, and ease and cost-related studies will be performed. Results of all testing are required to be reported every 6 months to the Nuclear Regulatory Commission, the states and the affected tribes.

Site Selection Phase. This phase begins after the completion of site characterization. It includes yet another detailed comparative evaluation of the characterized sites, including a systems analysis or detailed repository performance assessment based upon data collected during site characterization. This phase includes the preparation of an environmental impact statement leading to the Secretary of Energy's recommendation to the President of a single site for repository development. If the President approves the recommendation, he recommends it to Congress for action which initiates the state/tribal veto provisions of the NWPA described previously.
The Siting Guidelines, as outlined in Chapter III, are organized into two distinct sets—postclosure provisions that govern the evaluation of repository performance after it is decommissioned and closed, and preclosure provisions which govern the siting, construction, operation, decommissioning, and closure periods. The substantive elements of both sets of guidelines were discussed in Chapter III. The paragraphs that follow summarize additional regulatory provisions in the Siting Guidelines that can affect the repository location decision.

Each technical guideline has a qualifying condition specified for it. The sum of all these qualifying conditions constitutes the minimum requirements for repository site qualification. Twelve of the technical guidelines are defined to have disqualifying conditions associated with them. The presence of a single disqualifying condition is considered sufficient evidence to eliminate a given site from further study. The technical guidelines also define favorable and potentially adverse conditions for each location factor. These provisions are designed to provide an early indication of total system performance, primarily for use in the site screening phase.

The Siting Guidelines provide that site comparisons must be based on systems guidelines to the extent that data will allow.
Systems guidelines are aggregations of technical guidelines and, basically, are the categories of location factors discussed in Chapter III. When such systems guidelines cannot be employed for site comparisons, the regulations require the use of the technical guidelines. Here, again, the regulations provide explicit direction to the location decision process.

One of the most intriguing provisions of the Siting Guidelines relates to the codification of value systems in the location decision. Section 960.3-1-5 states that, "Except for screening for potentially acceptable sites . . ., such evaluations shall place primary significance on the postclosure guidelines and secondary significance on the preclosure guidelines, with each set of guidelines considered collectively for such purposes." The regulations go beyond this in the same section to place a relative order of importance on the preclosure guidelines by stating, "The preclosure guidelines . . . contain eleven technical guidelines separated into three groups that represent, in decreasing order of importance, preclosure radiological safety; environment, socioeconomics, and transportation; and ease and cost of siting, construction, operation, and closure."

Thus, the regulations go beyond specifying the location decision process, and the detailed location factors to require that the
location decision be made in accordance with generic sets of weights that express social values. Clearly, however, there remains complete latitude to explore the implications of different values for the site screening phase, and bounded latitude within the above constraints for other phases of repository location. For example, the regulations do not specify an order of importance between environmental, socioeconomic, and transportation location factors. It is quite easy to conceive of different value systems ordering these factors in different ways in decision-making. The next chapter provides a model for accommodating the need to examine the geographical expression of such value differences in the repository location decision.

A few key points about 10 CFR 960's Implementation Guidelines are also important shapers of the repository location decision. This section is designed to expand upon the procedural framework mandated by the NWPA. Specifically, "The guidelines of this Subpart establish the procedure and basis for applying the postclosure and preclosure guidelines . . . to evaluations of the suitability of sites for the development of repositories."\(^{16}\) These provisions require that the search for a licensable repository location include a variety of geologic media and geohydrologic settings. This recognizes the risk of a fatal flaw being found in a given medium or setting, and buffers this risk by requiring diversity in the
search. Carrying on the concept of regionality established in the NWPA, the Siting Guidelines require that consideration be given to the regional distribution of the second and any subsequent repositories. Finally, Appendices III and IV of the Implementation Guidelines provide explicit direction concerning what kind of analytical findings are required for each major location decision, as well as specific types of information that are expected to be used in site nomination decisions.\(^{17}\)

**Nuclear Regulatory Commission Regulations (10CFR60)**

The final selection of a repository location is subject to the Department of Energy's ability to secure a license to construct the facility from the Nuclear Regulatory Commission. The procedures for this licensing process are contained in 10 CFR Part 60, "Disposal of High-Level Radioactive Wastes in Geologic Repositories: Licensing Procedures."\(^{18}\) This section briefly describes the provisions in these regulations with the potential to affect the repository location decision. With the application for a license to construct the repository, the Department of Energy must submit a Safety Analysis Report and an Environmental Report. The Safety Analysis Report must include, in part:\(^{19}\)

1) "A description and analysis of the site at which the proposed geologic repository operations area is to be
located with appropriate attention to those features that might affect the facility design and performance. The assessment shall contain an analysis of the geology, geophysics, hydrology, geochemistry and meteorology of the site and the major design structures, systems, and components, both surface and subsurface that bear significantly on the suitability of the geologic repository for disposal of radioactive waste."

2) "A description and discussion of the design, both surface and subsurface of the geologic repository operations area...."

3) "A description and analysis of the design and performance requirements for structures, systems, and components of the geologic repository which are important to safety."

4) "An identification of the natural resources at the site, the exploitation of which could affect the ability of the site to isolate radioactive wastes."

Thus, it is clear that the Nuclear Regulatory Commission will examine many of the same technical location factors that lead to the Department of Energy's site recommendation, prior to issuing a license to construct. Should the Commission have reservations about any of these factors, they have the authority to reject the application, leading to the need to locate the repository at another site.
The Environmental Protection Agency has the responsibility to promulgate radiation protection standards for high-level waste disposal. These standards are found in 40 CFR Part 191, "Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes." They apply to radiation doses received by members of the public as a consequence of the management (except for transportation) and storage of high-level waste, as well as its ultimate disposal. The standards also concern themselves with the contamination of ground water sources in the vicinity of a geologic repository.

The containment requirements under proposed 40 CFR 191 are "designed to provide a reasonable expectation, based upon (repository) performance assessments, that the cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal system shall:"

1) have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to (Table 2); and


<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Release Limit per 1000 MTHM or Other Unit of Waste (Curies)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Americum -241 or -243</td>
<td>100</td>
</tr>
<tr>
<td>Carbon -14</td>
<td>100</td>
</tr>
<tr>
<td>Cesium -135 or -137</td>
<td>1000</td>
</tr>
<tr>
<td>Iodine -129</td>
<td>100</td>
</tr>
<tr>
<td>Neptunium -237</td>
<td>100</td>
</tr>
<tr>
<td>Plutonium -238, -239, -240, or -242</td>
<td>100</td>
</tr>
<tr>
<td>Radium -226</td>
<td>100</td>
</tr>
<tr>
<td>Strontium -90</td>
<td>100</td>
</tr>
<tr>
<td>Technetium -99</td>
<td>10,000</td>
</tr>
<tr>
<td>Thorium -230 or -232</td>
<td>10</td>
</tr>
<tr>
<td>Tin -126</td>
<td>1000</td>
</tr>
<tr>
<td>Uranium -223, -234, -235, -236, or -238</td>
<td>100</td>
</tr>
<tr>
<td>Any other alpha-emitting radionuclide with a half-life greater than 20 years</td>
<td>100</td>
</tr>
<tr>
<td>Any other radionuclide with a half-life greater than 20 years that does not emit alpha particles</td>
<td>1000</td>
</tr>
</tbody>
</table>

2) have a likelihood of less than one chance in 1000 of exceeding ten times the quantities calculated according to (Table 2)."

The ground water protection requirements require that the repository, "shall be designed to provide a reasonable expectation that, for 1000 years after disposal, undisturbed performance of the disposal system shall not cause the average annual radionuclide concentrations in the water within any significant source of ground water outside the controlled area to exceed:

1) 5 picocuries per liter of radium - 226 and radium - 228;
2) 15 picocuries per liter of alpha-emitting radionuclides (including radium-226 and radium-228); or
3) the combined concentrations of radionuclides that emit either beta or gamma radiation that would produce an annual dose equivalent to the total body or any internal organ greater than 4 millirems per year if an individual continuously consumed 2 liters per day of drinking water from such a source of ground water."^22

Here again, if the above standards of performance cannot be expected to be met at a given repository site, another site must be found that can be reasonably expected to meet the standards. Thus the Environmental Protection Agency plays a potentially significant role in the location decision.
Other Federal Regulatory Constraints

The previous sections of this chapter have reviewed the major legal/regulatory constraints at the Federal level that shape the repository location decision. This section recognizes that there are a whole host of additional Federal regulations that can incrementally shape the spatial distribution of repositories. Table 3 summarizes additional Federal regulatory requirements that relate to major nuclear public works projects.23 It is not a comprehensive list, but provides additional perspective on the potential effects of such authority constraints on the public facility location decision, or in many cases, also the private facility location decision.

State and Local Legal/Regulatory Constraints

In addition to Federal legal/regulatory constraints, the siting of noxious public facilities is shaped by state and local constraints. Bruce addresses one major category of such constraints, state and local environmental regulations, when he points out that, "They can delay or even prohibit industrial development of an area. Unforeseen technical problems, such as soil conditions or ground water contamination, can make it impractical to develop a piece of property. The local government's permitting process may be cumbersome—if zoning changes or conditional land use
## TABLE 3
TYPICAL CONSTRUCTION/OPERATING PERMITS REQUIRED FOR NUCLEAR FACILITIES

<table>
<thead>
<tr>
<th>Agency</th>
<th>Required Approvals</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Construction</strong></td>
<td></td>
</tr>
<tr>
<td>Environmental Protection Agency</td>
<td>Clean Air Act approvals</td>
</tr>
<tr>
<td>U.S. Army Corps of Engineers</td>
<td>Dredge and fill permit for waterfront construction</td>
</tr>
<tr>
<td>Federal Aviation Administration</td>
<td>No hazard determination</td>
</tr>
<tr>
<td>Department of Interior</td>
<td>Approval to construct on certain Federal lands;</td>
</tr>
<tr>
<td></td>
<td>Consultation under Rare and Endangered Species Act</td>
</tr>
<tr>
<td><strong>Operations</strong></td>
<td></td>
</tr>
<tr>
<td>Nuclear Regulatory Commission</td>
<td>Operating license</td>
</tr>
<tr>
<td>Environmental Protection Agency</td>
<td>National Pollutant Discharge Elimination Permit under the Clean Water Act</td>
</tr>
</tbody>
</table>

authorizations are needed, they often require public hearings, legislative actions and other time-consuming steps". While this point is focused on private sector industrial development, the same constraints can shape public sector location decisions.

Thompson and Harding also address the significance of state and local legal/regulatory constraints, primarily related to the private sector location decision. These authors point out that, "There has been little attention paid to the seemingly mundane issue of how administrative procedures associated with permitting a new plant affects the site selection process". They point to several instances where plant location decisions were materially affected by difficulties in securing requisite environmental permits and land use zoning changes. In addition, they cite experience with companies where the siting demands were so urgent that whole states were dropped from consideration on the basis that they did not have a track record of being able to issue environmental permits within a six month period.

What is the influence of state and local legal/regulatory considerations in repository siting? The Department of Energy has articulated a policy of abiding by state and local laws and regulations, as long as they do not compromise the ability to meet their responsibilities under the NWPA. This sets up a very sticky predicament. States which pass cumbersome or unnecessarily
burdensome requirements, targeted at driving the repository location decision out of that state, could prompt a determination by the Department of Energy to ignore those laws or regulations. This would quickly lead to litigation over the supremacy of the NWPA over state and local statutes. State and local requirements that could lead to such a confrontation include:

1) requirements for a state environmental assessment prior to repository-related field investigations,
2) requirements for drilling permits prior to exploration of the subsurface environment,
3) requirements for state administered air quality, water quality, or solid/hazardous waste permits,
4) requirements for state involvement in the transportation of waste.

Consequently, the tangible influence of state and local laws/regulations on repository location is somewhat difficult to predict. Certainly, the Department of Energy cannot drop states from consideration on the basis of anticipated legal/regulatory difficulties. This would not be equitable, and would reinforce state incentives to create legal/regulatory impediments as a tool to keep the facility out of their area. However, the Department must take the state and local perspective on environmental, safety, and land use issues into account, and this may help shape the location decision. Likewise, conflict between Federal, and state and local authorities is conceivable, and the courts may well play a
significant role in determining the extent to which state and local laws/regulations will impact the location decision.

Implications for Inductive Generalization. This section has reviewed the role of Federal, state, and local laws/regulations in decisions to locate a repository for high-level nuclear waste. It is clear that, in the case of repository siting, both Federal law and regulation have a very direct and material effect on the location decision in the following ways:

1) The N W P A and the Siting Guidelines (10 CFR 960) provide an explicit framework for the location decision process itself.

2) The N W P A and the Siting Guidelines (10 CFR 960) provide detailed direction concerning multiple location factors that must be considered in making repository location decisions.

3) The N W P A and the Siting Guidelines (10 CFR 960) provide generic guidance on the social value judgments that must be made in trading off the relative importance of location factors. They also direct that value judgments be incorporated into the decision process.

4) The regulations promulgated by the Nuclear Regulatory Commission and the U.S. Environmental Protection Agency impact the location decision largely on the basis of "bottom line" regulatory provisions that establish thresholds of acceptability in repository preformance.
5) State and local laws/regulations also have the potential to spatially influence repository location, but through vehicles that are less certain given potential conflicts between Federal, and state and local authority.

**Institutional Authority Constraints**

This section describes another category of authority constraints that can influence the location of noxious public facilities, the institutional constraint. Such constraints are defined herein to include the roles, responsibility, authority, and accountability of government institutions in siting noxious public facilities. The credibility of these institutions in the performance of their individual roles has a significant effect upon the degree to which successful location decisions are possible, upon the pace at which such decision making will proceed, and upon the spatial distribution of such facilities. The Office of Technology Assessment has concluded that, "the greatest single obstacle that a successful waste management program must overcome is the severe erosion of public confidence in the Federal Government."[^26] This public confidence problem is conditioned by policy instability, poor execution of public policy directives, and general perceptions of trustworthiness.
The paragraphs that follow summarize the roles, responsibilities, authority, and accountabilities of key Federal, state, local, and tribal actors in making repository location decisions. The role of the court system and of general public involvement is also described. The objective of all this is the search for insights into the role of institutional constraints in repository location that can be generalized as a contribution to location theory applicable to noxious public facility location problems.

Federal Institutional Actors. Previous pages have referenced the U.S. Department of Energy, the Nuclear Regulatory Commission, and the U.S. Environmental Protection Agency as important Federal contributors to repository location decisions. This section describes the roles these and other Federal institutions play in repository siting, and the degree of influence such institutions exert on the spatial distribution of such facilities.

The Department of Energy. As previously referenced, the Department of Energy (DOE) is the lead Federal Agency charged under the Nuclear Waste Policy Act (NWPA) with the responsibility to find suitable and licensable repository sites. The Department promulgated the Siting Guidelines (10 CFR 960) to direct this effort. In executing this responsibility, the DOE must develop productive relationships with other Federal agencies, and with state and tribal governments. One
important vehicle authorized by the NWPA to achieve this is the "consultation and cooperation agreement" discussed earlier. The DOE must maintain clear traceability of documentation for each screening decision made, including the preparation of major decision documents such as the environmental assessments that must accompany site nomination. It must defend such decisions in various public forums, and as required, in the courts. Ultimately, the DOE is responsible for the recommendation of repository sites to the President; for the defense of such recommendations to the states, tribes, and Congress; for the submittal of an application to the Nuclear Regulatory Commission to construct the facility; and for the operation, maintenance, decommissioning, and closure of the facility.

The authority to execute these responsibilities is contained in the NWPA. In doing so, the DOE is directly accountable to the President, to Congress, to the Nuclear Regulatory Commission, and is more indirectly accountable to the states, affected Indian tribes, and to the public at large. Exercising this authority, within the constraints specified in the NWPA, the DOE will have a direct proactive impact upon repository location decisions.

The Nuclear Regulatory Commission. The Nuclear Regulatory Commission (NRC) is the independent regulatory authority that licenses the construction and operation of high-level waste repositories. In support of this role, the NRC is responsible for
the development and implementation of licensing regulations that ensure the protection of the public health and safety (see previous discussion of 10 CFR 60). The NRC has the potential to directly affect location decisions by refusing to issue a license to construct, or a license to operate at a site deemed inadequate to meet the stringent requirements to protect public health and safety. The NRC, an independent agency, is somewhat insulated from the President and from Congress. It is ultimately accountable to the general public in its decisions.

The Environmental Protection Agency. The Environmental Protection Agency (EPA) is responsible for the development and application of regulations that set standards for radiological exposures, for ground water protection, and for the attainment of air quality, water quality and waste management goals. (See previous discussion of 40 CFR 191). These regulatory standards provide bounds within which the search for suitable repository sites must proceed. The standards have direct implications for the desired physical characteristics of candidate sites, and consequently, for the spatial distribution of repository facilities. The EPA, also an independent agency, is indirectly accountable to the President and to Congress and the public at large.

Other Federal Agencies. There are a whole host of additional Federal agencies, each with its own mission objectives, that may
play a role in repository location decisions. For example, the U.S. Geologic Survey (USGS) consults with the DOE on geotechnical issues, conducts relevant independent geologic investigations, and will ultimately make independent geotechnical recommendations to NRC in the licensing process. The Department of Interior (DOI) has agencies with custodial responsibility for Federal lands. To the extent such lands might be affected by repository location decisions, the DOI will have the responsibility to review such proposals and make recommendations to the President regarding changes in dedicated land uses. The Department of Agriculture's Forest Service has similar responsibility for National Forest Lands.

State Institutional Actors

The NWPA, as described previously, provides a role for both the executive and legislative branches of affected state governments. While this role is often as an antagonist to the DOE in the location decision process, the maintenance of an open and constructive dialogue between state and Federal authorities is mutually important. The NWPA and 10 CFR 960 attempt to provide the structure for this interaction in the following ways:

1) Requirements for open sharing of information relating to location decisions,

2) Formal consultation and cooperation agreements that commit to a structure and responsiveness in Federal/state interactions,
3) Federal funding of state participation for contributing to and monitoring the results of location studies,

4) Formal opportunity for the executive and/or legislative branches of state government to veto site recommendations (subject to the Congressional override).

One of the intriguing complexities of the repository location problem is that both the executive and legislative branches of state government are accountable to state political constituencies. These constituencies, for the most part, view the location of a repository in their state as a distinctly negative prospect because of the perceived risks involved. Consequently, while there is an undeniable national waste management problem to solve, virtually no state is likely to be willing to seek out such a facility for their state. This results in significant state resistance, and stress between Federal and state authorities throughout the decision process. The National Research Council put it this way: "The federal government is the advocate of the national interest in safe, efficient disposition of spent fuel and radioactive wastes; states, through their governors or legislatures, are presumed to speak for locally affected populations concerned about risk, protection of property rights, due process, and other burdens borne by those living near a proposed site."27
Local Government Institutional Actors

The NWPA, respecting the customs of federalism, did not provide directly for institutional links between local and Federal agencies. Local interests are presumed to be incorporated by state authorities in their interactions with DOE. Thus, local community interests are indirectly represented to Federal authorities via the states, and there is no guarantee that Federal funds provided the states will be used in ways that satisfy local communities. Nonetheless, it is certainly conceivable that local government actions could influence location decisions in favor of the facility on economic grounds, or against the facility on health and safety risk grounds. Predicting the influence is very difficult, however, particularly since additional uncertainty is generated in the nature of the local-state relationship.

Tribal Institutional Actors

The NWPA provides potentially affected Indian tribes with basically the same roles, responsibilities, and authority as it does the states. For example, tribal governments may be party to individual consultation and cooperation agreements with DOE, may request Federal funding support, and may exercise veto rights if the site location decision directly affects tribal lands.
One of the major geographic uncertainties concerning tribal involvement relates to the definition of a potentially affected tribe. Clearly, such status is achieved when tribal reservation lands might be directly impacted. Less clear, however, are those lands for which tribes hold off-reservation hunting, fishing, and gathering rights. In some cases, Indian tribes maintain such rights over vast expanses of lands. The resolution of this issue, perhaps ultimately in the courts, may affect the geographic influence of Indian tribes over the repository location decision.

One other tribal issue could have an effect upon the possibility of locating a repository on tribally owned lands. This is the issue of land transfer. The DOE can exercise the right of eminent domain to acquire non-Indian lands, if direct purchase proves difficult. The direct transfer of Indian lands to the DOE typically, depending on the specifics of treaties, requires an Act of Congress. Consequently, an additional institutional constraint or barrier would be faced in the transfer of Indian lands for repository development. This would provide additional opportunity for tribal representatives to prevent such development, thus potentially influencing the location decision by transferring development to another site.
Judicial Institutional Actors

Previous sections of this chapter have alluded to specific examples of disputes between the various actors involved in the repository location decision that could end up in the courts for resolution. Section 119 of the NWPA specifies that, "Except for review in the Supreme Court of the United States, the United States Courts of Appeals shall have original and exclusive jurisdiction over any civil action-

A) for review of any final decision or action of the Secretary (of Energy), the President, or the (Nuclear Regulatory) Commission under this subtitle;

B) alleging the failure of the Secretary, the President, or the Commission to make any decision, or take any action, required under this subtitle;

C) challenging the constitutionality of any decision made, or action taken, under any provision of this subtitle;

D) for review of any environmental impact statement prepared pursuant to the National Environmental Policy Act of 1969 (42 U.S.C. 4321 et seq.) with respect to any action under this subtitle, . . . or alleging a failure to prepare such statement with respect to any such action;

E) for review of any environmental assessment prepared under section 112 (b)(1) or 135 (c)(2)."
Consequently, the Act specifies rather clearly the scope of judicial review, the courts that have jurisdiction, and even in some instances, the criteria to be employed in judicial review.

Thus, the courts are equipped to resolve disputes among institutional actors throughout the decision process. The decisions of the courts could have a direct effect upon the location of repositories. For example, if a court ruled that the Final Siting Guidelines (10 CFR 960) were inadequate, the DOE and NRC could have to rethink the decision process, the detailed location factors, and/or the value system proposed for categories of location factors. The courts could also rule that environmental assessments accompanying site nomination were inadequate in some way. Both of these hypothetical rulings could directly affect the spatial distribution of repositories.

Public Involvement

Now that the major government institutions involved in shaping repository location decisions have been described, it is appropriate to briefly discuss the role of general public involvement in the decision process. Often cited advantages of a well-structured and thoughtfully executed public involvement program include:

1) It achieves a higher level of public acceptance or, at least, a lower level of active public opposition.
2) It improves the quality of the decision through sensitizing
decision-makers to public values and factors not subject to
predictive modeling.

3) It enhances the ability to defend decisions as being
procedurally reasonable.

Section 111 of the NWPA notes that "state and public
participation in the planning and development of repositories is
essential in order to promote public confidence in the safety of
disposal of such waste and spent fuel." This statement
recognized that public involvement, in essence, conditions the whole
environment within which institutions function in making repository
location decisions. While it is impossible to predict the precise
spatial implications of such involvement, it should not be
overlooked as a force in helping to shape location decisions. The
section on "political constraints" discusses these influences in
somewhat more detail.

**Implications for Inductive Generalization**

This discussion of institutional constraints in repository
siting has surveyed the diverse array of actors that have relevant
roles, responsibilities, authority, and accountability. Reflecting
upon these constraints leads to the following generalizations that
need to be kept in mind as applicable location theory is formulated:

1) Models or methods developed to assist in predicting
location outcomes for noxious public facilities must recognize the potential spatial influence of institutional constraints. That is, it is important to understand and accommodate the complexities of institutional interactions in decision-making.

2) It is easier to accommodate the direct influences of major institutional actors in predicting location outcomes, than to accommodate the subtle influence of minor players or diffusely defined participants (e.g., the general public).

3) Some sort of boundedly rational behavior must be assumed in institutional interactions. This requires significant generalization (e.g., states act to prevent the location of a repository within their borders).

Political Authority Constraints

The final category of authority constraint reviewed in this chapter is the political constraint. It is clear that the successful siting of a noxious public facility is a political as well as a technical challenge. This section characterizes the nature of the political constraints that condition the repository location decision, as well as the spatial implications of such constraints. Here again, the objective is to search for useful generalizations that will help in the formulation of applicable location theory.
Politics of Locally Undesirable Land Uses

The high-level waste repository can be classified with confidence as a locally undesirable land use (LULU). Other types of noxious public facilities or LULU's include low-level radioactive waste disposal facilities, chemical/hazardous waste disposal facilities, municipal waste disposal facilities, correctional facilities, and freeways. Each of these facilities serves an essential and useful social function which yields benefits to a large and often diffuse segment of society (e.g., users of nuclear energy in the U.S.). However, the location of such facilities also imposes rather significant costs on a localized segment of society. Such costs might include economic and social disruption, incrementally higher health and safety risks, and related costs. This creates a political environment in which, in the case of the high-level waste disposal problem, state and local politicians are naturally motivated to avoid the political risks of advocating the solution of a national problem at the expense of their state/local constituents. In fact, the typical motivation, politically, is to visibly fight any attempt to locate a LULU within a politician's district or jurisdiction. In contrast, politicians with a national perspective are more likely to advocate a location decision that solves the problem, even though some locale will necessarily bear a disproportionate share of the costs of that solution.
It is precisely this political predicament that the Nuclear Waste Policy Act was designed to resolve. It provides the framework for the complete range of political motivations to work their will in the location decision process. Ultimately, the outcome is designed to solve a problem that is national in scope while preserving the rights and responsibilities of the state and local actors to challenge the location decision at each step in the process.

Examples of Political Constraints

The concept of political constraints permeates the entire location decision process. Such constraints also often have quite unpredictable results because of the complexity of political interactions. Understanding the political process, and the major driving forces of that process, is important to predicting the spatial distribution of locally undesirable land uses. This section reviews examples of political constraints at work in repository location.

The search for the Nation's second repository currently involves study of seventeen eastern states, some of which border Canada. While the NWPA did not mention proximity to Canada as an important location factor, international political considerations have led the DOE, in concert with the Department of State, to agree with the
Canadians that no repository location would be selected that would require field investigations on Canadian soil. This has had the effect of limiting candidate sites to beyond approximately 25 miles from the Canadian border. All of this negotiation was driven by concerns in Canada about the impacts of a repository located across the border in the U.S.

The concept of regionality built in to the NWPA is, in part, a result of the application or political constraints. When the NWPA was conceived, it was recognized that the first repository was most likely to be located in a Western state. Given the fact that most of the Nation's nuclear power plants are in the Eastern U.S., political equity called for the location of the second repository to consider the location of the first. A technical risk management argument could also be made for such a regional distribution on the grounds that transportation miles/exposures should be minimized in getting the waste from the sources to the repository.

Implications for Inductive Generalization

The concept of political authority constraints on the location of noxious public facilities must also be considered in the search for predictability through applicable location theory. Some
Inductive generalizations about political constraints drawn from this research include:

1) Political constraints both affect, and are affected by, the institutional constraints discussed previously. Institutional constraints such as the NWPA and the Siting Guidelines (10 CFR 960) provide structure for political interaction. They are also a target for politically motivated change.

2) With respect to repository location decisions, there is clearly an antagonism between state and local, and Federal interests. While provision has been made for full state and local participation in the location decision process, it must be presumed that an informed national perspective will be maintained when Congress makes the ultimate decision.

3) Predictability in theory development for noxious public facilities requires an understanding of the fundamental political constraints and of how decision-makers are likely to act on those constraints.

4) It must be assumed that the political process is rational enough that it will not yield a location decision that does not meet the requirements of the technical location factors.
Summary of Public Policy Influences

This chapter has examined ways in which public policy shapes noxious public facility location decisions through legal/regulatory, institutional and political authority constraints. These public policy influences include:

1) Laws/regulations provide an explicit framework for the location decision process.

2) Political interactions are largely focused within the specified decision framework, although political forces may be exerted to modify that framework.

3) Laws/regulations provide explicit definitions of the location factors that must be employed in evaluating location options.

4) Laws/regulations provide generic guidance on the application of social values in the location decision.

5) Laws/regulations specify minimum levels of performance for the facility, below which an alternative location must be found.

6) State and local laws/regulations can spatially influence the location decision, but in a less predictable manner given potential conflicts with Federal authority.

7) Institutional interactions within the decision process are largely well-defined in law and regulation. These interactions, particularly between DOE, NRC, EPA, states and tribes, directly shape the location decision.
8) Boundedly rational behavior must be assumed in the decision process such that any resulting location decision meets the technical requirements, as well as being politically acceptable.

The next chapter discusses the development and application of a regional model or methodology for incorporating technical requirements and authority constraints into the location decision for high-level waste repositories.
CHAPTER IV REFERENCES


CHAPTER V
DEVELOPMENT AND APPLICATION OF A REGIONAL SCREENING
METHODOLOGY FOR NOXIOUS PUBLIC FACILITIES SITING

Chapter Overview

This chapter describes a methodology conceptualized by the author, and developed and implemented under the author's supervision, to perform the regional phase screening for the Department of Energy's Crystalline Repository Project.* The objective is not to repeat work documented in other reports, but to use this methodology development and application experience as a vehicle for deriving additional inductive generalizations to help form the foundation for the contributions to location theory outlined in the final chapter. This Crystalline Repository Project case study is thus utilized to extract theoretical concepts that are more broadly applicable to the location of noxious public facilities.

* The Crystalline Repository Project is a Department of Energy initiative, under the NWPA, designed to identify candidate sites for the Nation's second repository in crystalline rock formations. Battelle's Project Management Division, the author's employer, is the prime contractor for the DOE in the management and execution of this project.
A review of the appropriateness of multiobjective screening approaches for the noxious public facilities location problem is provided. A brief summary of the range of potentially applicable multiobjective approaches is followed by an explanation of the rationale for selecting the weighted summation approach. The key methodology design criteria are characterized and related to the driving forces described in previous chapters. These driving forces include the multiobjective nature of the repository location problem, the technical complexity involved, and the authority constraints that shape the location decision.

The chapter includes a summary level description of a four-step screening methodology designed to accommodate the driving forces in noxious public facility location decisions. For each step, not only are key concepts described, but sample results of the application of that step to the three-state North Central Region are presented. The North Central Region is one of three regions involved in the regional phase of the Crystalline Repository Project. It is comprised of the States of Minnesota, Wisconsin and Michigan (Upper Peninsula). This region was selected for illustrative purposes because it is representative of the complexity of applying a multiobjective screening approach to a multi-state region.
Review of Multiobjective Screening Approaches

The literature review presented in Chapter II compared and contrasted the noxious public facility location problem with the private industrial location decision that has been the principal focus of location theory development. It pointed to the following characteristics that differentiate the two location problems and drive the selection of a model for use in theory formulation:

1) Private sector-oriented location theory is driven principally by assumptions of economic rationality (e.g., profit maximization, cost minimization etc.). While noxious public facility location problems must account for economic considerations (usually cost minimization), they are driven by non-economic factors, such as service maximization, impact minimization, health and safety protection, etc.

2) The location of noxious public facilities requires consideration of multiple objectives expressed through a diverse set of location factors that are not measurable in a common dollar metric (e.g., health and safety, environmental, socioeconomic, transportation, and ease and cost).

3) Because of the numerous categories of distinctly different location factors, the expression of value judgements or preferences can have a substantial effect upon the location
decision. It is, therefore, important to be able to explore the trade-offs, in geographic terms, of using alternative factor weights in the location of noxious public facilities.

4) In its essence, the noxious public facility location problem is not an optimization problem, but rather one of satisficing or finding a location that is good enough to satisfy the multiple objectives at acceptable levels. Such acceptable levels are specified in the authority constraints described in Chapter IV for repository siting.

Considering these characteristics of the noxious public facility location problem, multiobjective screening approaches provide the best model of how such decisions are spatially expressed. The following summarizes the characteristics of major multiobjective decision approaches, and describes why the weighted summation method was selected as most appropriate for regional phase studies of repository location, and for the extension of location theory in this dissertation.

**Exclusionary Screening**

This approach to location decision-making relies on a clearly defined boundary between acceptable and unacceptable conditions for each location factor employed. The disqualifying conditions in the DOE Siting Guidelines (10 CFR 960) provide examples of factors
where exclusionary screening is appropriate. The disqualifiers define specific conditions which, if present, would eliminate the affected geographic area from further consideration. Examples of such conditions include areas within the boundaries of National Parks or highly populated areas. A single disqualifier is sufficient to eliminate such areas. The exclusionary screening approach requires that location factors be defined in black/white, unacceptable/acceptable terms. Thus, the problem with this approach is that many location factors cannot be defined with a single threshold of acceptability. For many factors, there are only "shades of grey" differences in the acceptability of conditions for that factor, and it makes little sense to define them in black/white terms. The exclusionary approach also ignores important value-laden trade-offs among location factors and is not sensitive to subtle differences in levels of acceptability. Often these subtle differences are important discriminators in the location decision.

Conjunctive-Ranking Method

This approach is quite similar to exclusionary screening, with one significant exception. This method treats every location factor but the last one applied as an exclusionary factor. Geographic areas that survive the application of all the black/white (exclusionary) factors are then ranked in order of acceptability in terms of a final location factor, with the top-ranked site being selected.
This method is most commonly used in the final stages of site location. For example, it could be used after all candidate sites are qualified on environmental, socioeconomic, transportation, and ease and cost factors. The final ranking could then be accomplished on health and safety grounds as defined by postclosure repository performance. It should be noted, however, that this method shares the same weaknesses as the exclusionary approach, specifically in its inability to capture value trade-offs between location factors in the location decision.

Copeland's Reasonable Social Welfare Function

This approach is also most applicable in the latter stages of site comparison and selection. It focuses upon a series of pairwise comparisons among candidate sites. Each site is compared with every other site, one at a time, using what is termed the "Majority Rule". The Majority Rule calls for the pairwise comparison of site attributes and the selection of the one site with the largest number of better attribute levels. Doing so ignores the degree to which the preferred site is better than the second site. For example, a few large differences in attribute conditions may be more important than many small differences. It also typically assumes that all factors are of equal importance to the location decision. These weaknesses make this approach unattractive as a model for the noxious public facility location problem.
Direct Determination of Indifference Curves

This approach to the location decision requires that decision-makers decide what combinations of attribute levels define a level of indifference, or what economists term the diminishing marginal rate of substitution, among attributes. Basically, this method results in a series of indifference curves, each of which represents different levels of equal aggregate suitability. The site determined to lie on the highest indifference curve is the preferred site.

This method has its own set of advantages and disadvantages as a model for the noxious facility location decision. It employs direct value judgments elicited from location decision-makers, which is a distinct advantage. However, the approach becomes a quagmire of complexity as one proceeds beyond the consideration of two attributes to consider the numerous attributes that need to be accounted for in noxious public facility location. This makes it largely impractical to apply until possibly the final major trade-offs that need to be considered in the location decision.

Goal Programming

This multiobjective location decision approach seeks to identify the location alternative which exhibits the smallest deviations from
a set of prespecified goals. In performing such an analysis, this approach "assumes than an attribute level X amount greater than a goal is just as desirable as an X amount less." Thus, it is the magnitude of the deviation, not the direction of the deviation, which is of consequence to this approach.

This method was not deemed an appropriate model for the noxious public facility location problem for several reasons. As Hobbs puts it, "Most . . . attributes, however, are either monotonically increasing or decreasing with respect to site desirability (e.g., cost, water availability, aquatic ecosystem impact, ground water contamination potential). Setting goals for such considerations is artificial and difficult." Thus, goal setting itself presents a problem. Secondly, this method does not lend itself to geographical expression. It also does not apply very well to regional scale location decisions.

Hurwicz Procedures

This class of location decision rules concerns itself only with extreme values of site attributes, that is with each candidate site's worst (minimax) or best (maximax) attributes. Decisions are driven by minimizing the worst conditions or by maximizing the best conditions. This approach is also most applicable in the final stages of the location decision. However, it shares a distinct
weakness with previously described approaches in that its application does not make trade-offs between location factors explicit, nor does it address the issue of value judgments or expressed preferences. It also is not very geographic in the expression of results.

**ELECTRE**

ELECTRE is a method that combines key elements of the Copeland Reasonable Social Welfare Function and Hurwicz procedures. In this approach to the location decision, each identified site is compared to each of the other sites through the calculation of two indices: 1) the concordance index, and 2) the discordance index. The concordance index is defined to be the weighted sum of the number of attributes for which the first site is better than the second. The discordance index is defined to be the maximum weighted difference in value of an attribute for which the first site is worse than the second. Hobbs states that, "The first site is said to 'outrank' the second when the concordance index exceeds a prespecified threshold, while the discordance index is not worse than another given level. Many sites not outranked by any alternative may remain. For this reason, ELECTRE is most appropriate for reducing a large number of candidate sites to a more manageable set for final selection."
The ELECTRE method shares some of the weaknesses of the two approaches from which it was derived. For example, it may be difficult to define the threshold for the concordance index. In addition, this approach does not geographically express value trade-offs in the location decision.

Decision Analysis

Decision analysis is a general approach to location decision-making which has one major difference from other multiobjective methods. The difference is that it explicitly takes into consideration uncertainty or risk through the development of probability distributions for each location factor at each candidate location. This treatment of location factors as stochastic rather than as deterministic phenomena offers the potential for improved information upon which decisions can be based. However, decision analysis is not without its own set of problems. First, it is often quite difficult to quantify probability distributions or risks for the wide range of factors that must be addressed in many location decisions. Doing so adds substantial complexity to the location decision, and sometimes can lead to difficulty with decision-makers more accustomed to the application of subjective probabilities. Consequently, decision analysis is difficult to implement in practice, and is also difficult to explain to the various affected constituencies in public sector location decisions. It is not
easily adapted to generate products with a geographical orientation. It seems most applicable to the kinds of comparative site analyses that need to be conducted in the final stages of the location decision, where the location problem is more tightly defined than earlier location screening studies done at national or multi-state regional scales.

Weighted Summation Method

This method has been employed in numerous location decision applications, and is viewed in this research as the preferred model for the noxious public facilities location problem at the multi-state regional scale. In the weighted summation method, aggregate or composite suitability is estimated as follows:

$$\text{Suitability} = \sum_{i=1}^{n} W_i V_i (X_i)$$

where $W_i$ is the weight, and $V_i ( )$ the value function of attribute $X_i$.

Thus, this method relies upon the development of standard measures for each location factor and upon the assignment of weights to each factor that represent the relative importance of the factors in the location decision. While the detailed application of this method will be described subsequently in the context of regional
screening for repository sites, it is important to understand the fundamental assumptions upon which weighted summation is based. Hobbs describes these assumptions as follows:

1) The attributes or location factors are additive independent. This means that each attribute's value function or measure is constant over all levels of the other attributes.

2) Attributes or location factor value functions or measures are interval scales. Interval scales are defined as those for which there is an arbitrary zero point but the differences between numbers are meaningful. Such scales can have mathematical operations performed on them.

3) Weights are ratio scaled and are indications of the relative importance of unit changes in attribute or location factor value functions. The zero point on a ratio scale is not arbitrary. It indicates a zero quantity of the item being measured.

4) Decision-makers are more concerned with making informed, multiobjective trade-offs than with achieving predetermined goals. In addition, decision-makers must be willing to express value judgements in the process of making trade-offs.

The weighted summation method offers several important advantages as a model of the multiobjective noxious public facilities siting problem, at least at the multi-state regional
scale. It is readily adaptable to geographic expression in map products that can serve as useful tools in predicting the geographic distribution of such facilities. It explicitly recognizes the need to evaluate trade-offs among multiple objectives that otherwise would be obscured, including trade-offs between economic and non-economic objectives. Thus, it is a model oriented to satisficing, rather than to optimizing. It can be adapted to account for the diverse range of location factors that typically must be accounted for in predicting the outcome of noxious facility location problems. It can also accommodate various kinds of legal/regulatory, institutional and political authority constraints that, as discussed in Chapter IV, materially affect such location decisions. This is accomplished through the selection, definition, and measurement of location factors; through the use of weights that are broadly representative of a range of value systems; and through the use of maps that can geographically express the implications of alternative value systems for the location decision. This last advantage offers a type of sensitivity analysis that is geographically based. Such analysis aids in the formulation of applicable location theory, and in the capture and potential accommodation of diverse public interests in the application of the model.

The weighted summation method has been criticized by some on several grounds, and it is important to understand the implications
of such criticism before using the method as a vehicle for theory
development. Hobbs summarizes the criticisms of weighted summation
as follows:10

1) It is prone to violations of measurement theory in the
scaling and weighting of attributes or location factors. This
problem can be avoided simply by attentiveness to the
differences among ordinal, interval, and ratio measures,
and by ensuring that location factors are measured by
interval or ratio measures and that weights are ratio
measures. This will allow for the valid application of the
simple mathematics called for by weighted summation.

2) It is subject to unrealistic assumptions about how
decision-makers' values are structured. This can be
handled, in large part, by the commitment to examine the
geographic significance of a wide range of value systems
for the location decision. This is particularly important
to public facility location which is subject to influence
from a much larger cross section of values that is the
typical private sector location decision. More on this
subject will be presented in the discussion of weighting
subsequently in this chapter.

3) The method leads to ambiguous and unreliable results.
Complex, multiobjective and value-laden location decisions
are bound to be plagued by a full measure of ambiguity.
Being able to deterministically predict the exact location
of all such facilities is beyond the realm of possibility using this or any other model. However, the weighted summation method provides a useful framework for evaluating the noxious public facility location problem, and for the extraction of theoretical implications.

4) Such methods are essentially irrelevant to a location decision process that is inherently political, and as such, must take into account many intangibles and different perspectives in decision-making. The previous chapter recognized this reality in the discussion of authority constraints, including institutional and political constraints. The development of theory applicable to the noxious public facility location problem requires that a certain rationality be assumed in the way such constraints influence location decisions. The open decision process called for by law and by regulation in repository siting provides a useful study of how such constraints might be handled in the formulation of theory. The regional screening methodology described in this chapter recognizes the influences of political authority constraints, and provides the structure from which Chapter VI's theoretical conclusions are drawn.
Examples of Weighted Summation Applications

This section describes several examples of how weighted summation models have been utilized in location analysis. This review sets the stage for the subsequent discussion of the regional screening methodology employed in the search for high-level radioactive waste repository sites in crystalline rock. It also provides additional insight into the utility of weighted summation as a model for theory development applicable to the location of noxious public facilities.

Davis used a weighted summation model in his dissertation research designed to integrate economic and environmental considerations into a model for land use planning. He used a three point numerical scale to depict three levels of suitability for each of several economic and environmental location factors. Separate suitability estimates were calculated for the economic and the environmental factors using these scales and differential weights taken to be indicative of the relative importance of the factors to the location decision. A composite
environmental/economic suitability score was calculated for each area under consideration according to the following formula:

\[
\text{Suitability index (SI)} = \sum_{i=1}^{n} K_i \text{EVS}_i + \sum_{j=1}^{m} K_j \text{ECS}_j
\]

Where \( \text{EVS} \) = environmental suitability

\( \text{ECS} \) = economic suitability

\( K_{ij} \) = weighting constants.

Davis' research assumed that all weighting constants \( (K_{ij}) \) were equal to 1. Thus he did not address the significance of alternative value systems expressed through weights for the location decision. He also used a three point scale of suitability that borders on being an ordinal scale. The use of an ordinal scale in such weighted summation applications invalidates the suitability index calculations. Finally, Davis did not address the influence of authority constraints very directly in the formulation of his model. He did, however, use map overlays to geographically express individual factor and composite suitabilities. Davis' objective in his research was to assist the local development planner in evaluating the desirability, through associated impacts, of recruiting different types of industry to a given substate region.

The weighted summation method has been applied to location decisions for low-level radioactive waste disposal facilities.
Di Mento, et al., discuss the execution of a defensible siting process that consists of the following steps:

1) Establish Federal legal requirements – This constitutes recognition of the role of this category of authority constraints.

2) Develop location factor inventory – This step involves the identification and definition of the factors applicable to the location decision.

3) Evaluate the compatibility of location factors – This step calls for the early recognition of factor trade-offs in general terms (a satisficing, not an optimizing, process).

4) Scope the socio-political location issues – This step involves a process of interaction with various stake-holders in the location decision, and is designed to characterize the full range of political authority constraints.

5) Prioritize/weight location factors – This step is designed to capture value judgements expressed as factor weights. The authors suggest that this be done by the responsible government agency.

6) Conduct regional screen – This is the step which is conducive to the application of computer-assisted weighted summation methods to estimate the aggregate favorability of location alternatives.
7) Select alternative sites - This is to be done through a process that recognizes the influence of legal/regulatory, institutional, and political authority constraints, as well as the application of technical location factors in a weighted summation model.

8) Conduct site-specific studies - This step requires additional detailed study culminating in a comparative analysis of all of the sites using the full range of location factors.

9) Choose a site - This is assumed to be the responsibility of elected public officials motivated by the full range of technical analyses and authority constraints.

Thus, the low-level waste facility location problem is a multiobjective problem well-suited to the application of the weighted summation model.

The weighted summation model has also been applied in the Nevada Nuclear Waste Storage Investigations (NNWSI) to identify favorable locations for a high-level repository in tuff, a volcanic host rock. This application concentrated on 31 attributes or location factors designed to satisfy 56 repository performance objectives. The attributes were broadly categorized into two categories: 1) geographical attributes, and 2) host rock attributes. The geographical attributes were scaled according to degrees of favorability and the geographic distribution of favorability levels.
was shown on maps. These geographical attributes included: volcanic potential, fault density, fault trend, age of faulting, natural seismic potential, weapons seismic potential (because of weapons testing at the Nevada Test Site), bed attitude, erosion potential, flood potential, terrain ruggedness, resource potential, groundwater resources potential, groundwater flux, groundwater flow direction, thickness of the unsaturated zone, sensitive floral species, sensitive faunal species, revegetation potential, known cultural resources, potential cultural resources, air pollution potential, permitting difficulties, and private land use. The host rock attributes included: thermal conductivity, compressive strength (containment), compressive strength (construction), expansion/contraction, mineral stability, stratigraphic setting, hydraulic retardation, and hydraulic transmissivity. While these attributes could also be expressed in geographic form on maps, the degrees of favorability for them were expressed in tabular form. These location factors were not considered as "geographic attributes".

The NWWSI application of the weighted summation model addressed the following hierarchy of performance objectives:  

1) Identify locations with a high capability for radionuclide containment,  
2) Identify locations which ensure radionuclide isolation,  
3) Identify locations where a repository can be constructed and operated safely and efficiently,
4) Identify locations where adverse environmental impacts can be easily mitigated.

It should be noted that this particular work was done prior to the NWPA and the DOE Siting Guidelines (10 CFR 960). Consequently, these authority constraints were not formalized to guide the effort. Even so, the above performance objectives are quite similar to those that were subsequently incorporated within legal/regulatory authority constraints, as were many of the individual attributes or location factors.

Using the hierarchy of performance objectives just described, an NNWSI panel of experts was used to derive a set of attribute weights for each level in the hierarchy. It is notable that, in this application, the assignment of weights was left to technical staff. This indicates that the project viewed such relative importance assessments as largely technical judgements. As indicated earlier, this dissertation suggests that the assignment of weights is an expression of values or preferences, as much as it is a technical exercise. The implications of this difference will be addressed in the description of the location model in the pages that follow.

In any event, the NNWSI application then calculated composite or aggregate favorabilities for one half mile square land units or grid cells by multiplying the favorability value of each attribute by the weight assigned to that attribute for each lower level performance
objective. These weighted favorabilities were then summed for all the geographic attributes, thus yielding a composite favorability estimate for each grid cell. These results were displayed on maps for the geographical attributes. Similar calculations were made for the host rock attributes, and the results were displayed in numerical tables. From this exercise, candidate repository locations were identified.

A Regional Screening Methodology for Noxious Public Facility

This section reviews a methodology developed for application in the Department of Energy's Crystalline Repository Project. The objective of this case study is to extract cumulative generalizations from the author's experience with the conceptualization, development, and execution of this methodology that contribute toward the formulation of location theory applicable to noxious public facilities.

Methodology Design Criteria

In developing the regional screening methodology, there were specific design criteria that guided the effort. These criteria are typical of those required to be met in many public facility location
studies. The criteria, and a brief description of their significance, are summarized below:

1) Consistency with NWPA and DOE Siting Guidelines - The methodology, while an application of these authority constraints, had to be consistent with both the spirit and the letter of these legal/regulatory considerations.

2) Comprehensively scoped - The methodology had to address the full range of geologic, environmental, and socioeconomic location factors applicable to the multi-state regional scale.

3) Systematically applied and replicable - The methodology had to be a logical progression of steps that was capable of being reasonably replicable, if applied by others using the same data base, scales, and weights.

4) Equitably applied - The methodology had to provide a consistent measure of the composite favorability of a 17 state region, and one that was free of regional or state-specific bias.

5) Capable of geographically evaluating value systems expressed in the form of variable or location factor weights - Recognizing that different people view the significance of location factors in different ways, the methodology had to geographically express these differences for input to location decisions.
6) Capable of performing sensitivity analysis - Because the repository location decision requires consideration of a broad range of potential trade-offs in a satisficing mode, the methodology had to be capable of performing various kinds of sensitivity analyses to assist with the characterization and examination of such trade-offs.

Methodology Overview

Based upon the above design criteria, a four-step methodology was formulated. These steps provide a useful model of the noxious public facility location decision process. The four steps are as follows:

1) Step 1 - Apply relevant disqualifying conditions,
2) Step 2 - Apply relevant potentially adverse and favorable conditions (as defined in 10 CFR 960),
3) Step 3 - Perform sensitivity analyses,
4) Step 4 - Select candidate areas/potentially acceptable sites.

The pages that follow summarize each of these steps in more detail in the search for inductive generalizations applicable to the development of location theory. Sample output maps accompany the discussion of each step. This output is designed to provide useful illustrations of key concepts in the methodology, and not to report the results of the application of the methodology in the Crystalline Repository Project.
Step 1 - Apply Disqualifying Conditions

The review of multiobjective location decision approaches earlier in this chapter mentioned the exclusionary screening model. This model was found to be limited in its applicability to situations where the location factors can be defined in clear-cut (black-white) terms of unacceptability and acceptability. The disqualifying conditions specified in the DOE Siting Guidelines (10 CFR 960) provide definitions of unacceptability for a subset of the location factors that must be considered in the regional phase of repository siting. Step 1 applies these applicable disqualifiers to identify the geographic distribution of features that require the elimination of rock bodies, or portions of rock bodies, from further consideration as a site for repository surface facilities, or support facilities.

The disqualifying factors used in this step in the Crystalline Repository Project were:

1) Deep mines and quarries,
2) Federal-protected lands,
3) State-protected lands,
4) Population distribution and density,
5) Components of the National Forest lands.

Because of the hydrologic and repository performance implications of deep mines and quarries, this variable was defined to disqualify both the surface and subsurface where it is present.
These disqualifying factors were selected because, on a regional scale, data were available to allow their systematic application over a 17 state region. The regulations (authority constraints) also call for the evaluation of an additional five disqualifiers that could not be applied in Step 1 because of data constraints. These disqualifiers are considered in Step 4.

The application of Step 1 in the Crystalline Repository Project required the collection of data on all five disqualifiers for the entire study area. Because of the scale at which a 17 state location analysis must be conducted, only features in excess of 320 acres in size were utilized in the regional phase. The boundaries of each disqualifying feature were digitized into a computer cartographic data base for ease of use. Figure 9 illustrated the output of Step 1. Disqualifying features were mapped in relation to the crystalline rock bodies. The areas bounded by the borders of each disqualifying feature were excluded from further consideration as a repository site.

Step 1 has some implications for the development of location theory applicable to noxious public facilities. It recognizes that there are features that, if present, are enough to disqualify an area from further consideration. These features may be defined in law or regulation, as in the repository case, or may be defined by the public agency with the siting authority. In the latter case,
Figure 9  Sample Disqualified Areas Map

this is commonly done with public input. The exclusionary decision model is applicable only to this category of location factors. However, such disqualifying factors are typically a relatively small subset of the total range of location factors that must be accounted for in noxious public facility location decisions. Steps 2 and 3 are designed to address the other factors.

**Step 2 - Apply Potentially Adverse and Favorable Factors**

Step 2 is applied to the undisqualified areas that emerge after the completion of Step 1. This Step recognizes there are many location factors that cannot be defined in strictly unacceptable/acceptable or black/white terms. These factors are defined in terms of degrees of favorability. For a given variable or location factor, those areas which exhibit favorable characteristics should be favored over areas which display potentially adverse characteristics. When applying a large number of variables or location factors, the objective is to select areas for further examination that, in the aggregate, exhibit favorable over adverse characteristics. Step 2 was structured to accomplish this objective using a weighted summation model.

**The Grid Cell Concept.** Before the details of Step 2 are described, it is important to understand the concept of the grid cell as the unit of analysis for this Step and for Step 3. Figure 10
Figure 10 Conversion of Polygonal to Gridded Data for Hypothetical Rock Bodies

Source: Department of Energy, Office of Civilian Radioactive Waste Management, Crystalline Repository Project Office, Region-to-Area Screening Methodology for the Crystalline Repository Project, April, 1985, pp. 88
demonstrates the concept of converting polygonal data to a gridded representation. In the regional phase repository application, a standard one square mile grid was imposed over all polygonal, geographic data. The conversion to a gridded representation allows for the aggregation of geographic data for each square mile of the study area, with a focus on those grid cells underlain by crystalline rock.

Selection of Step 2 Variables. The selection of the variables or location factors appropriate for Step 2 began with the legal/regulatory authority constraints specified in the NWPA and in the DOE Siting Guidelines (10 CFR 960). Institutional and political authority constraints also played a role in variable selection through the conduct of three structured meetings or workshops with the 17 crystalline states, in part, to select/define variables and to determine how they should be measured. For each variable selected, there had to be data available at a reasonably consistent level of aggregation and quality across all 17 crystalline states. This was because of the methodology design criterion related to equity. The Step 2 variables utilized for the Crystalline Repository Project are listed in Table 4. Each of these variables also had to be measured, according to degrees of favorability, on an interval scale. This helped ensure that a weighted summation model could be used in the execution of Step 2.
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<th>Geologic</th>
<th>Environmental/Socioeconomic</th>
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<td>Rock mass extent</td>
<td>Proposed Federal-protected lands</td>
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<td>Major ground-water discharge zones</td>
<td>Population density</td>
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<td>Rock and mineral resources</td>
<td>Proximity to Federal-protected lands</td>
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<td>Seismicity</td>
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<td>Suspected quaternary faulting</td>
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<td>Postemplacement faulting</td>
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<td>Designated critical habitat for threatened and endangered species</td>
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<tr>
<td></td>
<td>Proximity to highly populated areas or to 1 square mile areas with 1000 or more persons</td>
</tr>
</tbody>
</table>

Source: Department of Energy, Office of Civilian Radioactive Waste Management, Crystalline Repository Project Office, Region-to-Area Screening Methodology for the Crystalline Repository Project, April, 1985, pp. 88
Variable Scaling/Measurement. The degrees of adverse conditions/favorable conditions present for each Step 2 variable are numerically portrayed by a standardized 1 through 5 scale, with 1 representing the adverse extreme and 5 the favorable extreme. Scaling is the process by which physical conditions for each screening variable (potentially adverse or favorable) are translated into a numerical value that can be used to evaluate the aggregate suitability of the remaining study area after the application of Step 1.

Hobbs has described the significance of scaling methods to the validity of location results using the weighted summation model. The most important characteristic to consider in scaling is the level of measurement or type of scale being used. The three scale types of concern here are ordinal, interval, and ratio scales. Ordinal scales may be simple rank orders, discrete, or continuous scales. The only meaningful relationships on an ordinal scale are that a given scale value may be equal to, greater than, or less than another scale value. Measurement theory permits no simple mathematical processing of ordinal scale values (e.g., addition or multiplication). In practice, ordinal scales are typically developed by the exercise of personal judgements by decision-makers concerning a rough order of desirability for each variable condition. On an interval scale, the differences between scale values are meaningful beyond the simple order relationships of the
ordinal scale. The zero point on the interval scale may be arbitrary, however. An example of such a scale is the temperature scale for degrees Fahrenheit. The units of this scale have a standardized physical meaning. Interval scales can be defensibly summed, and weighted through multiplication/division operations.

The Step 2 variable scales developed for application in the Crystalline Repository Project are interval scales. The ratio scale is similar to the interval scale with one significant exception. The zero point on a ratio scale indicates a zero amount of the quantity measured.

The scaling done for the repository location analysis was done with input from the 17 crystalline states as part of an interactive workshop process. Figure 11 illustrates representative scales that resulted from this process. Similar scales were developed for each Step 2 variable. To the extent possible, the scales were assigned the same number of increments. There were instances, however, where this was not possible because of data-related constraints or an inability to technically justify the standard number of scale increments. In every case, the end points of the scale were ascribed to a corresponding physical condition, along with one or more intermediate scale points.

Each of the scale values for all of the Step 2 variables or location factors was given a standard shade of grey to depict that
### 1. Seismicity

Maximum Probable Ground Acceleration (%g)

<table>
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<tr>
<th></th>
<th>&gt;70</th>
<th>&gt;50-70</th>
<th>&gt;30-50</th>
<th>&gt;10-30</th>
<th>&lt;10</th>
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<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>More Adverse</td>
<td>Scale Value</td>
<td>More Favorable</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 2. Postemplacement Faulting

Distance From Fault (miles)

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<tr>
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<th>&gt;3-4</th>
<th>&gt;4-5</th>
<th>&gt;5-6</th>
<th>&gt;6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scale</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>More Adverse</td>
<td>Scale Value</td>
<td>More Favorable</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 3. Population Density

Population Density (persons per square mile)

<table>
<thead>
<tr>
<th></th>
<th>800-999</th>
<th>600-799</th>
<th>400-599</th>
<th>200-399</th>
<th>0-199</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scale</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>More Adverse</td>
<td>Scale Value</td>
<td>More Favorable</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 4. Proximity to Federal - Protected Lands

Distance From Boundary (miles)

<table>
<thead>
<tr>
<th></th>
<th>0-3</th>
<th>&gt;3-4</th>
<th>&gt;4-5</th>
<th>&gt;5-6</th>
<th>&gt;6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scale</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>More Adverse</td>
<td>Scale Value</td>
<td>More Favorable</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 11 Step 2 Variable Scales

Source: Ibid, DOE, Region-to-Area Screening Methodology for the Crystalline Repository Project, pp. 88-117
scale value assignment on variable favorability maps. Generally, the convention used in the preparation of these maps was the darker the grey, the more adverse the condition being portrayed. Figures 12 through 15 provide examples of such variable favorability maps. These maps provide a key building block for the estimation of aggregate or composite favorability using the weighted summation model. They do so by, in effect, assigning a single scale value for each variable to each square mile grid cell in the study area.

Variable Weighting. While variable scales depict a physical condition for an individual location factor, variable weights are developed to depict value judgments concerning the relative importance of the complete set of location factors. These value judgments may clearly be influenced by technical inputs, by variable scales and by other considerations. However, the assignment of weights is, in essence, an exercise in expressing human value judgments or preferences. Because of this and particularly for public facility location decisions, it is important to capture the implications of a wide range of value judgments or preferences in the location decision. This means that the development of weights should not be left solely to the technical team performing the location analyses. Their weight values are arguably no more "correct" than the values expressed by other groups with a stake in the decision. In addition, it is important to be able to geographically express such values in the location decision.
Figure 12  Sample Favorability Map: Groundwater Discharge Zones

Source: Crystalline Repository Project, Computer Cartographic Data Base, May, 1986
Figure 13  Sample Favorability Map: State Protected Lands

Source: Crystalline Repository Project, Computer Cartographic Data Base, May, 1986
Figure 14  Sample Favorability Map: Rock Mass Extent

Source: Crystalline Repository Project, Computer Cartographic Data Base, May, 1986
Figure 15  Sample Favorability Map: Highly Populated Areas

Source: Crystalline Repository Project, Computer Cartographic Data Base, May, 1986
There are several different approaches to the generation of weights. Hobbs described some of the alternatives as follows:

1) Ranking - This is the simplest technique. It requires an individual or group to rank the location factors in their perceived order of importance, with the lowest ranked factor assigned a value of 1. After doing this, the weights can be normalized by dividing each rank value by the sum of the original weights. The weights that result are ordinal, and thus cannot be validly employed in the weighted summation model of the location decision.

2) Rating - This procedure calls upon an individual or group to assign weights according to their view of the location factors' relative importance on a standard scale (e.g., 1 to 10, with 10 being the most important). The results of such a process are also typically normalized. Here again, however, the results are not ensured to be a ratio measure. Consequently, it is not recommended for use in the weighted summation model.

3) Ratio Questioning - This technique for developing weights is based upon pair-wise comparison. The comparisons are made by asking, "How many times as important to the location decision is location factor or variable A than variable B?" Where there are n attributes, at least n-1 questions of this type are required to complete the exercise. Weights are then normalized according to the
ratios established. Such a technique results in ratio weights which can be validly used in the weighted summation method.

4) Metfessel allocation - This approach asks individuals or groups to distribute a standard set of weight points (e.g., 1000) in accordance with their views of the relative importance of the location factors or variables. This approach is particularly well adapted to group applications. It also results in ratio weights which can be validly applied in weighted summation models of the location decision.

In order to illustrate how weighting can be performed in noxious public facility siting, the paragraphs that follow briefly summarize a workshop process completed for the Crystalline Repository Project. The first workshop involved only personnel that were directly associated with the project. The second involved only representatives from the 17 crystalline states, largely from the executive branch of state government.

The approach to the weighting exercises in both workshops was the same, and provides an example of how weighting can be conducted for other facility siting studies. Each workshop started with an orientation session in which the variables or location factors were described in some detail, including their scales, which could have an influence on the assignment of weights. Next each individual was
asked to complete a weighting exercise using the Metfessel allocation technique to assign 1000 points to the location factors on the basis of their relative importance to the selection of candidate areas for a repository. It should be noted that these individual exercises reflected individual preferences for some, and group (e.g., state) preferences for others. Thus, the weighting process can be a forum where political authority constraints are expressed.

The individual weighting exercises were then statistically evaluated using the cluster analysis software in the Statistical Package for the Social Sciences (SPSS). Individuals were grouped into small groups (e.g., under 12 people) based upon the similarity of their weights. Clustering on the basis of similarity is motivated by the desire to capture, in the small groups, representative value systems for use in the identification of candidate areas for further study. The focus in weighting then shifts to small group discussions of weights using the group mean as a point of departure. Each group, in the case of the Crystalline Repository Project example, was facilitated by an independent, neutral, outside facilitator skilled in nominal group technique. Group discussions lead to a series of iterations punctuated by additional individual exercises that provide the opportunity to modify the original weights based upon interaction with others in the group. After each iteration, the group's revised mean weights
are calculated. When there is no significant change in the mean weights from one iteration to the next, it is assumed that the weight set is indicative of group preferences or values. This does not mean, however, that there is not individual variation within the group concerning the assignment of weights. It simply means that each member's views are sufficiently fixed that further group discussion does not materially affect the group's mean weights.

There were five groups involved in the Crystalline Repository Project weighting workshop and four groups involved in the crystalline states' workshop. Tables 5 and 6 summarize the results of both weighting workshops, as an example of the products that are generated through this kind of weighting process. A review of these two tables indicates that the workshops were successful in eliciting a broad spectrum of values, as reflected in weights, regarding the relative importance of the variables to the location decision. Some weight sets strongly view those variables with postclosure performance implications as being of paramount importance. Others ascribe substantially more importance to the preclosure variables. No single set of weights can be assumed to be the "correct" set for the location decision. Similar results could be obtained through such a weighting workshop process in other facility siting applications. The key is the extraction of variable weights that are representative of the value systems held by stakeholder groups in the siting process.
**TABLE 5**

**MEAN WEIGHTS BY CRP SUBGROUP OUT OF A TOTAL OF 1000 FOR 16 VARIABLES**

<table>
<thead>
<tr>
<th>SUBGROUP 1</th>
<th>SUBGROUP 2</th>
<th>SUBGROUP 3</th>
<th>SUBGROUP 4</th>
<th>SUBGROUP 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 399.5</td>
<td>2 201.1</td>
<td>2 154.3</td>
<td>2 101.3</td>
<td>8 144.9</td>
</tr>
<tr>
<td>1 242.8</td>
<td>1 178.4</td>
<td>5 141.0</td>
<td>8 86.4</td>
<td>1 113.0</td>
</tr>
<tr>
<td>6 106.2</td>
<td>6 118.4</td>
<td>4 126.0</td>
<td>15 79.1</td>
<td>2 99.1</td>
</tr>
<tr>
<td>5 52.0</td>
<td>5 78.8</td>
<td>6 97.7</td>
<td>1 78.7</td>
<td>16 86.8</td>
</tr>
<tr>
<td>3 38.2</td>
<td>4 76.1</td>
<td>3 94.3</td>
<td>5 75.6</td>
<td>6 80.0</td>
</tr>
<tr>
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<td>8 69.3</td>
<td>1 91.0</td>
<td>6 74.8</td>
<td>13 74.8</td>
</tr>
<tr>
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<td>7 60.8</td>
<td>4 64.1</td>
</tr>
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<td>15 49.3</td>
<td>15 53.3</td>
<td>14 60.1</td>
<td>9 64.0</td>
</tr>
<tr>
<td>16 13.5</td>
<td>16 39.3</td>
<td>9 27.7</td>
<td>9 60.0</td>
<td>5 52.0</td>
</tr>
<tr>
<td>13 13.3</td>
<td>9 26.1</td>
<td>13 25.8</td>
<td>16 57.0</td>
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<tr>
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<tr>
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<td>4 54.6</td>
<td>7 36.4</td>
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<tr>
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<td>14 21.6</td>
<td>10 21.8</td>
<td>12 51.1</td>
<td>14 30.7</td>
</tr>
<tr>
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<td>7 19.3</td>
<td>11 19.3</td>
<td>3 36.5</td>
<td>11 26.2</td>
</tr>
<tr>
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<td>11 35.8</td>
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<td>12 13.8</td>
<td>14 14.3</td>
<td>12 33.0</td>
<td>12 20.9</td>
</tr>
</tbody>
</table>

**LEGEND - SCREENING VARIABLES**

1 ROCK MASS EXTENT
2 MAJOR GROUND-WATER DISCHARGE ZONES
3 ROCK AND MINERAL RESOURCES
4 SEISMICITY
5 SUSPECTED QUATERNARY FAULTING
6 POST-EMPLACEMENT FAULTING
7 PROPOSED FEDERAL-PROTECTED LANDS
8 POPULATION DENSITY
9 PROXIMITY TO FEDERAL-PROTECTED LANDS
10 PROXIMITY TO STATE-PROTECTED LANDS
11 NATIONAL FOREST LANDS
12 STATE FOREST LANDS
13 DESIGNATED CRITICAL HABITAT FOR THREATENED AND ENDANGERED SPECIES
14 WETLANDS
15 SURFACE WATER BODIES
16 PROXIMITY TO HIGHLY POPULATED AREAS

### TABLE 6

**MEAN WEIGHTS BY CRYSTALLINE STATE SUBGROUP OUT OF A TOTAL OF 1000 FOR 16 VARIABLES**

<table>
<thead>
<tr>
<th>SUBGROUP 1</th>
<th>SUBGROUP 2</th>
<th>SUBGROUP 3</th>
<th>SUBGROUP 4</th>
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<td>109.1</td>
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<td>176.9</td>
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<td>97.7</td>
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<tr>
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<td>164.3</td>
<td>119.5</td>
<td>84.5</td>
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<tr>
<td>6</td>
<td>166.8</td>
<td>98.3</td>
<td>80.3</td>
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<tr>
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<td>62.5</td>
<td>93.8</td>
<td>75.9</td>
</tr>
<tr>
<td>11</td>
<td>62.1</td>
<td>84.6</td>
<td>74.5</td>
</tr>
<tr>
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<td>52.1</td>
<td>75.8</td>
<td>71.4</td>
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</table>

**LEGEND - SCREENING VARIABLES**

1. ROCK MASS EXTENT
2. MAJOR GROUND-WATER DISCHARGE ZONES
3. ROCK AND MINERAL RESOURCES
4. SEISMICITY
5. SUSPECTED QUATERNARY FAULTING
6. POSTIMPLACEMENT FAULTING
7. PROPOSED FEDERAL-PROTECTED LANDS
8. POPULATION DENSITY
9. PROXIMITY TO FEDERAL-PROTECTED LANDS
10. PROXIMITY TO STATE-PROTECTED LANDS
11. NATIONAL FOREST LANDS
12. STATE FOREST LANDS
13. DESIGNATED CRITICAL HABITAT FOR THREATENED AND ENDANGERED SPECIES
14. WETLANDS
15. SURFACE WATER BODIES
16. PROXIMITY TO HIGHLY POPULATED AREAS

**Source:** Department of Energy, Draft Area Recommendation Report for the Crystalline Repository Project, Vol. 1, January, 1986, pp. 2-12
Composite Maps. After variable scales and weights have been developed, the weighted summation approach can be utilized to estimate the aggregate favorability of each square mile grid cell in the study area of interest. This was done for the regional phase of the Crystalline Repository Project using the following formula:

\[
AF = \frac{1}{1000} \sum_{i=1}^{n} W_i S_i
\]

where:
- \( n \) = number of variables or location factors
- \( \sum_{i=1}^{n} \) = summation over \( n \) items
- \( W_i \) = weight of variable \( i \)
- \( S_i \) = scale value for variable \( i \)
- 1000 = total number of weighting points allocated.

This formula is a slight modification of the formula previously discussed as the standard weighted summation formula. The difference is that the weighted sum is divided by 1000 in order to normalize the results to the 1 to 5 scale used in the scaling of individual variables. This is done simply to maintain consistency with the scaling concept in order to enhance understanding of the results.
The mathematical calculation outlined above was then performed for each square mile grid cell in the repository study area. The result was thousands of estimates, on a grid cell basis, of the aggregate favorability for a repository within the constraints of a regional investigation. When these results are assigned shades of grey according to standardized ranges of favorability estimates (e.g., 4.00 - 5.00 is the lightest grey), the product is a composite favorability map that graphically illustrates the geographic distribution of the most favorable areas, as defined by a given set of scales and weights.

In essence, the composite map displays the geographic expression of values or preferences regarding the relative importance of location factors to the location decision. By preparing composite favorability maps for multiple sets of weights it is possible to examine the spatial implications of different value systems or preference judgements for the location decision. Figure 16 illustrates the composite map concept for the equally weighted case applied to a portion of the North Central Region in the Crystalline Repository Project. An examination of such composite maps can clearly illustrate distinct geographic differences in the most favorable portions of the study areas, as well as overlaps in the spatial distribution of the most favorable subareas. Such maps also
Aggregate Favorability

- White: 4.5 to 5.0
- Light gray: 4.0 to less than 4.5
- Medium gray: 3.5 to less than 4.0
- Dark gray: 3.0 to less than 3.5
- Black: less than 3.0

Not Underlain By Crystalline Rock

Figure 16  Sample Composite Favorability Map

demonstrate that this model of the location decision can be useful in predicting location outcomes given the specification of location factors, scale values, and representative weights.

Step 3. Sensitivity Analysis

The third step in the proposed screening methodology for noxious public facilities allows for the opportunity to perform several types of sensitivity analysis. This sensitivity analysis is structured to examine the spatial effects on the location decision of the following:

1) Modifying selected variable scales,
2) Using an alternate index of aggregate favorability,
3) Incorporating additional geologic variables,
4) Developing and evaluating summary composite maps.

The paragraphs that follow briefly summarize each of the types of sensitivity analysis. Special emphasis is given to the summary composite map concept because of its relevance to location theory formulation.

Scale Modification. A previous section described the concept of variable scaling for application in the weighted summation model. Each variable scale value represents a physical condition or range
of conditions for that variable (e.g., a certain distance from a sensitive feature). The definition of scale increments determines the geographic extent of the penalty or favor provided to a given grid cell for that variable. Recognizing that scales themselves can be the subject of controversy in location analysis, sensitivity analysis can be structured to evaluate the implications of alternative scales for one or more factors on the location decision.

Three variables had particularly controversial scales in the Crystalline Repository Project example, and thus were judged to be the best candidates for this kind of sensitivity analysis. These three variables were rock mass extent, seismicity, and proximity to highly populated areas or to 1-square mile areas with 1000 or more persons. Of course, the aggregate favorability estimates in the weighted summation model are a function of both scales and weights. After testing for the modified scales in the repository example, it was determined that the results were not dramatically different from those obtained with the original scales. In general, weight variation has significantly more influence on the geography of the most favorable areas than does scale modification.

Alternate Index of Favorability. This type of sensitivity analysis is designed to evaluate whether the use of the geometric mean, instead of the modified weighted summation formula, has a material effect upon the spatial distribution of the most favorable areas.
The geometric mean is calculated as the \( n^{th} \) root of the product on \( n \) numbers, in this case:

\[
W_1S_1, W_2S_2 \ldots W_nS_n,
\]

where:
- \( W_i \) = the weight for variable \( i \),
- \( S_i \) = the scale value for variable \( i \),
- \( n \) = number of variables.

Using the geometric mean instead of the weighted average as the index of aggregate favorability, it was determined in the Crystalline Repository Project application that the same areas showed up as most favorable with the geometric mean.\(^{19}\) The only difference was these areas had incrementally lower aggregate favorability scores. This is explained by the tendency of the geometric mean to buffer the effects of extreme values compared to their influence using the weighted average. Consequently, this type of sensitivity analysis was judged to not be of significance to the location decision.

**Incorporating Additional Geologic Variables.** The previous discussion of Step 2 variables indicated that one of the factors in their selection in the repository example was the presence of a reasonably consistent data base across 17 states. This necessarily eliminated from consideration variables for which only scattered data were available. This was of particular concern to some of the crystalline states because of the view that geologic data with repository performance implications should be used wherever it was
available. This concern led to the concept of the Step 3 variable as part of sensitivity analysis.\textsuperscript{20}

The Step 3 variable is defined as a location factor for which either only scattered data are available, or for which the cost of collecting the data would be economically prohibitive. The variables that met this definition for the Crystalline Repository Project were:

1) Thickness of rock mass.
2) Thickness of overburden,
3) State-of-stress,
4) Ground-water resources.

For each Step 3 variable, five point scales are developed in the same way as is done for the Step 2 variables. In addition, the Step 3 variables must be added to the complete list of variables for consideration in weighting exercises. Consequently, in the repository example, weights were developed for these variables in the same way as for the original list of Step 2 variables.

After the most favorable areas emerge from the completion of the Step 2 analysis, the data base is reviewed to identify any Step 3 variable information that could affect the favorability of those areas. Where such data are present, the appropriate scale and weight values are incorporated into revised aggregate favorability estimates. Thus, for grid cells with Step 3 variable data available
for them, the weighted average calculations are done using a larger number of variables. Where such data are not available, nothing is assumed about the conditions existing in that grid cell for the Step 3 variable.

The Step 3 variable concept ensured, in the regional phase of the Crystalline Repository Project, that rock body-specific data were used in making location decisions. However, the relative scarcity of such data, in the end, did not materially affect the identification of the most favorable areas. In some cases, the addition of Step 3 information resulted in relatively minor adjustments to the boundaries of such areas, but not major shifts in the spatial distribution of the areas.

The Summary Composite Map. Given that multiple sets of weights could be used in the location decision process, and given the various permutations and combinations of sensitivity analysis that are possible, an approach is needed to simplify and clarify the location decision. The summary composite map concept effectively meets this need. The summary composite map is a synthesis of geographic data extracted from a related series of composite maps. It is designed to identify similarities or overlaps in the definition of the most favorable areas on sets of related composite maps.
The summary composite map utilized by the Crystalline Repository Project in making draft area recommendation decisions was developed on a frequency of occurrence-best candidate area basis. To develop such a summary composite map in the repository example using all nine available weight sets involved the following:  

1) For each of the nine composite maps, the most favorable areas were defined by lowering the aggregate favorability score in 0.1 increments, from the top score of 5.0, until at least 20 areas of suitable size appeared. The minimum size was determined by an authority constraint (40 CFR 191) which defines the maximum size of the repository controlled area as 30 mi$^2$. In addition, no deep mines or quarries could be located in the area because such features disqualify both the surface and the subsurface. A limited number of surface only (environmental) disqualifiers could be present within the area.

2) The number of favorable areas on each composite map could exceed 20 if the aggregate favorability score at which the twentieth area appeared brought in more than 20. The number 20 was selected because it was the high end of the target range identified by DOE as the desirable number of candidate areas to take into the next phase of location analysis. The aggregate favorability score that brought in the twentieth area was called the "benchmark."
3) Every undisqualified grid cell was examined (via computer software) to determine the number of times (out of 9) that the cell has an aggregate favorability score higher than the benchmark for each of the nine sets of weights. The results of this examination is geographically expressed on the summary composite map as a frequency of occurrence (e.g., 9 out of 9, 8 out of 9, etc.). It is assumed that the higher the frequency of occurrence for a given grid cell or cluster of grid cells, the more broadly that area is perceived as worthy of further location analysis.

Figure 17 illustrates the concept of the summary composite map outlined above for a portion of the Crystalline Repository Project's North Central Region. This map illustrates, in effect, the degree of consensus on the top-rated areas in this subarea, taking into consideration widely varying value systems (represented by nine sets of weights). As the map clearly shows, there are areas which show up at the 9 out of 9, 8 out of 9, and the 7 out of 9 frequency of occurrence levels. Thus, the summary composite map is capable of illustrating the spatial distribution of areas that are highly regarded by a broad spectrum of interests. This can be of substantial significance to both the technical and political defensibility of the location decision.
Frequency of Occurrence

- 9 of 9
- 8 of 9
- 7 of 9
- 6 of 9
- 0 through 5 of 9
- Not Underlain By Crystalline Rock

Figure 17 Sample Summary Composite Favorability Map

Step 4 Selecting Candidate Areas/Identifying Potentially Acceptable Sites

The final step of the screening methodology involves the review of the results from the previous three steps. This is done to confirm the acceptability of the candidate areas that emerge as most favorable. This final step is subject to the influences of the full range of legal/regulatory, institutional and political authority constraints described in Chapter IV.

The specific activities included within the scope of Step 4 for the Crystalline Repository Project are summarized as follows:

1) A qualitative review of the available literature for each preliminary candidate area was conducted. This review was designed to help ensure that all available information, whether or not it could be incorporated into Steps 1-3, was utilized in the selection of candidate areas. In performing the literature review, anomalies were looked for that could compromise the selection of a given preliminary candidate area. For example, an area could be dotted with numerous disqualifying features less than 320 acres in size. The geographic distribution of the preliminary candidate areas was also examined to determine if, in the extreme, all of the areas were located in a single state or region. As mentioned previously, an international
commitment to Canada agreeing that no subsequent field investigations would be conducted on Canadian soil lead to the deferral of an area that was close enough to the border to require such investigations.

2) The regulatory findings required by Appendix III of the DOE Siting Guidelines (10 CFR 960) for ten disqualifying conditions had to be made in order to label a candidate area as a potentially acceptable site. This provision of 10 CFR 960 requires that the "evidence shall support a finding that the site is not disqualified in accordance with the application requirements set forth in Appendix III . . . and shall support the decision by DOE to proceed with the continued investigation of the site (in the area phase) on the basis of the favorable and potentially adverse conditions identified to date."\(^{23}\) Five of the ten disqualifiers were incorporated into Step 1 of the methodology. One was demonstrated to not be applicable to crystalline rock (dissolution). The remaining four had to be independently evaluated before the requisite finding could be made. If it could be demonstrated, at the regional scale, that the site should be disqualified, that site could clearly not be carried further. This structure for making technical findings is another example of the influence of regulatory authority constraints on the repository location decision.
3) The results of the regional phase location analysis were documented in the Draft Area Recommendation Report for the Crystalline Repository Project. After release of this major decision document, the DOE undertook an extensive series of public briefings, public hearings, and institutional interactions with state and tribal authorities. During this entire review process the draft decisions pass through the gauntlet of institutional and political scrutiny. Each comment will be formally responded to in a Comment Response Document prepared by DOE. The Final Area Recommendation Report will be prepared taking such comments into account. This review process provides another opportunity for institutional and political authority constraints to influence the location decision by critically scrutinizing the technical and procedural approaches taken to make that decision.

Implications for Inductive Generalizations

This chapter has examined multiobjective models for the noxious public facility location decision, with a particular focus on a regional phase methodology used to identify potentially acceptable sites for the Nation's second high-level waste repository. The final chapter of this dissertation outlines a theory of location
for noxious public facilities based, in part, upon the following inductive generalizations:

1) The exclusionary model of multiobjective decision-making is applicable only where the location factors can be defined in clear unacceptable/acceptable or disqualified/qualified terms. Some, but not all, location factors can be defined in this manner.

2) The weighted summation model of multiobjective decision-making is a useful model for the noxious public facility location problem. It recognizes satisficing rather than optimizing as the major objective. Consequently, the characterization of location factor trade-offs, in geographic terms, is a critical component of the location decision.

3) The geographic expression of value systems through location factor weights is another key to such location decisions. There is no single set of weights that can defensibly be regarded as "correct" in public facility location decisions. Capturing representative value systems through alternative weight sets and expressing their geographic implications, is possible through the weighted summation approach using composite maps.

4) The use of summary composite maps can identify the geographic coincidence between the most favored candidate areas on a related set of composite maps. Doing so, in
effect, identifies areas that may be taken to represent a consensus among widely variant views in the location decision process. This ability enhances the technical and political defensibility of the location decision. It also provides a model for accommodating the complex influences of institutional and political authority constraints.

5) Authority constraints influence the definition of location factors; their measurement; the structure and content of the decision process; and the final location decisions themselves. Certain simplifying assumptions concerning the rationality of these influences must be made in theory development.

Chapter VI attempts to draw upon the inductive generalizations developed in this and previous chapters to formulate a generally applicable theory of the location of noxious public facilities.
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CHAPTER VI
IMPLICATIONS FOR LOCATION THEORY AND
FUTURE GEOGRAPHIC RESEARCH

Chapter Overview

This dissertation has examined the applicability of classical and contemporary location theory to the noxious public facility location problem. The principal research objective has been to extend, modify, or reformulate theoretical principles in order to enhance the ability to explain the spatial distribution of such facilities. This chapter summarizes the inductive generalizations developed in the study. It reviews the status of location theory, and the applicability of theory to the noxious public facility location decision. A set of theoretical principles drawn from this research are proposed, along with a summary of the spatial implications of the reformulated theory. Finally, the applicability of these theoretical principles to other public facility location problems is discussed, along with some suggested productive avenues for further research.
Review of Inductive Generalizations

This study has explored a complex array of technical, legal, regulatory, institutional, and political influences that shape the location decision for noxious public facilities. The focus has been on the examination of these influences in the siting of a geologic repository for high-level nuclear waste, in contrast to the focus on economic factors in classical location analysis. During the course of this research, a number of inductively-derived generalizations have been developed. These generalizations provide the foundation for the theoretical principles outlined later in this chapter.

The Traditions of Geography

Each of the four twentieth century geographic traditions has a measure of relevance to the noxious public facility location problem. The man-land tradition, and specifically environmental determinism, held that the natural environment controlled man's activities. In repository location decisions, this is true only to the extent that the geographic distribution of host rock formations with suitable natural characteristics is clearly a necessary condition in such decisions. Regulations require that primary emphasis be placed upon natural over engineered barriers in the isolation of high-level waste. Consequently, certain natural, host-rock characteristics are necessary, but not sufficient in themselves, for repository location.
The areal differentiation tradition's criticism of the man-nature dualism called for an expansion of the definition of "environment" beyond the physical/biological scope of the man-land definition. This study has demonstrated that "sufficiency" in noxious public facility location is conditioned by a definition of "environment" that includes physical, biological, cultural, technological, socioeconomic, institutional, and legal/regulatory considerations. The areal differentiation emphasis on synthesis, and the use of maps as principal geographic tools, has been a direct influence upon the model developed for the noxious public facility location problem.

Likewise, the spatial tradition's focus on the search for theoretical insights, in part through the use of mathematical tools, has been a significant influence in the conduct of this study. The search for explanation in spatial terms, without an emphasis on sterile geometry, has been an important motivator for this study. The weighted summation model of the noxious public facility location decision has its roots in the spatial tradition.

Finally, the behavioral tradition has materially affected the theoretical concepts proposed herein. Specifically, this tradition's focus on subjective reality, and on the geographic expression of human values, is key to understanding the multiobjective location problem. Similarly, this tradition's
emphasis on the decision process, that is on how decisions are made, is an important influence that permeates this study. This is particularly the case in the examination of public policy influences on the location decision through various categories of authority constraints (legal/regulatory, institutional, and political).

Public Versus Private Location Decisions

Most location theory developed to date has been directed toward explanation of private sector industrial location decisions. The predominant driving forces in such theory have been economic (e.g., cost minimization, profit maximization, or revenue maximization). Given the economic orientation of such theory, the common metric used to measure location alternatives is the dollar. Typically, the theory relies upon an optimization framework using the dollar metric.

In contrast, the public sector location decision is customarily driven by different objectives. These objectives may include service maximization, risk minimization, adverse impact minimization, etc. Economic forces, usually cost minimization, are subordinate to these other drivers in public facility location. In addition, because such location decisions are influenced by a complex array of technical factors, authority constraints, and public policy considerations, both monetary and non-monetary measures must be employed. This requires a multiobjective model.
capable of measuring/scaling on a common metric, and capable of making variable trade-offs explicit in decision-making. It also requires a satisficing rather than an optimizing model of the location decision. The satisficing model allows for the treatment of complex multiple objectives in a manner that recognizes inverse relationships between objectives, and that explicitly characterizes trade-offs between objectives.

**Technical Location Factors**

The location of noxious public facilities typically must address a scope that includes environmental, socioeconomic, transportation, engineering, and health and safety considerations. In repository siting, these categories of location factors are defined in regulations (10 CFR 960) in terms of disqualifying, qualifying, potentially adverse and favorable conditions. The large number of individual location factors to be accounted for makes the prediction of outcomes difficult, and opens the decision process to substantial disagreement about the relative importance of the factors in the location decision. While such weighting judgements benefit from technical knowledge, in the end they reflect differences in human values. Thus, there is no single correct set of values expressed in location factor weights. The geographic expression of different values through alternative weight sets provides the opportunity to explore the implications of such differences for the location
decision. It also provides the opportunity to search for geographic coincidence or consensus on the most suitable locations as viewed by widely varying perspectives on the relative importance of the location factors.

Authority Constraints

Authority constraints have a direct and substantial effect upon the noxious public facility location decision. Three general categories of authority constraints of consequence include legal/regulatory, institutional, and political constraints. The extent to which such constraints shape noxious facility location depends, in part, upon the specific type of facility under consideration. While the focus of this research has been on high-level nuclear waste repositories, the same categories of authority constraints influence the location of other noxious facilities, such as low level waste disposal facilities, chemical/hazardous waste disposal facilities, and even public prisons. In repository location, legal/regulatory constraints are explicitly defined, and such constraints largely define the context or framework for decision-making. The Nuclear Waste Policy Act of 1982, and the supporting DOE Siting Guidelines (10 CFR 960), outline both the spectrum of location factors that must be addressed, and the general process to be followed in making the location decision. These legal/regulatory authority constraints also direct
decision-making on the application of social values through the specification of the relative importance of categories of location factors. Other Federal regulations define minimum levels of acceptable facility performance (e.g., 40 CFR 191 and 10 CFR 60). State and local laws/regulations also have the potential to materially affect the spatial distribution of noxious public facilities. Consequently, this category of authority constraint must be accounted for in the formulation of applicable theory.

Institutional authority constraints relate to the timing, nature, and content of interactions among stakeholder institutions in the noxious public facility location decision. In the case of repository siting, such institutions include Federal agencies (principally the Department of Energy, the Nuclear Regulatory Commission, and the Environmental Protection Agency), state institutions (executive and legislative branches), tribal institutions, (e.g., tribal councils), and the courts. Here again, the NWPA and supporting regulations explicitly define the decision process, as well as what roles, responsibilities, authority, and accountability each institution has in that process.

Political authority constraints also exert influence on the location of noxious public facilities. The nature of this type of location problem is such that a localized area is asked to bear the burdens associated with the solution of a much more diffuse social
problem. In the case of repository siting, this creates an antagonism between Federal authorities charged with the responsibility of solving a national problem, and state/tribal/local authorities who have constituencies that stand firmly against a location within their locale. The NWPA provides the framework within which this dynamic plays itself out, including provision for a state/tribal veto of the location decision subject to an override by a majority vote of both Houses of Congress.

This study has thus concluded that public policy, as embodied in authority constraints, has a direct and substantial impact upon the spatial distribution of noxious public facilities. Theoretical principles addressing the noxious public facility location problem must account for these constraints in attempting to enhance the ability to explain such location decisions.

**Implications for Location Theory**

The noxious public facility location problem has been demonstrated in this study to be significantly different from the private sector industrial location problem that has been the historical focus for location theory development. The development and application of a multiobjective, weighted summation model has proven to be useful for the extraction of theoretical principles applicable to the noxious public facility problem. This section proposes such principles.
Principle #1

The noxious public facility location problem involves multiple, often competing, location factors. These factors include both economic and non-economic factors, but non-economic factors (e.g., public health and safety) exert the most spatial influence. Only a subset of these factors can be defined as disqualifying conditions. The remainder are characterized by relative degrees of favorability.

Principle #2

The noxious public facility location problem is a satisficing problem rather than an optimization problem. A common metric, developed through location factor scaling (on an interval or ratio scale), is necessary to explore the trade-offs between variables in the location decision. The use of location factor weights and scales in the weighted summation formulation geographically expresses the location preferences associated with different value-based views of the relative importance of the location factors.

Principle #3

Noxious facility location decisions are based upon a necessity to meet technical requirements while satisfying as many institutional and political constituencies as possible. Thus, the composite map and summary composite map concepts are useful in explaining location outcomes after the application of disqualifiers. The composite map displays the location preferences
of a single value system as expressed by factor weights. The summary composite map displays the geographic coincidence of multiple location preferences derived from multiple value systems or sets of weights. Consequently, noxious public facility location decisions include areas within the geographic intersection of preferences expressed by diverse constituent groups or stakeholders. Political rationality is defined in terms of satisfying multiple constituencies without compromising the need to meet defined technical objectives.

**Spatial Implications of Theoretical Principles**

The three theoretical principles outlined above have implications for the geographic distribution of noxious public facilities. Each set of weights applied in the weighted summation model penalizes or favors the affected land area in accordance with the characteristics of the area and the relative importance ascribed to those characteristics. Thus, adverse conditions drive the location decision away, and favorable conditions attract the location decision to them. In the repository example, the location decision is generally driven away from population concentrations, protected lands, sensitive environmental features, geologic faults, ground-water discharge zones, etc., and toward areas with suitable host rock characteristics, low population densities, and a lack of environmental sensitivities.
The expectation from the application of these principles is that noxious public facilities would generally be located in areas with low population densities; with an absence of sensitive environmental features; with an abundance of natural characteristics that suit facility construction and operation; with good transportation access; and with proximity to the source of material it is designed to manage.

**Applicability to Other Public Facility Location Problems**

The weighted summation model and theoretical principles outlined herein may be effectively employed in the identification candidate locations/sites for a variety of public facilities. The model is also applicable to private sector location decisions faced with public policy constraints. It is best adapted to the candidate site identification function at a rather small geographic scale (e.g., a multi-state region or a large substate region). It is not as well adapted to comparative site evaluation and final site selection. Other models that incorporate probabilistic risk considerations, such as decision analysis, are best utilized to perform these functions.

The weighted summation model simply needs a list of location factors (e.g., derived from authority constraints) that can be scaled, weighted and geographically expressed on a map. These
factors will differ somewhat by facility type. For example, a chemical waste disposal facility may have a different list of location factors than a low-level radioactive waste facility or a prison facility. The applicability of the composite and summary composite map concepts to explain location outcomes, however, would proceed in the same manner outlined in this research for geologic repositories.

**Suggested Future Research**

The research documented herein has reviewed a category of location problems that has not received much attention in the literature or in theory. The theoretical principles reviewed earlier in this chapter, and the weighted summation model of noxious public facility location decisions, incrementally extend classical and contemporary location theory. This research has also identified several related topics that might benefit from additional study.

With respect to technical location factors, a comparative analysis of the applicable factors for different types of noxious public facilities would be useful for predicting the spatial distribution of such facilities in a more generic model. In addition, the study of the genesis of location factors (e.g., from legislation, regulation, agency discretion, etc.) might prove useful to the development of a more generic model of such location decisions.
The influence of authority constraints on the location decision would be more fully characterized after a review of legal/regulatory, institutional, and political considerations in the siting of other facility types. Such an investigation could lead to the further extension of location theory, particularly if coupled with case studies of how such decisions are made. Such studies could be constructed from a behavioral perspective.

One of the most fruitful avenues of future research might well relate to the topic of geographically expressing human values in location decisions. Such research could further test the thesis that the assignment of location factor weights in the weighted summation model leads to the geographic expression of location preferences. In addition, other models that share this geographic objective could be developed, tested, and compared with the results of the weighted summation model. Alternative approaches to the formation of summary composite maps could also be evaluated as an aid to explaining location outcomes.

Finally, additional multiobjective approaches to performing site comparisons and site selection should be researched. Decision analysis offers significant promise to perform these functions, but the incorporation of probability distributions adds additional complexity to the location decision. It also offers additional potential for the extension of location theory beyond the deterministic model that was the focus of this study.
It is hoped that location theorists will devote more attention to topics that go beyond the conventional emphasis on economic forces and optimization models to examine more fully the influences of non-economic forces, including risk analysis, authority constraints, and behavioral foundations for the multiobjective location decision. Doing so will enhance the explanatory power of location theory, and improve the utility of models for applied location analysis for a broad range of location decisions.


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