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CONSERVATION IN LONG-TERM CONJUNCTIVE USE: IRRIGATION DEMANDS USING DISAGGREGATE CHOICE MODELS

by

David H. Marks
and
John L. Wilson

DEPARTMENT
OF
CIVIL
ENGINEERING

RALPH M. PARSONS LABORATORY
Hydrology and Water Resource Systems

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
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Final Report

Conservation in Long Term Conjunctive Use: Irrigation Demands Using Disaggregate Choice Models

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David H. Marks
Co-Principal Investigator

John L. Wilson
Co-Principal Investigator

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Ralph M. Parsons Laboratory
Massachusetts Institute of Technology
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This final report consists of three sections:

Section 1: Introduction and Executive Summary

by Bruce C. Arntzen, David H. Marks, John L. Wilson, Roman Krzysztofowicz

Section 2: Institutional Objectives in Conjunctive Management of Surface and Groundwater

by Richard Revesz, David H. marks, John L. Wilson, Roman Krzysztofowicz and Bruce C. Arntzen

Section 3: Predicting the Acceptance of Water Conservation Policies by High Plains Irrigators: An Application of Probabilistic Choice Modelling

by Bruce C. Arntzen, Roman Krzysztofowicz, David H. Marks and John L. Wilson

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Section I

Introduction and Executive Summary

Abstract

This report presents the hierarchy of sub-problems involved in modelling the demand for conjunctive use. An historical description of the development of conjunctive user irrigation and a review of current policy initiatives of local water management institutions support the contention that the prime determinants of the demand for new conjunctive use systems for irrigation are their profitability and local water policies. The possible future implementation of comprehensive water management policies needs to be explored by 1) examining the institutional objectives of local water management agencies, and 2) developing a predictive model of the acceptance of conjunctive use policies by irrigators. The research needs identified in this section are further developed in Section II (Institutional Objectives in Conjunctive Management of Surface and Groundwater) and Section III (Predicting the Acceptance of Water Conservation Policies by High Plains Irrigators: An Application of Probabilistic Choice Modelling).

I. Introduction

Because surface water and groundwater posses different temporal, spatial, and legal characteristics, it is often desirable to exploit these differences to improve water supply system performance. Many studies have combined physical and economic models to design economically optimal and technically feasible operating policies for conjunctive use systems. This study examines the issue of the demand for using both surface water and groundwater by irrigation farmers. The goals of the project are as follows:

1. To understand the role of conjunctive use in the overall picture of irrigated agriculture,
2. To understand the demand for conjunctive use;
    - who needs conjunctive use,
    - identify the critical factors limiting this demand, and
3. To identify and pursue research needed to model the irrigation demand for conjunctive use.

1.2 Format of Presentation

This research is presented in the following three volumes:

Section I - Introduction and Executive Summary

Section II - Institutional Objectives in Conjunctive Management of Surface and Groundwater.

Section III - Predicting the Acceptance of Water Conservation Policies by High Plains Irrigators: An Application of Probabilistic Choice Modelling.

Section I addresses the first two goals. It develops and understanding of the role of conjunctive use in irrigated agriculture and examines the nature of the demand for it. Based on this understanding of the demand for conjunctive use Sections II and III identify and pursue two related areas of research needed to model this demand. Section II provides an analysis of the nature and objectives of water management agencies and paves the way for the construction of detailed conceptual models of the decision making processes of these institutions. Section III develops an understanding of the water policy accptance problem and investigates the suitability of behavioral decision methods for predicting water policy acceptance within the scenario of the High Plain.

II. Conjunctive Management

Much of the previous work on conjunctive use has dealt with improving water supplies for irrigated agriculture. Section II-1.1 presents a review of conjunctive use literature.
Nearly all studies reviewed address the problem of designing an optimal operating policy for an irrigated region using a physical model of the stream-aquifer system and an economic model of the farming business. Although the methodologies differ between studies most invoke the assumption that there exists a basin manager with centralized control of all surface and groundwater allocations.

This assumption is invalid in much of the United States where ownership of farms, wells, and water rights are quite dispersed and control of water is decentralized.

The present study attempts to back up from these highly focused, "optimal operating policy" studies and examine irrigation water supplies in general. It seeks to understand the origins of conjunctive use in agriculture and to define its present and future possibilities. In order to understand which farmers desire conjunctive use, and why, it is necessary to look at the history of irrigated agriculture. This is presented below in the scenario of the High Plains.

III. Historical Perspective

Much of the area which today relies on irrigation water to make farming possible, was considered to be a desert for most of history. The Homestead Act of 1862 and the Desert Land Act of 1875 encouraged many settlers to move west and take advantage of free or cheap government farm land. Most of this early development took place in the bottom lands near rivers and streams because of the need for wood and water. Those settlers locating west of the 98th meridian found it too dry to raise crops successfully every year. The drought of the 1890's caused these farmers, where possible, to begin irrigating their fields using surface water diverted from the rivers. An extensive network of diversion dams and canals which ran nearly parralel to the rivers was developed (see Figure A1.1, Section III, Appendix I). Surface water became institutionalized as well. Water rights and water doctrines were developed and irrigation companies and agencies were formed. Later improvements and reservoirs helped increase the reliability of surface water irrigation systems. However, since most of the canals were gravity-flow, only the lands fairly close to the streams could be irrigated.

The Dust Bowl of the 1930's reinforced the opinion that the land could not be farmed without irrigation.

In the 1930's pump and well technology continued to advance to the point where it was soon possible to irrigate using groundwater. This allowed lands which were previously not irrigated, especially land far from streams, to be farmed. The first major surge in well drilling occurred in Texas in the 1950's (Bittinger and Green, 1980). Groundwater had less temporal variation than surface water and thus provided a dependable supply for those with wells. Such users were not dependent upon the weather or irrigation companies. In most states very few legal constraints on groundwater existed for many years, until the mid 1970's.

Thus, originally, there were no conjunctive use irrigators, only surface water irrigators and groundwater irrigators. The first conjunctive use in agriculture occurred when surface water irrigators drilled wells to augment and stabilize their water supplies. Figures 2.1a and 2.1b in Section III demonstrate graphically the inverse relationship between well drilling activity and stream flows in the South Platte River Basin in Colorado. More recently, surface water irrigators along the Platte River in Nebraska have begun pumping groundwater to lower the water tables. Leakage from canals and laterals caused the groundwater levels to rise and begin flooding some low-lying areas. Pumping groundwater for this reason is less common and considered a luxury by those who need water.

Conjunctive use by groundwater irrigators is much less common mainly because surface water is not usually available to them.

Recall that groundwater irrigators were originally located away from streams and thus using surface water was not an option to them. However, as groundwater levels continue to drop conjunctive use is becoming more popular. In the mid 1960's elaborate plans were made to impart water via canals, pipes, etc. from Alaska and the Mississippi River to the High Plains (see Appendix II of Section III). Recently attempts have been made to recharge aquifers using playa lake water, treated wastewater, and spreeding flood flows for infiltration. Cloud seeding has also been tried many times in attempts to bring more water to the land.

The most important factor causing irrigators to seek conjunctive use is simply to obtain more water. It appears doubtful that farmers actively seek new sources of water in order to exploit the different characteristics of the sources to optimize their efficiency. Therefore, it is expected that the demand for conjunctive use parallels the demand for water with the characteristics of the source of water being a secondary consideration only.

IV. Comprehensive Water Management

The legal and institutional systems which govern the use of groundwater are not catching up to those for surface water. Many states have created local Groundwater Management Districts (GWMD's) and have empowered them to govern groundwater use in their districts. Nebrasks has farmed Natural Resources Districts (NRD's) to have jurisdiction over all natural resources. Recently, Texas court cases have addressed the question of determining the rights to atmospheric moisture which is being sought through cloud seeding (Templer, 1980). Therefore, before too long, rules and regulations will be in effect governing the use of water in all phases of the hydrologic cycle. Much of this legal system is in effect already. However, tremendous problems have arisen from the failure of state laws to recognize the connections between water in the various phases of the hydrologic cycle. Appendix I of Section III discusses a case study in southwest Nebraska where recent groundwater irrigators have severely reduced the surface water supplies to long established irrigation districts. No legal connection between surface and groundwater is recognized in Nebraska.

It seems unavoidable that eventually the connections between the various components of the hydrologic cycle will be legally recognized and that new comprehensive water management policies will be phases in. Whether such policies arise from the legislatures or from the courts, it is likely that implementation of such policies will be best accomplished through the local NRD's or GWMDS's since they enjoy the most popular support among the irrigators. The final form of such comprehensive management policies to be implemented will certainly reflect the objectives of the NRD's and irrigation districts, GWMD's and the objectives of the farmers.

V. Modelling the Irrigation Demand for Conjunctive Use

To pursue the second goal of this research it was necessary to zero in on: 1) who in irrigated agriculture wants conjunctive use?, and 2) what are the critical factors limiting this demand? This

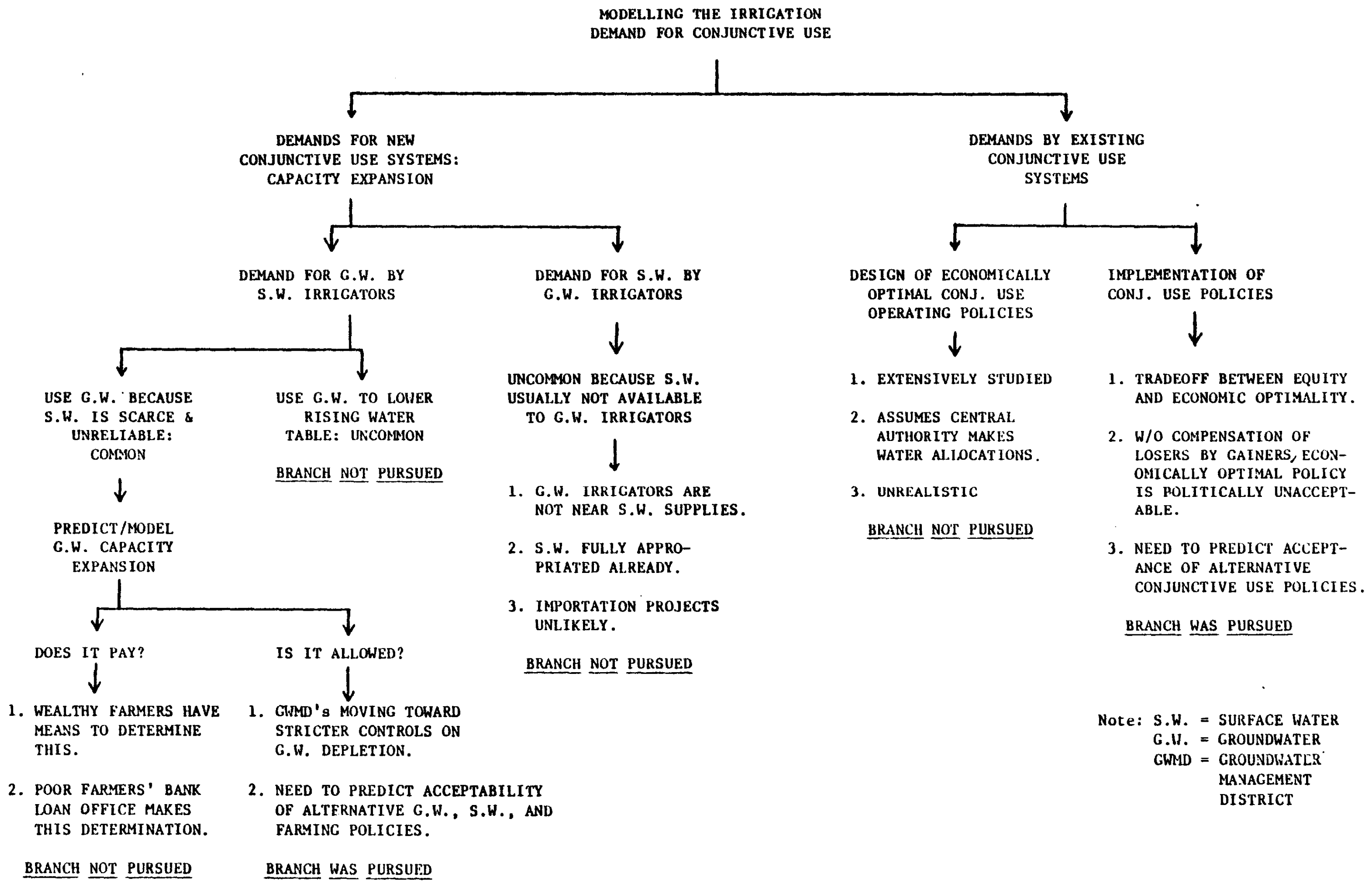

Figure 1: Hierarchy of the Irrigation Demand for Conjunctive Use

phase of the research is best summarized by the hierarchy of conjunctive use demands shown in Figure 1.

The demand for conjunctive use by irrigators breaks down into 1) demands by existing conjunctive use systems, and 2) demands for new conjunctive use systems (i.e., capacity expansion). Studying the demands by existing conjunctive use systems includes at least two stages, 1) designing economically optimal operating policies and 2) implementation of conjunctive use policies. Much previous research has been devoted to designing efficient operating policies and it is reviewed in Section II - 1.1. The present study did not pursue this because 1) it has already been studied extensively and 2) several unrealistic assumptions (e.g., centralized water authority) are required.

However, studying the implementation of conjunctive use policies was pursued. It seems likely that economic efficiency will be only one of a number of criteria which become important in attempting to implement conjunctive management policies. If water is reallocated among farmers to improve the regional economic efficiency it is likely that some farmers will gain by this and others will lose. If there is no trusted mechanism for the gainers to compensate the losers, such as there is none in many decentralized farming areas, then such an economically optimal regional plan is politely infeasible. Instead policies which compromise efficiency with equity will be more acceptable. In addressing this branch of the hierarchy in Figure 1, Section II examines the institutional objectives in conjunctive management and Section III develops a model to predict new water policy acceptance by irrigators.

The demands for new conjunctive use systems (capacity expansion) by single source users breaks down into: 1) demands for surface water by groundwater irrigators and 2) demands for groundwater by surface water irrigators. Often surface water is not available to groundwater irrigators because of their distance from surface supplies. Also, most western streams have been fully appropriated for many years making it difficult for new users to obtain surface water. Unusual sources of surface water, such as treated waste water, water, do exist but are often of limited availability. Finally, water importation plans to provide surface water to groundwater irrigators are sufficiently unlikely to make this branch of the demand hierarchy less important to demand modelers than other branches. This research did not pursue this branch.

The demand for new groundwater capacity by surface water irrigators seems to have two very different causes: 1) use of groundwater to lower a rising water table and 2) use of groundwater because surface water is scarce and unreliable. The first reason is less common than the second and is seen as a luxury by those who fall into the second category. In several places where there is extensive surfacewater irrigation with plentiful supplies (near the Platte River in mid-Nebraska) canal leakage has elevated water tables to the point where they must be pumped to prevent flooding. However, this surplus of water is much less common than the scarcity which exists throughout the High Plains. Therefore, this type of demand was not pursued in this study.

The demand for groundwater because surfacewater is scarce and unreliable is quite high and quite a common occurrence. This problem was vigorously pursued by this research by exploring predictive modelling possibilities for groundwater capacity expansion. A field study was conducted in McCook, Nebraska to gain familiarity with this problem. Many conversations with farmers and local water officials helped to clarify the problem and identified two very simple but key questions that affect groundwater capacity expansion: 1) "Does it pay?" and 2) "Is it allowed?"

It appeared that farming businesses and agencies were in much better positions to determine the profitability of capacity expansion (installing a new well and pump) than the authors. Discussions with agricultural extension agents revealed their own personal knowledge of agribusiness and the computerized resources at their disposal. It was assumed that if a farmer could afford to pay for a new well and pump on his own that he probably possessed the necessary skills to find out if it would be profitable or not. Conversely, it was assured that if a farmer had to borrow money, the bank loan office would only cooperate if the venture was expected to be profitable, and the bank would make this determination. Therefore, this study focused on the other key question, "Is it allowed?"

The study of the legal structures governing the use of groundwater revealed a changing situation in many parts of the West, especially in the High Plains. Because of decreasing groundwater supplies and conflicts between surface and groundwater users, many states, via their local GUMD's or NRD's are moving toward stricter groundwater controls. Chapter 5 of Section III reviews all the rules and regulations of the 29 GWMD's on the High Plains, and discusses possible water policy alternatives. The question of "Is it allowed?" is best addressed by predicting which new groundwater, surface water, and farming policies will be implemented by the local GWMD's and NRD's. The remainder of this study addresses this question from two sides. Section II examines the objectives of the various management instiutions involved in water policy. Section III explores methods to predict the acceptability of alternative water policies to the farmers. Thus, this study reduces "Modelling the Irrigation Demand for Conjunctive Use" down to examining the implementation of alternative water policies.

VI. Implementation of Conjunctive Use Policies

To address the third goal of this research, "to identify and pursue research needed to model the irrigation demand for conjunctive use", it is necessary to identify critical issues concerning water policy implementation.

6.1 Decision Components

The first step in understanding policy formation and implementation is to identify the decision components in the irrigation management system. It is necessary to schematicize the hierarchy of institutions and agencies and to decide the legal and practical extent of their authority. Many states (e.g., Nebraska, Kansas, Colorado, and Texas) have established local GWMD's or NRD's which are governed by a board of 8-10 members which the water users elect from among their peers. Since these boards generally enjoy local support, higher level agencies often seek to work through them to achieve their goals. On the other hand the local boards often reflect only a slightly more regional viewpoint of various problems than the individual farmers. It is also necessary to determine what role the farmers play legally and practically in the implementation of new water policies. Chapter 2 of Section II and III both discuss the decision components of the irrigation management system.

6.2 Objectives of Decision Components

The surface and groundwater problems which affect the farmers and the water management agencies stimulate the creation of objectives by these decision components. It is necessary to understand the problems which instigate new policies and the objectives of the decision makers who will design and judge the new policies. Chapter 3 of Section II discusses objectives of local irrigation institutions including 1) profit maximization, 2) local control, 3) conflict resolution, 4) equity, and 5) maximization of internal utility. Chapter 5 of Section III describes some of the objectives used by farmers to judge new policies including:

1) Elimination of uncertainty about future water supplies,
2) equity,
3) effectiveness in halting groundwater mining,
4) effectiveness in stretching existing supplies,
5) inexpensive,
6) convenience,
7) traditional,
8) privacy, and
9) short term production outputs.

6.3 Equity Versus Economic Efficiency

Discussions with GWMD and NRD managers, State and Federal officials, and farmers overwhelmingly confirmed the opinion that no water policies can be successfully implemented without the popular support of the farmers. It is, therefore, not surprising that many GWMD's and NRD's conduct extensive public information campaigns including everything from distributing educational comic books in the schools (Texas' High Plains Underground Water Management District No. 1) to broadcasting their monthly board meetings over the radio (Upper Republican NRD, Imperial, Nebraska). The aim of these campaigns is to expose the individual irrigators to a much more regional discussion of their problem in hopes that they will adopt more regional objectives and thus accept proposed water management policies.

Chapter 5 of Section III reviews the rules and regulations currently in effect in each GWMD and NRD on the High Plains. These usually consist of measures such as well spacing requirements, pumping rotations, and groundwater allocations. Of the various objectives mentioned above, equity is perhaps the most important factor affecting policy acceptance. Examination of the policies of the 29 GWMD's shows that they all attempt to treat farmers equally and fairly. For instance in the Upper Republican NRD (Nebraska) groundwater is allocated uniformly to all irrigators on the basis of their number of irrigable acres. In addition all wells must be metered. The minutes of the board meetings of this district reveal that they are very reluctant to grant variances to individuals who claim a "special case" on the grounds that it would be unfair to others. Thus equity is seen as a major concern of the local institutions.

Most of the literature on conjunctive use policies to date have dealt with designing operating policies which maximize the economic efficiency of the region. It is herein proposed that in actual practice a tradeoff is made between various objectives. For instance Figure 2 shows a hypothetical tradeoff between economic efficiency and equity objectives. Whatever conjunctive use policy is finally implemented will represent a compromise between the various objectives. Points A-E depict the locations in objective space of 5 non-dominated hypothetical conjunctive use policies. If these were the only two objectives then the decision concerning which of the policies A-E will be implemented would depend on the acceptability of the policies to the irrigators. Similar tradeoffs are made implicitly between all objectives whenever a policy is finally implemented.

Section II of this study concentrates on defining the objectives of local irrigation institutions. Section III concentrates on developing a model to predict which of the alternative groundwater, surface water, and farming policies will be the most acceptable to the irrigators. Together these sections attempt to define the nature of Figure 2 for irrigation management systems and to predict which compromise solutions are the most acceptable to the irrigators.

VII. Remainder of Report

The contents of Sections II and III are described below.

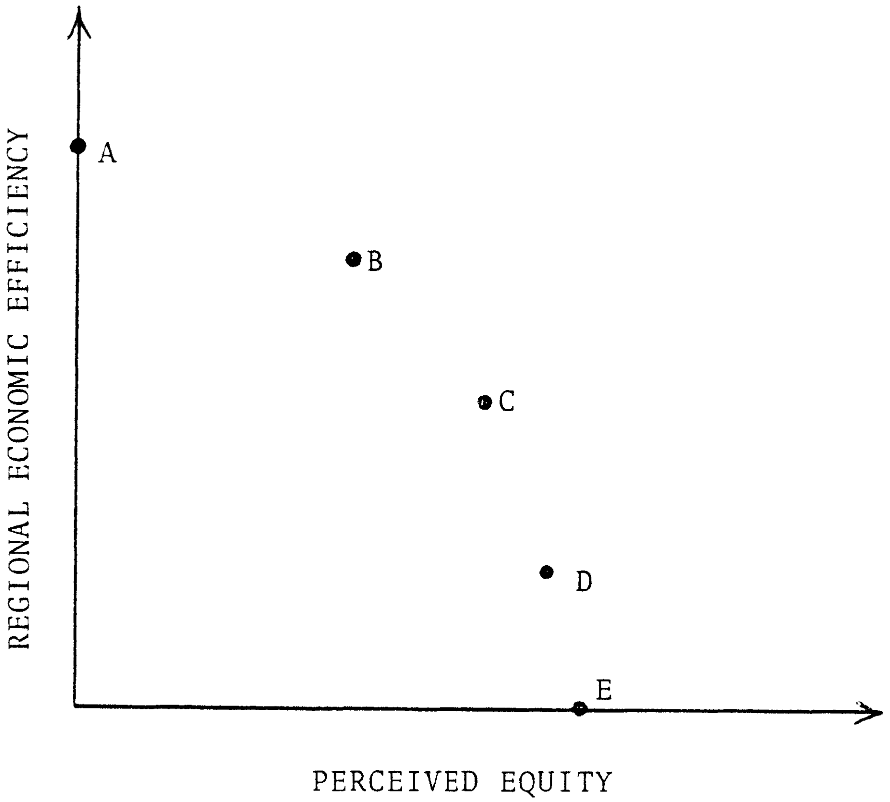

Figure 2: Tradeoffs Between Regional Economic Efficiency and Equity as Perceived by Individual Farmers

7.1 Institutional Objectives in Conjunctive Management of Surface and Groundwater (Section II)

by

Richard Revesz, David H. Marks, Roman Krzysztofowicz,
John L. Wilson and Bruce C. Arntzen

7.1.1 Executive Summary

A comprehensive study of the conjunctive use of surface and groundwater should address three interrelated issues:

1. The role of irrigation institutions in the supply of water.
2. the demand of farmers for water from different sources, and
3. the physical characteristics of surface-groundwater systems.

In general, the engineering literature on this subject, has focused on the third issue and ignored the first two. In doing so, it has failed to recognize that the major unanswered questions in the conjunctive management and use of surface and groundwater involve institutional and behavioral problems.

The engineering literature on the conjunctive management of surface and groundwater has failed to incorporate realistic representations of the operation of irrigation institutions into an overall management model. A great deal of the effort of investigators has been devoted to solutions which are mathematically interesting, but which are bad predictors of the behavior of real systems.

Ironically, the importance of better representations of reality has been recognized (Knopman, 1978; Flores et al., 1978) and good descriptions of the operation of irrigation institutions have been provided in case studies of semi-arid regions (Maass and Anderson, 1978), but little effort has been devoted to finding ways to link this information to other components of studies on the conjunctive management of surface and groundwater.

An accurate analysis of the nature and objectives of irrigation agencies paves the way for the construction of detailed conceptual models of the decision-making process of these institutions. These models can either predict or describe the behavior of a particular agency and can be incorporated into a general framework suitable for the analysis of most issues relating to the conjunctive management of surface and groundwater.

7.1.2 Findings and Conclusions

A systematic analysis of the literature on the conjunctive management of surface and groundwater revealed five serious deficiencies, two of which were analyzed in depth. The assumption of centralized control does not accurately describe the operation of local irrigation agencies, since the powers of these institutions are limited to very specific areas. Ironically, the recent formation of National Resources Districts (NRD) in Nebraska might herald a transition to more centralized control. Indeed, these Natural resources Districts replace all existing special purpose public districts in the state and have the power to supply surface water and to declare groundwater control areas (Axthelm, n.d.). However, even these districts do not conform to the descriptions provided by most engineering studies because they do not have complete control over groundwater withdrawals. Single objective functions in general, and aggregate profit maximization in particular, are not successful at explaining the decisions of irrigation agencies. In addition, other important objectives were identified: local control, equity, conflict resolution, and maximization of "internal utility." However, a comprehensive list of objectives can be elucidated only through a case study of a particular irrigation agency.

This study shows how the knowledge obtained from studying the nature and objectives of irrigation agencies can be used to build a prescriptive or descriptive model of such an agency. Section II also discussed the ways in which a model of this type can be incorporated into an overall decision model used to study problems involving the conjunctive management of surface and groundwater. The hypothetical example presented in Section II-4.3 illustrates which alternatives may be available to a particular agency to deal with declining groundwater levels and how agencies might assess the impact of their policies on their objectives.

7.1.2.1 Contributions of the Research

The central contributions of this report are that it shows that:

1. Institutional problems need to be studied in any overall examination of the conjunctive management of surface and groundwater.
2. Reasonably complex multi objective organizational models may be incorporated with relative ease into these studies.
3. The term "conjunctive management of surface and groundwater" is actually misleading because in most cases, an irrigation agency can only regulate groundwater withdrawals by indirect methods.
4. Most of the components of the model of a political institution discussed by Easton and the multi objective technique used to find a preferred alternative should be defined to be compatible with the case study being planned.

7.1.2.2 Suggestions for Further Research

This study has discussed some areas in detail, outlined others and hinted at the importance of yet others. Thus, it opens up countless opportunities for further research. First, a case study of either a public irrigation district would illustrate the methods to elucidate objectives and rank alternatives presented in this paper. Second, a model of an irrigation agency could be incorporated to an existing study of conjunctive use of surface and groundwater. The study best suited for this attempt is that of Young and Bredehoeft (1972) because it recognized that farmers, and not a centralized agency, make most of the groundwater withdrawal decisions. In any event, the study used should be one which employs linking as the method for combining hydrologic and economic models. Embedding models should not be used because they cannot account for the physical behavior of overdeveloped aquifers. Response function models cannot be used because it is not possible to derive precise mathematical expressions linking surface and groundwater levels with the degree of attainment of the various objectives. In the more distance future, this study should be coupled with works on farmer demand for surface and groundwater currently in progress (Section III).

7.2 Predicting the Acceptance of Water Conservation Policies by High Plains Irrigators: An Application of Probabilistic Choice Modelling, by Bruce C. Arntzen Roman Krzysztofowicz, David Marks and John Wilson

7.2.1 Executive Summary

This study addresses the groundwater depletion problem in the Ogallala aquifer beneath the High Plains and examines the suitability of probabilistic choice models for predicting the acceptability of alternative water conservation policies to the irrigators. The nature of the policy acceptance problem is discussed and the social, institutional, and legal environments present on the High Plains are described. An overview of choice models and behavioral factors of individual information processing is presented. Use of the Elimination by Aspects (EBA) model and the Luce choice model is explored in the context of predicting the degree of acceptance of alternative water conservation policies by irrigators. The existing and proposed policies of the groundwater management districts on the High Plains are reviewed and their characterization terms of aspects is proposed. These alternatives are then used in an experimental application of the EBA and Luce choice models. Two laboratory experiments are conducted to examine the performance of these models in the contexts of predicting water conservation policy acceptance.

The experiments confirm the validity of the regularity and moderate stochastic transitivity assumptions (EBA model) and the multiplicative inequality (both models) but do not confirm the validity of the similarity hypothesis (EBA model), or the constant ratio rule and strong stochastic transitivity (Luce's model). In the experiments, the EBA model was a more accurate predictor of the choice probabilities than Luce's model. Furthermore, use of the EBA model appears to be most appropriate for problems characterized by many feasible alternatives which can be described by many concrete aspects which are easily recognized by the decision makers. Recommendations are made concerning field applications of the EBA model and future research needs of predictive choice modelling.

7.2.2 Findings and Conclusions

The major findings and observations which have been made throughout Section III are presented as follows. The first section presents a discussion of observations made concerning 1) the nature of policy acceptance, 2) developing a method to predict policy acceptance, and 3) tests of predictive models. The second section presents the results of the laboratory experiments. The third section describes the contributions made by this research. The fourth and final section makes recommendations concerning a field application of the EBA model and future research needs of predictive choice modelling.

7.2.2.1 Discussion

Much was learned about the accpetance of water conservation policies in the High Plains and predictive modelling which can provide valuable insight for those interested in the problem. These observations are discussed below.

Concerning the Nature of Policy Acceptance

A. The High Plains seems to consist of two distinct regions with the Platte River and the North Platte River forming the boundary. Different water conservation policies are relevant in each region (See Section III-1.2.2).

B. As the Ogallala problem and the various legal and institutional constraints were better understood, it appeared that High Plains irrigators and managers have fewer options for obtaining and transferring -ater than was originally supposed.

C. It was also discovered that the irrigators, as individuals acted economically rationally to use up the groundwater resources. Similarly, the state legislatures were too slow to react to the problem and missed their chance to curb overdevelopment. Importation plans, even within the same state appear to be politically unpopular. It seems that strict water conservation policies will be an important component of any solution, with or without importation.

D. Because of the traditional resentment by farmers of any state or federal policies, it appears that the major role in developing and implementing new conservation policies will be played by the local groundwater management districts (GWMD's) (See Section III-1.2.4).

Concerning Developing a Method to Predict Policy Acceptance

A. A literature search was conducted and revealed that no previous attempts have been made to model and predict policy acceptance; public opinion polls were the closest thing (See Section III-1.3).

B. Slovic, Fischhoff, and Lichtenstein (1977) in their review of behavioral decision theory note that: recent predictive research has moved away from regression and other "Black box" models and has moved toward 1) using disaggregate (individual) data, 2) accounting for the randomness of utility functions, and 3) developing conceptual models of human decision making behavior (See Section III-3.2.2).

C. Choice models (including the EBA model) seem more appropriate than aggregate black box models because of 1) the highly individual and subjective nature of policy acceptance, 2) the lack of previous data required for aggregate models, and 3) the desire to incorporate psychological decision theory into the model (See Section III-3.1).

D. For some problems, Tversky's EBA model has theoretical advantages over many more common choice models (including Luce's model) (See Section III-4.2).

E. Policy acceptance by its very nature usually lacks concrete aspects and thus the EBA model will probably never be as good of a predictor of policy acceptance as it would be at predicting the choice probabilities among tangible objects. It should accurately predict automobile sales, for instance.

Concerning Tests of Predictive Models

A. The choices which were predicted on the basis of the subjects' stated (uncommitted) preferences did not seem to agree well with their actual choices (committed behavior) among conservation policy alternatives (See Section III-6.3.7).

B. The predictive experiment results exhibited considerable disagreement between individuals concerning the possession functions (See Section III-6.3.7). When "fuzzy" aspects are involved, it is necessary for the subjects to realize a priori that possession of aspects is a relative matter which depends on the offered set of alternatives.

7.2.2.2 Major Findings

The following statements were shown to be trye in the experiments performed during this research:

A. Tversky's experiment showed that 1) the regulariyy hypothesis (EBA model) held slightly more often than the constant ratio rule (Luce's model) which held much more often than the similarity hypothesis (EBA model), 2) the moderate form of stochastic transitivity (EBA model) held consistently with the strong form (Luce's model) holding about half of the time, and 3) the multiplicative inequality (EBA and Luce models) was confirmed. The constant ratio rule and strong stochastic transitivity assumptions of Luce's model were shown to be weak.

B. The predictive experiment demonstrated that the expert's possession function should be used instead of individual possession functions and that the raw data should be aggregated first and then the model run, not vice versa.

C. The predictive experiment showed that the EBA model is a good predictor of choice probabilities when a large number of alternatives is available. It is a poor predictor when there are few alternatives or when individuals' possession functions are used.

D. Luce's model (additive utility function) is a good predictor of ratings but a poor predictor of choice probabilities.

7.2.2.3 Contributions of the Research

This research supports the view that the groundwater depletion problem in the Ogallala aquifer has now become a problem of conservation policy acceptance. Supply-side alternatives are now being thought of in conjunction with or replaced by controls on demand.

This research presented the first attempt known to the author to frame the managers, the farmers, their decisions, and the various physical and decision components into an irrigation Management System. Much more work needs to be done, however, in further specifying this system.

This study presented the first attempt ever to model and predict policy acceptance of any kind. This seems very ironic in light of how much time and effort is devoted to formulating and implementing new policies. Considering and predicting acceptance *a priori* has long been neglected.

This research provides the first application of Tversky's EBA model to a real problem and the first comparison of EBA to

Luce's model in an actual experiment. It also presented the first replication of Tversky's experimental test of the EBA model's assumptions.

Finally, the study presented many valuable recommendations for future applications of the EBA model, future improvements in choice and policy acceptance modelling.

7.2.2.4 Recommendation for Future Research

It seems that the phenomenon of switching from supply alternatives to demand alternatives (as is the case in the High Plains) because of political and economic resistance to supply alternatives is occurring more and more in many public services which provide water, power, waste disposal, etc. Since capacity expansion is opposed, controls on demands of all sorts of public goods will be necessary and thus predicting policy acceptance will become increasingly important.

The EBA model should be used on problems which lend themselves to the EBA strategy and not holistic judgments. Since most policy alternatives are not concrete enough for the EBA strategy, research should be done to either 1) devise a method for describing policy alternatives in more concrete terms in order to use the EBA model, or 2) to pursue other models. The EBA model should be tested under conditions which seem optimal for the EBA strategy (such as an automobile sales experiment) to confirm that it does indeed perform well under those conditions. Also, the EBA model should be compared to more sophisticated choice models, notably the Logit model, to confirm or refute the superiority of the EBA model for specific decision problems. Finally, a word on the future of choice modelling. The EBA strategy is just one of many possible heuristics which might be used in making a choice (see Section III, Table 3.1). These heuristics require that the alternatives and aspects (or attributes) of the decision problem be clearly defined and known to the decision maker. The key to future improvement in choice modelling and policy acceptance modelling lies in developing a processing model which would predict when and why decision makers use each heuristic and when they make holistic decisions.

VIII. Chronology of the Project

Pursuant to grant number 14-34-001-9430 from the Office of Water Research and Technology, U.S. Department of the Interior this project commenced on September 1, 1979. Professors David H. Marks and John L. Wilson (M.I.T., Department of Civil Engineering) were the co-principal investigators and Professor Roman Krzysztofowicz (M.I.T., Department of Civil Engineering) also supervised much of the research. Sections I and III were written by Bruce C. Arntzen (edited by Roman Krzysztofowicz) and Section II was written by Richard L. Revesz (edited by David H. Marks). Four progress reports were submitted to O.W.R.T. dated: December 21, 1979; March 14, 1980; March 31, 1980; and August 20, 1980.

In May of 1980, Professor David H. Marks and Bruce C. Arntzen travelled to Lincoln, Nebraska and discussed the possibility of a case study in Nebraska with members of the Nebraska Water

resources Center. The authors would like to thank Mr. Gary Lewis, Darryl Pederson, Ray Bental, Don Swoboda, Susan Welch, Vince Dreezen, and Mike Jess for their hospitality in Lincoln. Field work was done by Bruce C. Arntzen who spent two weeks in McCook, Nebraska and Denver, Colorado during June 1980, meeting with local water officials and the U.S. Water and Power Resources Service. The authors would like to thank Bob Klein (Agricultural Extension Agent, Red Willow County, Nebraska), Bob Jumps and Norman Sitzman (Frenchman Valley and H&RW Irrigation Districts), Dennis Aleker and Bob Kutz (U.S. Water & Power Resources Service, McCook, Nebraska), Fred Zabel (Department of Water Resources, Cambridge, Nebraska), Vernon Laverick and Lorene Stroud (Frenchman-Cambridge Irrigation Districts; Cambridge, Nebraska), Wayne Heathers (Middle Republican NRD, Curtis, Nebraska), Fred Krauss, Barry Anderson, George Wallen, and John Peterson (U.S. Water & Power Resources Service, Denver, Colorado), Ron Milner (Upper Republican NRD, Imperial, Nebraska), Jim Goeke (Agricultural Experiment Station, North Platte, Nebraska) all of whom were very helpful during the field work in Nebraska.

In november, 1980 two seminars describing this project were given by Bruce C. Arntzen at M.I.T. and the two laboratory experiments which are reported in Section III, Chapter 6 were conducted. The experiments used M.I.T. students who has permanent residences on farms or in small towns on the High Plains.

Finally, the authors would like to thank Mr. John Campbell and Mr. Ted Roeffs at O.W.R.T. for their cooperation with this project.

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Final Report

Conservation in Long Term Conjunctive Use: Irrigation Demands Using Disaggregate Choice Models

Section II

Institutional Objectives in Conjunctive Management of Surface and Groundwater

by

Richard Revesz, David H. Marks, Roman Krzysztofowicz,
John L. Wilson and Bruce C. Arntzen

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Section II

Institutional Objectives in Conjunctive Management of Surface and Groundwater

Abstract

Local irrigation agencies are not centralized institutions with complete power over all surface and groundwater decisions in their basins. Instead, the three major types of irrigation agencies: public irrigation districts, mutual water companies and commercial water companies have different and relatively limited powers. Most importantly, with certain exceptions, they cannot directly control excessive groundwater withdrawals and have to resort to indirect methods to achieve this goal.

The study of the decision-making process of two important types of local irrigation agencies, public irrigation districts and mutual companies can be simplified by hypothesizing that these agencies have similar objectives. However, single objective models should be discarded because they fail to predict actual decisions. Instead, multi-objective models should be used: aggregate profit maximization, local control, conflict resolution, equity and internal motives play an important role in shaping the choice between different policies.

An accurate analysis of the nature and objective of irrigation agencies paves the way for the construction of detailed conceptual models of the decision-making process of these institutions. These models can either predict or describe the behavior of a

particular agency and can be incorporated into a general framework suitable for the analysis of most issues relating to the conjunctive management of surface and groundwater.

Chapter 1

Introduction

A comprehensive study of the conjunctive use of surface and groundwater should address three interrelated issues:

1. The role of irrigation institutions in the supply of water.
2. the demand of farmers for water from different sources, and
3. the physical characteristics of surface-groundwater systems.

In general, the engineering literature on this subject, has focused on the third issue and ignored the first two. In doing so, it has failed to recognize that the major unanswered questions in the conjunctive management and use of surface and ground water involve institutional and behavioral problems.

The engineering literature on the conjunctive management of surface and groundwater has failed to incorporate realistic representations of the operation of irrigation institutions into an overall management model. A great deal of the effort of investigators has been devoted to solutions which are mathematically interesting, but which are bad predictors of the behavior of real systems.

Ironically, the importance of better representations of reality has been recognized (Knopman, 1978; Flores et al., 1978) and good descriptions of the operation of irrigation institutions have been provided in case studies of semi-arid regions (Maass and Anderson, 1978), but little effort has been devoted to finding ways to link this information to other components of studies on the conjunctive management of surface and groundwater.

The contributions of this report lies in three areas:

1. Systematic analysis of the more serious deficiencies of previous works,
2. description of the constitution, operation, attributions and objectives of local irrigation agencies, and
3. discussion of ways in which knowledge of the nature of irrigation institutions can be used to analyze the policy alternatives available to a given agency, define the criteria that it will use in ranking these alternatives and speculate on the effects of its decisions on the state of the basin.

This paper does not present an overall management model, but rather, identifies the important issues and discusses ways in which these issues might be treated by future researchers attempting to construct a detailed model of this system.

In a concurrent study, Arntzen (1980) analyzes the decision-making processes of individual farmers and constructs a predictive model of farmers' water demand and water choice decisions. He employs a case study to compare the accuracy of this model to that of existing models. Thus, these two studies fill an important gap, and pave the way for future comprehensive studies of the conjunctive use of surface and groundwater.

1.1 Review of the Literature

The literature on the conjunctive use of surface and groundwater addresses a wide variety of issues: groundwater mining, salt-water intrusion, low flow maintenance in a stream connected to an aquifer, inter-aquifer water transfer, groundwater quality, artificial recharge, etc. Most of the studies to date have concentrated on issues of supply and, in particular, on the supply of water in semi-arid agricultural areas. Among the topics presented are the efficient allocation of resources, the externalities of groundwater withdrawal when a stream and an aquifer are hydraulically connected, the non-linearity of pumping costs and the stochasticity of stream flows.

A comprehensive review of this literature was performed by Burges and Maknoon (1975). Despite its usefulness in other contexts, the historical approach developed by the authors does not shed light on the fundamental differences among the various studies. These differences may be analyzed more effectively when the studies are classified according to the characteristics of their components.

In general, studies on the conjunctive use of surface and groundwater employ both hydrologic and economic models. The sophistication of a hydrologic model depends, to a large extent, on the method through which it is coupled with an economic model. Therefore, the interaction between these models provides a good basis for the classification of conjunctive use studies. Three approaches have been used to couple hydrologic and economic models: embedding, linking and response functions. These approaches are illustrated in Figure 1.

1.1.1 Embedding

Embedding is by far the simplest coupling technique: the total capacities of the aquifer, the river and the surface distribution system are incorporated as constraints in the economic model. In its simplest form, the embedding technique can be expressed as follows:

$$\text{Min} \sum_i \sum_j c_{ij} x_{ij}$$

$$\text{s.t.} \sum_i x_{ij} \geq d_j$$

$$\sum_j x_{ij} \leq s_i$$

$$x_{ij} \geq 0 \qquad \forall(i,j) \qquad (1)$$

where:

x_{ij} - is the water transported from source i to user j

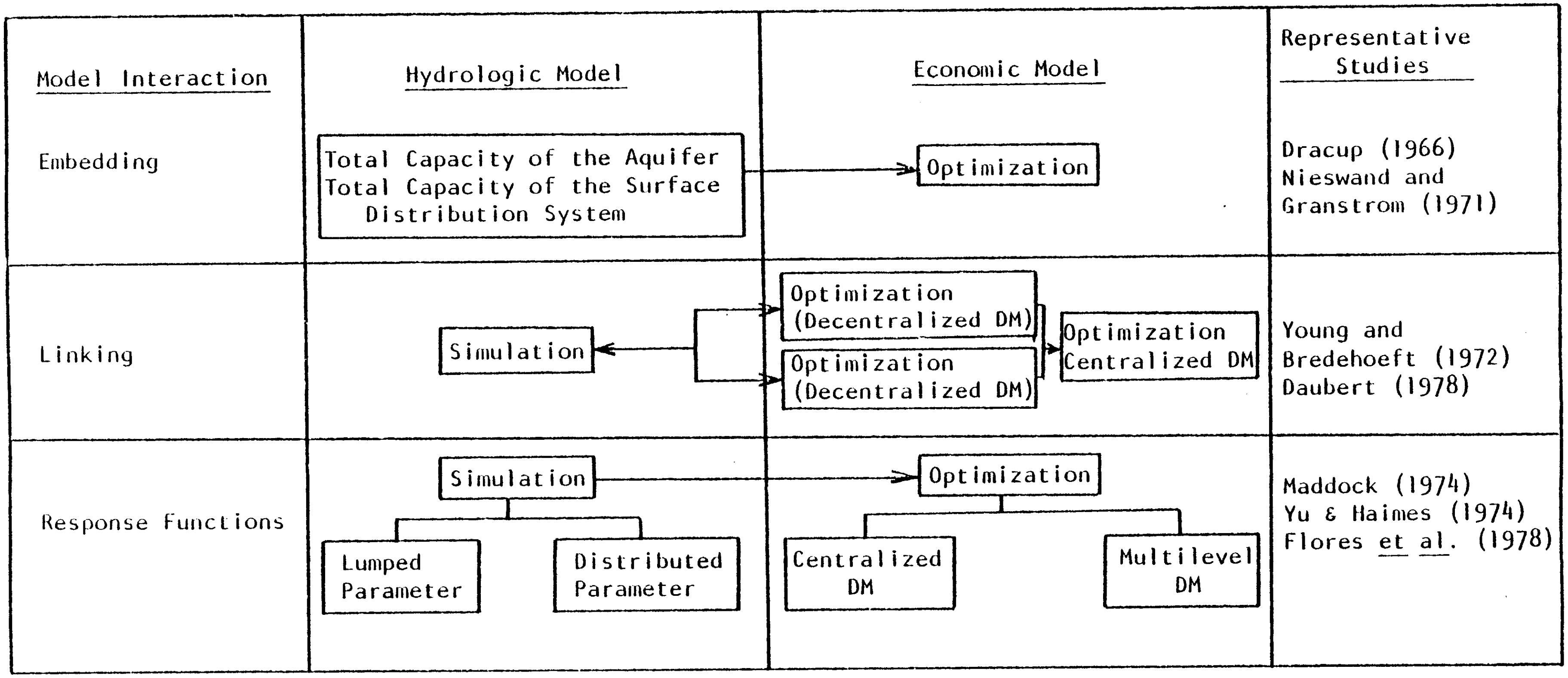
c_{ij} - is the unit cost of transporting x_{ij}

d_j - is the total demand of user j

s_i - is the total available supply of surface and/or groundwater from source i

As is readily apparent, this problem formulation corresponds to that of a "transportation" problem, commonly used in resource allocation sutdies (Bradley et al., 1977). A major shortcoming of this formulation is that it ignores both the physical characteristic of the aquifer and the interaction between the aquifer and the stream.

Figure 1: Conjunctive Use Studies - Classification



Model Interaction	Hydrologic Model	Economic Model	Representative Studies
Embedding	Total Capacity of the Aquifer Total Capacity of the Surface Distribution System	Optimization	Dracup (1966) Nieswand and Granstrom (1971)
Linking	Simulation	Optimization (Decentralized DM) Optimization (Decentralized DM) Optimization Centralized DM	Young and Bredehoeft (1972) Daubert (1978)
Response Functions	Simulation Lumped Parameter Distributed Parameter	Optimization Centralized DM Multilevel DM	Maddock (1974) Yu & Haimes (1974) Flores _et al_. (1978)

Despite its crudeness, this approach has been widely used (Castle and Lindeborg, 1961; Buras, 1963; Chun et al., 1964; Aron, 1969; Nieswand and Granstrom, 1971; Hamdan and Meredith, 1975). Castle and Lindeborg (1961) present a linear programming model that allocates surface and groundwater to two agricultural areas. Buras (1963) uses dynamic programming to determine design parameters for surface water facilities, the service area and operating policies for combined reservoir releases and aquifer pumping rates for a conjunctively managed system. Chun et al., (1964) employ simulation techniques to find ways of meeting the growing water demand in a region and at the same time correcting some of the undesirable effects of extraction, such as salt-water intrusion. Aron (1969) uses dynamic programming to determine the optimal allocation of surface and groundwater from sources to several users. Nieswand and Granstrom (1971) employ chance constrained linear programming to maximize the water delivered to a system with stochastic demands. Finally, Hamdan and Meredith (1975) present a model that uses both linear and dynamic programming solution techniques.

While the method of embedding might prove useful for screening models in which the problem of groundwater depletion could be ignored, it provides inaccurate results when the effects of well interference and changes in the piezometric head of the aquifer are important. In these cases, models which explicitly incorporate the characteristics of the physical system have to be employed.

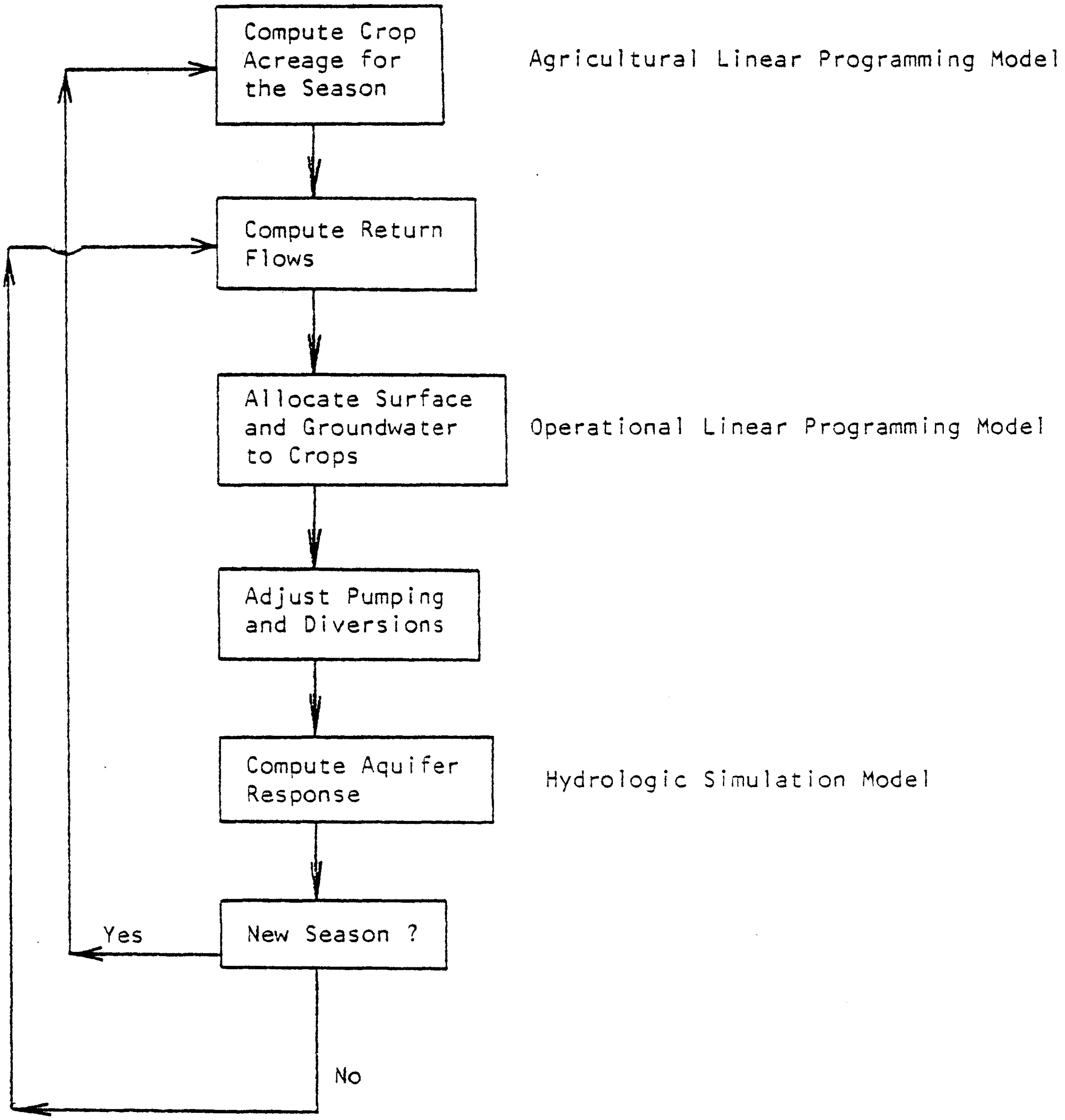
1.1.2 Linking

Linking provides an "ad-hoc" procedure for combining a groundwater simulation model with an economic optimization model. This method has been applied to a groundwater management problem by Bredehoeft and Young (1970) and to a conjunctive surface and groundwater problem by Young and Bredehoeft (1972). In the latter paper, the authors develop a basin-wide planning model that couples the physical relationships between the stream and the aquifer, the stochastic properties of surface flows and the response of individual water users. The study can be divided into the following four parts:

1. A hydrologic simulation model that describes the physical interactions in the stream-aquifer system,
2. an agricultural linear programming model that determines the allocation of land to different crops,
3. a monthly operating model that predicts the response of irrigators: their surface water diversion, groundwater use, etc. and
4. an overall simulation model that provides a structure for the coupling of the preceding three models. This model ranks alternative policies according to their impact on aggregate profits and can be used by a decision maker to evaluate the effects of his policies.

Figure 2 illustrates the structure of the Young and Bredehoeft (1972) study. Each season, the agricultural linear programming model computes the allocation of the existing land to the different crops. Each month, the operating linear programming model calculates the allocation of water to the different crops and the groundwater simulation model computes the aquifer response to the pumping and diversions.

Figure 2: Linking Technique as Used by Young and Brehehoeft (1972)



1.1.3 Response Functions

A more recent and powerful technique than linking, the response function method, directly incorporates a hydrologic model into an economic optimization model. This method (Maddock, 1974; Morel Seytoux, Morel Seytoux and Daly, 1975) relates the drawndown at each well to the pumping rates at other wells and to the stream aquifer intersection. Under assumptions of essentially horizontal flow and fully penetrating wells, the drawndown S(k,n) at the kth well at the end of the nth period is

$$S(k,n) = \sum_{i=1}^{n} \sum_{j=1}^{m} \beta(k,j,\ n-i+1)\ Q(j,i) \qquad (2)$$

where:

$Q(j,i)$ - is the quantity of water supplied by the jth well during the ith time period,

$\beta(k,j,i)$ - is the response at well k to unit pumping at well j during the ith time period, and

m - is the number of wells.

These functions are incorporated directly into the economic optimization model by expressing the energy costs of lifting water to meet demands in terms of the various drawdowns.

Flores et al., (1978) propose a lumped parameter model as an alternative to this distributed parameter model. While the farmer considers only spatial variations in aquifer properties, the latter includes both spatial and temporal variations. A typical lumped parameter model can be represented by the continuity equation:

$$S \frac{dh}{dt} = \varepsilon - q \qquad (3)$$

where:

S - is the average storage coefficient

h - is the average water level in the aquifer, and

ε - is an average set inflow which includes natural recharge, pumping etc.

q - is the stream-aquifer interaction

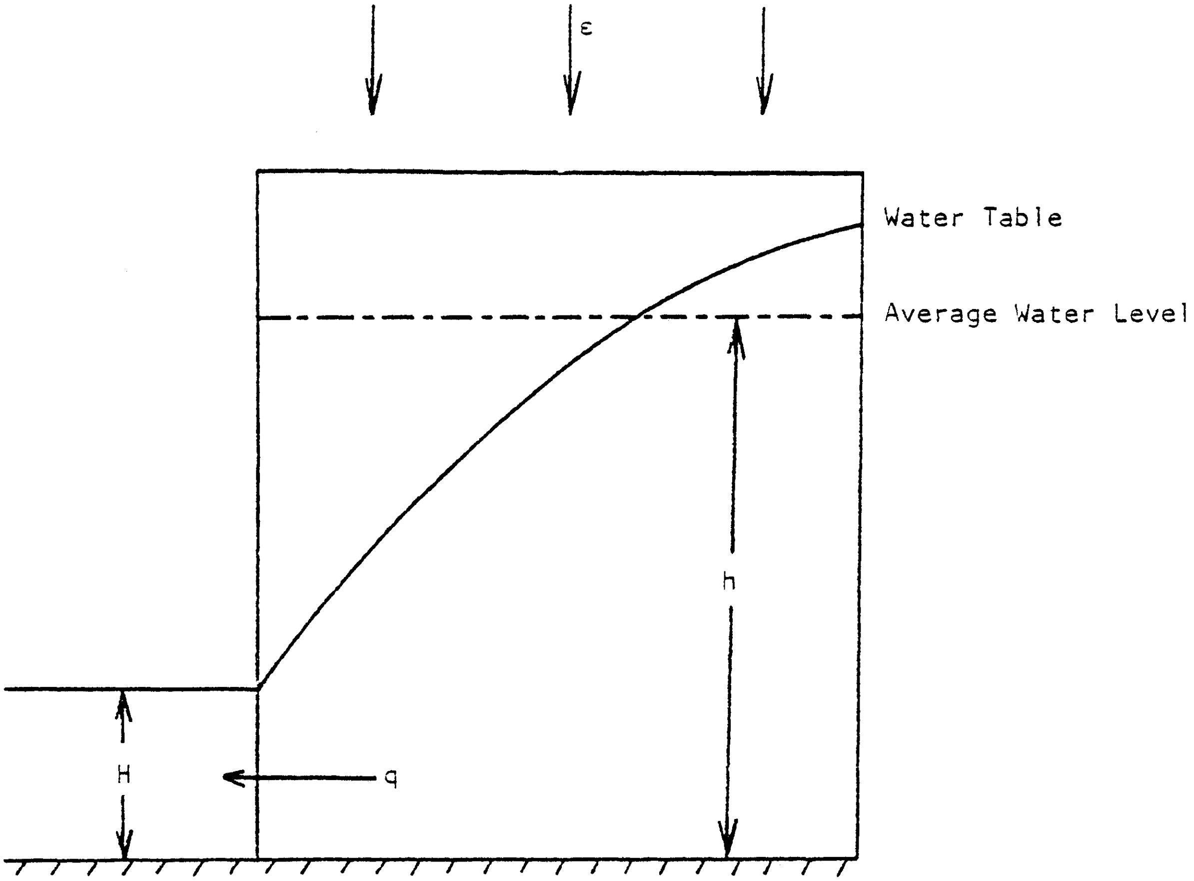
Figure 3 shows a schematic representation of this model. The authors defend their use of this method by citing a previous study (Young and Bredehoeft, 1972) which showed that management decisions were relatively insensitive to changes in the physical parameters of the aquifer. However, lumped parameter models should only be used as screening models for regional problems. When "near-field"effects are important, or when a high level of detail is required, distributed parameter models are clearly preferable.

1.2 Analysis of the Literature

At present, the economic models constitute the weakest component of studies on the conjunctive use of surface and groundwater because they do not adequately represent the political, economic and behavioral reality of irrigation systems in the United Staes, or in other countries with relatively decentralized decision-making processes. The most important shortcoming of many of these studies arise from:

1. The assumption of centralized control of all surface and groundwater allocations by a basin manager,

Figure 3: Schematic Representation of a Lumped Parameter Model



2. the assumption that the sole objective of these basin managers is to either minimize total costs or maximize aggregate economic benefits,
3. the assumption that farmers act as profit maximizers,
4. an incomplete analysis of the causes of uncertainty in the demand of water,
5. a lack of discussion of the impact of the construction of new facilities.

1.2.1 Centralized Control

With the exception of the paper by Young and Bredehoeft (1972), all the studies reviewed above assume the existence of a centralized agency which makes all the decisions concerning surface and groundwater allocations. This view is very convenient because it provides an easy method for "internalizing" the externalities present in groundwater development. These externalities arise from the "common pool" nature of groundwater resources which give a national irrigator an incentive to pump a great deal of groundwater, since the benefits of this additional water will usually outweigh his share of the adverse consequences of aquifer depletion.

The assumption of centralized control is inconsistent with the legal view of groundwater as a mineral resource (in some areas) and with the attitudes of fierce independence of individual farmers (Maass and Anderson, 1978; Adams, 1952; Foss et al., 1969). Thus, this assumption contradicts both the theoretical and practical realities.

Young and Bredehoeft avoid this assumption by constructing a model in which individual farmers made the decisions affecting groundwater withdrawal. The same type of decision-making structure can be obtained by adopting the multi-level optimization models presented by Yu and Haimes (1974) and Haimes and Dreizin (1977). These authors apply this model to a hypothetical water resource management problem in which a regional agency makes some of the decisions, but in which local agencies make many decentralized decisions. The same framework could be used to model the decisions of local agencies and farmers.

Recent studies (Templer, 1976), recognize the shortcomings of centralized models and present more realistic institutional structures. However, the usefulness of these papers is limited because they do not discuss ways to incorporate these structures into an overall framework of modelling decisions on the conjunctive management of surface and groundwater.

1.2.2 Basin Manager's Objective Function

In most studies reviewed above, the economic function is to minimize the total cost of operating a system under fixed demands (Dracup, 1966; Aron, 1969; Cochran and Butler, 1970; Yu and Haimes, 1974; Flores et al., 1978). In other studies, the objective function is to maximize the present worth of a system over its economic life (Buras, 1963) or the total benefits which accrue to a region as a result of water use (Young and Bredehoeft, 1972). The use of single objectives is inconsistent with descriptions of irrigation institutions (Maas and Anderson, 1978; Smith, 1962; Bain, 1966) and with the definition of a public organization as an institution that adjudicates competing claims.

1.2.3 Farmers' Objective Functions

The view that farmers act as profit maximizers, prevalent in most engineering studies, is contradicted by much of the current literature on farmer decision behavior (Lin et al., 1974; and Conner et al., 1972). For example, Lin et al., (1974) show that a utility function which incorporates a farmer's attitude toward risk is more effective at predicting his actual behavior than a model based on the microeconomic assumptions of profit maximization.

Some of the modern theory on farmers' behavior is being incorporated into studies on the conjunctive use of surface and groundwater. Daubert (1978) suggests that the agricultural linear programming model of the Young and Bredehoeft (1972) study should be replaced by one of the following three alternative models:

1. Cautious programming
2. focus-gain, focus-loss, or
3. expected income variance.

Cautious programming consists in the solution of the problem

$$
\begin{aligned}
&\text{Max } \pi(t)\ X_1(t) + \pi_2(t)\ X_2(t) \\
&\text{s.t. } (1 + B_1)\ X_1(t-1) \leq X_1(t) \leq (1+\bar{B}_1)\ X_1(t-1) \\
&\qquad (1+B_2)\ X_2(t-1) \leq X_2(t) \leq (1+\bar{B}_2)\ X_2(t-1) \\
&\qquad\qquad X_1(t) + X_2(t) \leq \bar{X} \qquad (4)
\end{aligned}
$$

where:

$\pi_1(t)$, $\pi_2(t)$ - are expected net returns per acre from each crop

$B_1, B_2, \overline{B}_1, \overline{B}_2$ - are flexibility coefficients

$X_1(t), X_2(t)$ - are acreages of a given crop planted in year t

$\overline{X}$ - is the total acreage available

In this method, the constraints model a behavioral assumption that farmers will not choose cropping patterns which differ significantly from those employed the previous year. Within the range defined by the flexibility coefficients, a farmer will attempt to maximize his profits, but he will not choose a cropping pattern outside the range, even if it promised higher economic returns. The farmers' attitude toward change is implicitly defined by the magnitude of the flexibility coefficients.

The focus-gain, focus-loss approach assumes, somewhat arbitrarily, that a farmer will not select a production plan where he risks reducing his income below the unavoidable expenses of variable production charges, half of the equipment depreciation charges, insurance, a minimum consumption level, and other general expenses.

Finally, the income-variance approach (generally known an mean-variance approach) assumes that a farmer evaluates alternatives on the basis of their expected income and on the variance of this income (performing those alternatives which have a high expected income and a low variance).

Knopman (1978) and Arntzen (1980) propose choice modeling as the method which best explains a farmers' decisions. Choice models used primarily in transportation studies, are disaggregate in that they specify utility functions for each individual consumer.

1.2.4 Uncertainty in Demands

Most studies on conjunctive use of surface and groundwater assume deterministic demands for water. When stochastic demands are adopted (Nieswand and Granstrom, 1971; Maddock, 1974) the causative relationships which produce these stochasticities are not studied. The view that demand for water is perfectly inelastic contradicts the conclusions of studies on demand for irrigation water (Ruttan, 1965) and for residential water (Howe and Linaweaver, 1967; Hogarty and McKay, 1975).

1.2.5 Capacity Expansion

Lastly, all of the studies reviewed above have been restricted to the operation of existing systems, and have not addressed circumstances that prompt agencies to expand their water supplies, or farmers to build new wells. Therefore, these models do not seem to adequately represent areas in which the number of wells has increased dramatically, such as the South Platte Basin in Colorado (Danielson and Qazi, 1966).

1.2.6 Summary

Table 1 lists and evaluates the assumptions behind the major components of economic models for conjunctive surface and groundwater management.

1.3 Structure of this Study

Chapter 2 describes the different types of local institutions currently in operation in the United States. It explains their historical emergence, political constitutions, attributions and modes of operation. Chapter 3 discusses the objectives of typical irrigation agencies. Chapter 4 shows how the findings of the previous two chapters can be used to define the policy alternatives available to a given agency, and the criteria that will be used in ranking these alternatives. Chapter 5 discusses the major issues raised by this study.

Table 1: Analysis of Economic Models

Component	Assumptions	Evaluation of Assumptions
1. Decision Makers		
a) Centralized Agency [Maddock (1974), Flores et al., (1978)].	Individual farmers do not participate in the decision making.	Inconsistent with laws and customs of most states (see Maass and Anderson, 1978).
b) Regional and Local Agencies [Yu & Haimes (1974)].	Either same as in a), or farmers participate in decision-making through the local agencies (e.g., ditch companies).	Acceptable where farmer cooperatives make decisions about groundwater pumping.
c) Farmers and Agency [Young & Bredehoeft (1972)].	Farmers make decisions about groundwater pumping. Local agency provides surface water.	Most realistic approach
2. Basin Manager's Objective Function		
a) Minimization of Cost of Agency [Yu & Haimes (1974), Maddock (1974), Flores et al, (1978)].	These approaches do not consider a) multiple objectives (income distributi regional development, environmental quality and b) the characteristics of the agency.	a) Federal regulations require the considerations of multiple objectives for the construction of water projects. b) Two objective functions should be used.
b) Maximization of Benefits for Region [Young & Bredehoeft (1972)].		(i) Agency's objectives for the region, (ii) Agency's "internal" objectives.
3. Farmers' Objective Functions		
a) Profit Maximization for Farmers.	a) Behavioral risk neutral attitude. b) Economic: (i) perfect information, (ii) production functions known by the farmers	a) Contradicts most case studies, b) (i) ignores complexities of both input and output markets, (ii) unrealistic.

Table 1: Analysis of Economic Models (Continued)

Component	Assumptions	Evaluation of Assumptions
4. Demands		
a) Fixed.	Water is abundant: demands are either met, or chance constraints are used.	Not valid in arrid environments
b) Stochastic, but with no causative relationships present.		
5. Capacity Expansion		
a) None	Decisions are short-term, the models examine only operating decisions for a given system.	Not valid: groundwater development occurs continuously as a result of both growing population and the threat of prolonged drought conditions.

Chapter 2

The Nature of Local Irrigation Institutions

The preceding chapter shows that in most engineering studies of the conjunctive use of surface and groundwater, the irrigation institutions are viewed as centralized entities that have complete control of surface water diversion and groundwater pumping. This chapter discusses the historical emergence of irrigation institutions, their classification and modes of operation and assesses the extent to which previous portrayals of these agencies have been accurate.

2.1 Historical Perspective

Irrigation agencies are formed for economic and political reasons. Economic rationality prompts the formation of water supply organizations because of the indivisibilities in the physical facilities used to store and transport water. Wells, pipes, canals and reservoirs exhibit decreasing average costs over a wide range of scales. In general, an individual user can efficiently provide for his own supply only if he transports the water over a relatively small vertical or horizontal distance. Thus, in the nineteenth century, land promoters increased the value of the land they were selling by constructing water systems based on gravity diversion from an adjacent river (Bain et al., 1966)

During the first half of this century, the formation of large water wholesalers: the Bureau of Reclamation, the Army Corps of Engineers and State Department of Water Resources, etc., acted as a catalyst for the emergence or irrigation agencies. Precluded by their charters from dealing with individual farmers, the large water suppliers were forced to sell their water to local agencies, which in turn, distributed it to the farmers in their basin.

In recent years, the major cause for the formation of irrigation agencies has been the rapid decline of groundwater levels. Groundwater depletion results from what hydrologists call "the 'common pool' problem" and is an excellent example of the "tragedy of the commons", a theory formulated to explain the depletion of pastures in medieval England. The common nature of these fields encouraged a rational herdsman to keep as many cattle as possible in them, since the benefits he attained from the sale of each additional animal outweighed his share of the negative effects of overgrazing. However, this same conclusion was reached by every rational herdsman sharing the commons and the unrestrained addition of cattle led to the destruction of the fields. Thus, "freedom in the commons brings ruin to all" (Hardin, 1968). The problems of declining water tables are: increased operating costs (these vary proportionately with pump lift), large capital costs to deepen wells and install larger pumps, and intrusion of brine into the aquifers.

Until very recently, the decline of groundwater levels led to the formation of agencies interested primarily in obtaining additional surface water. In the last few years, agencies charged specifically with the management of groundwater have emerged. For example, the Kansas legislature authorized the formation of groundwater management districts in the state on July 1, 1972. Its Nebraska counterpart took the same action on August 23, 1975.

Thus, local irrigation agencies, charged with the responsibility of supplying water to individual farmers, have arisen for a wide variety of reasons. However, these institutions may be easily classified into three distinct groups:

1. Public irrigation districts
2. mutual or cooperative irrigation companies, and
3. commercial water companies.

2.2 Public Irrigation Districts

Irrigation districts, also known as water conservation districts, water districts, water improvement districts, and conservation districts are government organizations that have legal status as political subdivisions of the state in which they lie (Adams, 1952; Goodall et al., 1978), but which operate outside the jurisdiction of the established state and local governments.

2.2.1 Formation Process

Public irrigation districts may be formed in two ways. The first, is by special state legislation that approves the creation of a district, defines its area, function, organization and financial authority (Bollens, 1961). The second, possible only in states that have general enabling legislation permitting the formation of institutions by public request, is through a special petition by local landowners. The former mechanism has been used extensively in the past, the latter is more popular today.

Where districts are formed by private initiative, an individual, or a group of landowners, presents a petition to the governing body of the county. The petition defines the boundaries of the proposed district (it may only include lands that will benefit directly from the agency's operation), the proposed sources of water, and is accompanied by a list of signatures. Upon receipt of the petition, the county government organizes public hearings in which interested parties discuss the merits of the proposals, and requests a feasibility study from the state engineer. If the approval of the county supervisor is obtained, the county government calls an election in which all the landowners within the boundaries of the proposed district may vote. A major deviation of this rule occurs in California, where the electorate consists of all registered voters (Bollens, 1961).

The agency is formally constituted if a majority vote is cast in its favor. Subsequently, a board of directors, an assessor, a tax collector and a treasurer are elected. In all cases, the newly formed board of directors hires an engineer to prepare a plan of works and estimate their cost. In general, the construction is financed through bond sales, and these have to be approved (usually by a 2/3 majority) by the eligible voters in the district. The day-by-day operation of the agency is carried out by a chief engineer and ditch tenders, and financed by ad-valorem assessments on the land, exclusive of improvements, and through water tolls.

Public irrigation districts belong to a group of organizations designated "special district governments" which include school districts, housing authorities, port authorities, etc. Labelled the "dark continent of American politics" because of the lack of attention paid to them by political scientists, special districts fill a vacuum created either by the inability of a general government to circumvent constitutional limitations of its tax and debt limit, or by constituent resistance to the expansion of the functional jurisdiction of the state or county. Thus, while a general government is prevented from expanding functionally once it reaches its tax or debt limit, residents of the same area are not legally prevented from organizing a special district that will possess the power to levy taxes or to incur dept or both (Bollens, 1961).

2.2.2 Historical Development

An 1865 law in the Territory of Utah was the first legislative act authorizing the creation of irrigation districts in the United States. A similar act was passed in California in 1872, and between that date and 1887, special acts of the state legislature created a large number of other districts (Smith, 1962). The formation of special irrigation districts in California received a big boost with the passage of the Wright Act in 1887. This act permitted citizens of towns having 500 or more electors to propose and approve by election the formation of an irrigation district. The proponents of this measure hoped that a district's assessments would finance irrigation works and at the same time produce the subdivision of large landholdings into relatively small tracts (Bain et al., 1966). In 1896, after a decade of litigation in state and federal courts, the U.S.

Supreme Court upheld the constitutionality of this law.

This decision paved the way for the formation of numerous irrigation districts in the Western United States. While at the turn of the century only California and Washington had active districts of this type, Nebraska, Colorado, Oregon and Idaho adopted them during the first decade of this century. In 1950, 483 local public irrigation districts were supplying water in 17 of the 19 western states (Adams, 1952; Bollens, 1961).

2.2.3 Powers and Modes of Operation

In this section, the major powers and modes of operation are summarized. A more detailed analysis can be found in Bain et al., (1966). Public water agencies supplying surface water possess the following powers:

1. Corporate Powers: They have the right to sign contracts, construct works, buy and sell water, operate irrigation works, sue and be sued, etc.
2. The Power of Eminent Domain: Subject to certain broad guidelines they can condemn property needed for designated uses.
3. The Power to Incur Bond Indebtedness: They can issue general obligation bonds, revenue bonds or both. In all cases, the floating of a bond issue must be approved at an election by the member landowners or eligible voters.
4. The Power to Fix Assessments on their Constituents: These assessments secure and retire bond indebtedness and cover operating expenses. In some cases, the legal uses of these revenues are limited by state laws. In other cases, the establishment of assessments may require the approval of the electorate.
5. The Power to Establish Charges: These tolls pay for the delivery of water or for other services.

6. The Power to Purchase Water: They may enter into short term contracts with local "overlay" agencies or with the large water supplying agencies (Bureau of Reclamation, Army Corps of Engineers, State Departments of Water Resources). In general, they may not sell water outside the jurisdiction of their districts. However, they may sell "surplus water" through short term contracts.

The powers allow public districts concerned primarily with the supply of surface water to have an impact of groundwater depletion. A land assessment imposes a fixed cost on farmers. Thus, the variable cost of surface water, collected through water charges, is less then the total cost of securing this water. Should the cost of pumping a comparable amount of groundwater fall between the variable and total cost of surface water, an economically rational farmer should prefer surface to groundwater even though, in the absence of a district, the groundwater would have been less expensive.

2.2.4 Groundwater Management Districts

Public irrigation districts that supply surface water may slow down the process of groundwater depletion by securing additional surface water or by setting high land assessments and low user charges on the water they sell. However, they cannot deal directly with the problem of falling aquifer levels. In some states, the legislatures take an active role in protecting groundwater resources. For example, in 1957, the Nebraska legislature prohibited the location of one irrigation well within 600 feet of another and mandated that irrigation wells be registered within 15 days of their completion (Nebraska Law Review, 1973). More recently the Kansas and Nebraska legislatures have authorized the formation of public groundwater management districts.

In general, these districts have the following powers (Groundwater Management Districts in Kansas, n.d.):

1. Metering: They may install or require the installation of meters, and read, or require water users to read these meters.
2. Set Standards: They may adopt and enforce reasonable standards for the conservation of groundwater within the district.
3. Ensure Compliance: They may enter private property to determine conformance with established rules in the use of water.

In addition, these organizations possess most of the powers assigned to irrigation districts that supply surface water.

2.3 Mutual Irrigation Companies

Mutual companies are the most common type of irrigation enterprise in the West. In 1950, there were 9,220 cooperative irrigation enterprises in the western states, of which the largest number (2,265) was in Colorado and the next largest (1,270) was in California. The United States Irrigation Census gives all these companies the classification "mutual". However, they are known by various designations, including "mutual water companies", mutual irrigation companies, cooperative irrigation companies, mutual canal companies, and mutual ditch companies (Adams, 1952). A mutual company is a voluntary, nonprofit enterprise engaged primarily in providing water for its shareholders.

2.3.1 Historical Development

Although there are characteristics common to most mutual companies, these enterprises differ considerably from state to state. To a great extent, the existing variations may be ascribed to the historical conditions surrounding their emergence.

In Colorado, the mutual companies were organized by the holders of water rights gained by prior appropriation. Thus, shareholders are allowed to use the water to which they are entitled on any land served by the irrigation system. This feature of the state's mutual companies gives its Colorado shareholders the right to sell surplus water to other shareholders in the same basin. This practice, known as "renting", is described in detail by Anderson (1961).

In Idaho, many mutual companies were organized under the provisions of the Carey Act of 1894. This act allocated funds for the reclamation of public desert land and authorized the states to contract with private construction companies for building irrigation works. These companies were then able to sell "water rights" to the settlers. The Carey Act stipulated that mutual companies would eventually operate the irrigation system. It also made water right appurtenant to the land, thus precluding intra-basin transfers. In contrast, in central California, mutual companies were formed without federal supervision. In this region, water can be sold or leased for use in any land that may be irrigated in the system (Adams, 1952).

In New Mexico, mutual companies incorporate practices brought to the southwest by the Spanish. For example, under New Mexico's law, ditches which are neither private nor incorporated but have more than two owners are "community acequias" in the absence of an agreement to the contrary.

2.3.2 Unincorporated Companies

A mutual company can be either unincorporated or incorporated. The former, in its simplest form, is merely an informal agreement among a small group of neighboring farmers to jointly operate irrigation facilities. More formal arrangements can be made under "articles of association" that set up a company organization with by-laws to govern the rights and obligations of its members, as well as the management and operation of irrigation facilities.

In 1950, 69 per cent of the irrigation cooperatives operating in the western states were unincorporated. Of these, the largest number (1,957) was in Colorado; the next largest group (994) was in Montana. The widespread popularity of unincorporated companies attests to the fact that institutions based entirely on cooperation among irrigators can operate successfully.

However, unincorporated mutual companies face many disadvantages. In particular:

1. The members of an unincorporated company are joint owners of the irrigation works, and all partners must consent unanimously to incurring depts, executing contracts, etc.,
2. individual members may be held liable for the debts of the enterprise, and
3. there is no practical way of compelling members to contribute to the operating costs.

2.3.3 Incorporated Companies

These disadvantages have led to the incorporation of many mutual companies. This procedure consists, in general, of filing "articles of incorporation" with the appropriate state agency. The enterprise then becomes a "body corporate", with the authority to hold property in the corporate name and to exercise the powers given to corporations in that state. The "articles or incorporation" also specify the following powers to be exercised by the corporation,number and terms of office of its governing body, number of shares of capital stock, etc. They also give the board of directors the authority to enforce regulations concerning delivery of water, care and operation of the irrigation system,time and method of payment for water and duties of the operating employees.

The main benefits that mutual irrigation companies gain through incorporation are the following:

1. The corporation, as a legal entity, can act in its corporate name without first obtaining the consent of all its members.
2. The board of directors elected by the shareholders has the authority to conduct the affairs of the enterprise and to enforce the payment of obligations by the shareholders.
3. The company is in a better position to borrow money, because it can pledge the assets of the company as collateral.

Unlike public irrigation districts, mutual companies cannot float bonds, do not have the power of eminent domain and cannot levy land assessments. They are not legally eligible to purchase water from federal and many state wholesalers. Thus, they depend mostly on their own integrated supply. Also, in general, they may not sell water to the outside public. The latter impediment often arises from charter provisions (and state water rights' doctrines) that makes water rights appurtenant to specific parcels of land held by the shareholders. However, even when provisions of this type are not present, the outside sales become subject to the limitations imposed on privately owned public utilities (Bain et al., 1966). In fact, if outside sales become important, the mutual company may risk being declared a public utility and thus become subject to the set of regulations discussed in the next section.

2.4 Commercial Water Companies

The mechanisms which govern the operation of commercial water companies are relatively simple: individual proprietorships operate as such under the general state laws while privately owned public utilities engaged in the water industry are established under federal and state laws governing private corporations.

Privately owned public utilities are especially restricted in that they must acquire franchises to provide services to defined areas and cannot refuse to serve customers in those areas. Also, the rates they charge for the water they deliver are regulated by the public utilities commission of the state in which they operate. However, unlike mutual companies, they have the power of eminent domain and can issue bonds (Bain et al., 1966; Adams, 1952).

Historically, commercial water companies have played an important role in the development of irrigation. As was discussed in Sections 2.1 and 2.3.1 private irrigation companies emerged in the latter part of the nineteenth century, usually in conjunction with land promotions. However, at present, commercial companies do not play a prominent part in the development and distribution of irrigation water.

As Bain et al., (1966) point out, on the surface, it would appear that commercial water companies, natural monopolies facing a demand that is relatively inelastic in the short run, should be very successful. However, they exhibit numerous weaknesses:

1. Although they are the only feasible suppliers of water to the farmers, these are also its only customers.
2. They are often caught between customers who insist upon regular service and sources of supply which are naturally uncertain.
3. The state public utilities commissions are often hostile in setting the water rates.
4. Their limited legal powers (compared to those of public districts) often lead to their replacement by stonger agencies when their customers decide to expand their water supply systems.

For these reasons, commercial water companies have almost disappeared (Adams, 1952). For example, in California, only one private irrigation company has survived (Bain et al., 1966).

2.5 Summary

Table 2 summarizes the major characteristics of irrigation enterprises. As should be readily apparent, the view advanced in most engineering studies of the conjunctive management of surface and groundwater on the centralized nature of this decision-making process, is contradicted by the evidence presented in this chapter. Except for the recently formed groundwater management districts, no irrigation agency has the type of control over groundwater withdrawals suggested by the literature.

Besides showing the contrast between reality and numerous engineering models, this chapter demonstrates that the term "conjunctive management of surface and groundwater" should be treated with care. Indeed, as long as groundwater diversions are unrestricted, the "conjunctive" nature of the management is very tenuous, since basin managers may only affect the rate of groundwater withdrawal by augmenting the supply of surface water, or by increasing assessment and/or decreasing the water tolls.

Table 2. Major Characteristics of Irrigation Enterprises

	Public District	Mutual Company[d]	Commercial Company
Formation	a) Special Legislative Act b) Landowner Petition	Articles of Incorporation	Articles of Incorporation
Management	Board of Directors	Board of Directors	Board of Directors
Voting	All Landowners[a]	Shareholders	Shareholders
Outside Regulation	None[b]	None[b,c]	State Public Utilities Commission
Power of Eminent Domain	That of Public Agencies	None	That of Public Agencies
Bond Issues	Government Bonds	None	Corporate Bonds
Land Assessments	Yes	No	No
Water Charges	Yes	Yes	Yes
Profit Making	No	No	Yes
Supplies of Water	Own Supplies, State and Federal Wholesalers	Own Supplies	Own Supplies

[a] In California, all waters

[b] Must comply with general State and Federal Laws

[c] As long as no important sales to non-members take place

[d] Incorporated

Chapter 3

Objectives of Local Irrigation Institutions

Section 1.2.2 shows that previous studies of conjunctive management of surface and groundwater portray local irrigation agencies as single objective decision-makers charged either with the minimization of the cost of the water supplied or with the maximization of the profits of their "clients"--the individual farmers. To a certain extent, Chapter 2 disproves the cost minimization model. Since, in general, local irrigation agencies possess little control over groundwater withdrawal, they cannot have an impact on the total cost of the water (both surface and groundwater) used in the system. Furthermore, the minimization of the cost of the water which the agency supplies directly leads to trivial results: no surface water should be supplied (zero cost) and the irrigators should be forced to rely exclusively on their own groundwater supplies.

The profit maximization model is slightly more compelling, but may be criticized on the same grounds. However, leaving aside the question of <u>who</u> controls <u>which</u> source of supply, these single objective models are poor representations of reality. This chapter argues that profit maximization alone cannot explain many <u>important</u> actions of local irrigation agencies and proceeds to identify other objectives which play an important role in the decision making process of these institutions.

3.1 Assumptions

Before embarking on a detailed study of the objectives of irrigation agencies, two assumptions are made. First, because of the relatively insignificant number of commercial companies presently in operation, this analysis focuses exclusively on public irrigation districts and mutual companies. Second, it is argued that although the latter two organizations differ in many ways, they have similar objectives.

3.1.1 Users' Cooperative Hypothesis

In a comprehensive study of the Northern California water industry, Bain et al. (1966) state that public irrigation agencies act as users' cooperatives in developing water for a specified group of "clients" and that, therefore, their actions are not significantly different from those of mutual irrigation companies. The authors point out that a public agency supplying water for a particular group of users is not an independent entity and does not have with its users the typical relationship of seller to buyer. Rather, a public irrigation district is an instrument created by a group of users to act in ways most advantageous to them.

The major pieces of evidence supporting this hypothesis are:

1. The legal process of forming most types of special purpose water organizations (such as public irrigation districts) is usually initiated by a prospective group of member-customers.
2. Public irrigation districts arise in response to pressures felt by their member customers rather than to profit opportunities scented by a conventional entrepeneur or promoter.

3. Public irrigation districts show little interest in engaging in transactions with outsiders (Bain et al., 1966).

The users' cooperative hypothesis is shared by Maass and Anderson (1978), who use the term farmers' cooperatives to refer to both public irrigation districts and mutual companies. It is important to note that this view is not universally held. For example, Wittfogel (1951) claims that irrigated agriculture leads to a strong centralization of power and that the great cooperative effort required to build dams and canals creates a powerful agro-managerial bureaucracy which wields political leadership and control. However, Wittfogel's theory, based on case studies of primitive societies, does not appear relevant to hydraulic societies in the United States (Maass and Anderson, 1978; Bain et al., 1966; Adams, 1952; Goodall et al., 1978). These two assumptions make it possible to present a discussion of the objectives of public irrigation districts and mutual companies without being hindered by the differences in the constitution of these agencies.

3.2 Profit Maximization

There exists a consensus in the literature that the maximization of the aggregate profits of the farmers under its jurisdiction is a major goal of local irrigation agencies (Young and Bradehoeft, 1972; Bain et al., 1966; Anderson, 1961; Maass and Anderson, 1978; Smith, 1962), and the evidence presented in these studies appears to support this consensus. However, these case studies present powerful evidence that profit maximization is not the only goal pursued by these agencies.

3.2.1 Definition

Under conditions of perfect markets for water, and in the absence of externalities, the aggregate profit of a basin is maximized if and only if each farmer acts as a profit maximizer (Weitzman, 1975).

Theorem 1: Let Y be a production set

y can be produced if $y \varepsilon Y$

y^* is efficient in Y if

a) $y^* \varepsilon Y$ and

b) $\nexists\, y' \varepsilon Y$ such that $y' \geq y^*$

Then, if y^* is profit maximizing in Y at positive prices, y^* is efficient in Y.

Lemma 1: Suppose an organization is made up of m subunits

Let Y^j be the production set of subunit j

y^j can be produced if $y^j \varepsilon Y^j$

Let Y be the aggregate production set

$$Y = Y' + Y^2 + \ldots + Y^m$$

$$y \varepsilon Y \rightleftarrows \exists \{y^j\}, \quad y^j \varepsilon Y^j \ \forall_j \qquad y = \sum_j y^j$$

Let $y^* = \sum_j y^{j*}$ where $y^{j*} \varepsilon Y^j$

Then, $$py^* = \max_{y \varepsilon Y} py \rightleftarrows py^{j*} = \max_{y^j \varepsilon Y^j} py^j \ \forall_j$$

Theorem 1 shows the equivalence between profit maximization and economic efficiency. Lemma 1 shows that the only actions which an agency solely interested in maximizing aggregate · has to engage in, are those which guarantee free markets and eliminate externalities.

3.2.2 Statutory Limitations

In many cases, irrigation agencies do not pursue strategies designed to eliminate externalities and guarantee free markets for water because they do not have the power to do so, or because they are limited in their actions by state laws.

Groundwater pumping in an area of heavy development is an example of an externality because the actions of one agent affect the environment of other agents (Varian, 1978). That is, when a farmer extracts water from one of his wells, he lowers the water table and increases thepumping costs of other farmers with nearby wells.

The negative effects of externalities can be eliminated by regulatory or fiscal measures. The former option consists in bringing the groundwater resources under the centralized control of a basin manager; the latter in taxing the use of groundwater in a way that equates the private and social costs of pumping. However, as the discussion in Chapter 2 shows, irrigation agencies do not have the power to enforce either type of measure. This situation will change in those states that have recently authorized the formation of groundwater management districts (Kansas and Nebraska), but the vast majority of irrigation agencies will only be able to diminish the loss in efficiency caused by externalities through the type of indirect measures presented in Section 2.2.3.

The restrictions on outside sales of water by public districts and mutual agencies discussed in Sections 2.2.3 and 2.3.3, respectively and the restrictions on intra-basin sales among shareholders of mutual companies in states where water rights are appurtenant to specific plots of land (Section 2.3.1) also hinder the efficient allocation of resources.

3.2.3 Voluntary Actions

Since the legal limitations discussed in the preceding section constrain the operation of local irrigation agencies, they shed no light on the objectives of these institutions. While it could be argued that these limitations reflect the preference structure of higher level decision making bodies, this hypothesis is not evaluated in this study.

For the purposes of this study, it is important to examine those roadblocks to the efficient market distribution of water which arise as a result of the voluntary actions of the local irrigation agencies. The most striking example of this phenomenon occurs in Utah. Under Utah laws, mutual companies can sell water rights separately from land. However, these companies only sell water rights to outsiders when urbanization and industrialization have greatly reduced the demand for irrigation water. Thus, they avoid placing their shareholders in a position where outside interests could control farmers' supplies, even when the latter would benefit economically from the sale.

The same reluctance to engage in water transfers is observed among farmers who are shareholders of the same mutual company. When short term water sales occur, the prices at which these transactions take place do not reflect those that could be obtained in a truly competitive market. Instead, "the farmer with excess water thinks it not right to charge all the traffic will bear, and the farmer with water needs thinks it wrong to pay such a fee" (Maass and Anderson, 1978). Because of this attitude, the marginal products of water and water-rich and water-poor farmers are different, and the overall production is inefficient. While the mutual companies in Utah could take action that would ensure a better operation of water markets (for example, by acting as intermediaries in the transfers), they are not actively involved in this operation.

A similar situation is seen in Colorado. Irrigation institutions in the South Platte Basin have well organized water "rental" markets which developed in response to small inbalances in water supplies among farmers. The major irrigation companies maintain a list of stockholders with excess water and those needing additional water. In some cases, the board of directors of the mutual company sets the rental price. In others, the company posts the asking price along with the quantity of water being offered and users who need additional water take the lowest price posted. However, invariably, the market price does not reach the level that farmers short of water would be willing to pay (Maass and Anderson, 1978). As a result, the quantity of water available for transfer is less than would be under free market prices. Thus, water at different farms has different marginal values and efficiency is not attained.

According to Maass and Anderson (1978), the roadblocks to the permanent transfer of water rights from less efficient to more efficient uses occur as a result of the fears of irrigation institutions in the West that the easy transfer of water is tantamount to inviting foreign control over the farmers' activities. This behavior shows a strong concern about local control over the decision making process. In contrast, the forces that keep the prices of short-term water transfers, or water rentals, from reaching their market levels reflect a concern over equity.

3.3 Other Objectives

The preceding sections shows that profit maximization is not the only objective of irrigation institutions. However, the generation of the remaining objectives which are considered by these institutions in making decisions is by no means an easy task. MacCrimmon (1969) offers the following approaches for generating objectives:

1. examination of the relevant literature,
2. analytical study, and
3. causal empiricism.

The only detailed study of the objectives of irrigation districts is presented by Maass and Anderson (1978). The authors rely primarily on the legislative history of the various ordinances, rules and regulations and court records of conflicts.

MacCrimmon (1969) suggests that by engaging in an analytical study of the inputs and outputs of the system under consideration, the suitable explanatory variables may become obvious. Lastly, objectives may be uncovered by causal empiricism, that is, by observing how decision makers behave when confronted with choices among several options.

This study does not propose to provide a comprehensive list of the objectives of local irrigation institutions. Indeed, it can be argued that a comprehensive list is meaningless because of the marked differences between agencies in different states. Instead, the following sections will present evidence for the inclusion of other objectives in a study of the decision-making process of public irrigation districts and mutual water companies.

3.3.1 Local Control

In a study of irrigation organizations in the United States, Adams (1952) observesthat local control over irrigation decisions is a paramount principle of both water users and irrigation cooperatives. This conclusion is now widely accepted (Maass and Anderson, 1978). Maass, in a criticism of Wittfogel's thesis, states that systems that were in existence before the central government invested money and expertise in them, have protected their autonomy to a remarkable extent. They even defied national policies that accompanied federal money when these policies proved to be a serious threat to local custom. Also, irrigation companies have strenuously opposed efforts by the states to readjudicate water rights in the light of abandonments and other changes and preferred to make their own adjustments.

A striking example of the strength of the idea of local control is given by the protracted negotiations between irrigation communities and the federal government on acreage limitations. The acreage limitation law states that no water from a federal reclamation project may be delivered to a property of more than 360 acres (160 acres if the farmer is a bachelor and has no parents). According to this federal law, if a large landowner wants to receive water from a federal reclamation project, he must sign a contract to sell his excess land at a price that excludes any increase in value that may be due to the building of the project.

The issue of acreage limitations pitted local irrigation companies against the federal government in the formation of the King's River (California) and Colorado-Big Thompson superdistricts. In both cases, the interests of family farms and big landlords were harmonious, and ultimately successful, in negotiations with the United States government. The small and large farms were equally concerned in maintaining local control over their irrigation system (Maass and Anderson, 1978).

The fact that local control is an important objective of public irrigation districts and mutual companies is hardly surprising. What is important is the zeal with which these institutions have opposed federal interference, even when this interference was reduced to the enforcement of clearly spelled out laws.

3.3.2 Conflict Resolution

The formation of public irrigation districts and mutual companies usually reflects a certain degree of common interest among those who prompt the formation of the institution. However, the acceptance of this common interest, does not imply that all conflicts are eliminated or that there is an underlying principle of harmony and equilibrium in the community (Smith, 1966). The role of irrigation companies, like the role of any government agency is to adjudicate these conflicts in a way that does not destroy the common interest among its constituents.

Water conflicts are notorious in the history and mythology of water civilizations (Maass and Anderson, 1978). The present causes for conflicts are also numerous. The physical system itself is often one source of conflict. For example, in one area of a basin, groundwater recharge may be called for to alleviate the economic hardships posed by a falling water table, while in another area, this policy may lead to compaction and drainage problems. The setting of assessment rates is another important source of conflict. In many states, these assessments have been changed from flat rates per unit of land to charges that depend on the soil characteristics and expected productivity of individual parcels of land (Brewer, 1959). The subjective judgements involved in setting these charges can easily lead to conflicts.

A successful irrigation agency is one which deals with these problems in a way that proves acceptable to the community and that stifles the formation of factions and dissension groups that might hamper the agency's ability to carry out its responsibility.

Some authors argue that irrigation agencies are successful in resolving conflicts because their constituents agree on basic objectives and on the means for achieving them (Foss et al., 1969). These authors say that the widespread success of these organizations engenders greater support, rather than opposition. Similarly, Smith (1966) states that irrigation agencies serve as a forum for organizing conflicting interests.

However, it is important not to confuse a basic philosophical agreement with daily unaminity of opinions. The success of irrigation agencies in dealing with the competing claims that inevitably arise from time to time, and in avoiding protracted lawsuits (Maass and Anderson, 1978) that could endanger local control, reflects, it seems, the importance these institutions assign to the objective of conflict resolution.

3.3.3 Equity

A concern for fairness in the distribution of water is apparent from the description of the operation of the water rental market in Utah and Colorado presented in Section 3.2.3. Utah's allocation of water in times of scarcity also reflects the importance given to equity by irrigation institutions in that state. During water shortages, irrigation agencies in Utah supply fractional parts of their water supply to their various customers (under a 20 percent shortage, the supply of each farmer would get cut 20 percent). In this way, the agencies spread the negative effects of a drought over a large number of water users. Under a strict application of the doctrine of prior appropriation in effect in that state, the cutbacks would affect only holders of junior rights. A simulation model presented by

Maass and Anderson (1978) shows that these lands would yield more crops if less emphasis were placed on proportionality in the sharing of seasonal shortages.

3.3.4 Maximization of "Internal" Utility

The internal motives of irrigation agencies should not be ignored. These agencies, like all government institutions, may derive bureaucratic satisfaction through their growth, or through the undertaking of large porjects.

As Bain et al. (1966) point out, these internal objectives may relate to the price or quality of the service provided to customers, or the price paid to suppliers. Alternately, they may encompass the welfare of persons who are not customers of the enterprise but are somehow affected by its operations.

3.4 Summary

The major conclusion that emerges from this chapter is that the maximization of aggregate profits (economic efficiency) is not the sole criterion guiding the decisions of local irrigation agencies. A second important conclusion is that no sole objective is important enough to explain these decisions and that multiobjective methods are needed if good models of the conjunctive management of surface and groundwater are to be built.

The list of objectives outlined in this chapter is not a comprehensive one. Rather, it serves the purpose of strengthening the two conclusions outlined above. Table 3 summarizes the major issues presented in this chapter.

Table 3. Objectives of Local Irrigation Institutions

Objective	Supporting Arguments	Counterarguments
Aggregate Profit Maximization (economic efficiency)	Evidence presented by major case studies	Statutory Limitations Voluntary actions: a) Operation of water rental markets, b) Reluctance to engage in outside sales, c) Proportional water sharing during shortages
Local Control	a) Opposition to federal acreage limitations b) Reluctance to engage in outside sales	
Conflict Resolution	Success in maintaining harmony in a system of competing interests	
Equity	a) Operation of water rental market b) Proportional water sharing during shortages	
Maximization of Internal Utility	Comparison with other government institutions	

Chapter 4

Conjunctive Management of Surface and Groundwater

This chapter examines the ways in which information on the nature of irrigation institutions can be used to analyze the policy alternatives available to a given agency, define the criteria that it will use to rank these alternatives and speculate on the effects of its decisions on the state of the basin. This goal is achieved by presenting a general management model, isolating from this model the component which explicitly describes the operation of an irrigation institution, defining a general model of a political system and showing how the findings of Chapters 2 and 3 can be used to determine the outputs from this system. A hypothetical example is presented and used to illustrate an analytical procedure to determine the policies of a given irrigation agency.

4.1. General Framework of the Management System

This study is undertaken as part of a broad examination of conjunctive use of surface and groundwater. The major objectives of the overall research project are:

1. Define the general management system depicting the relationships between basin managers, farmers and the physical system.
2. Examine public, mutual and commercial irrigation companies, describe their constitution, operation, attributions and objectives.
3. Develop a predictive model of farmers' water demand and water objectives.
4. Test the predictive model and compare its accuracy to that of existing models.

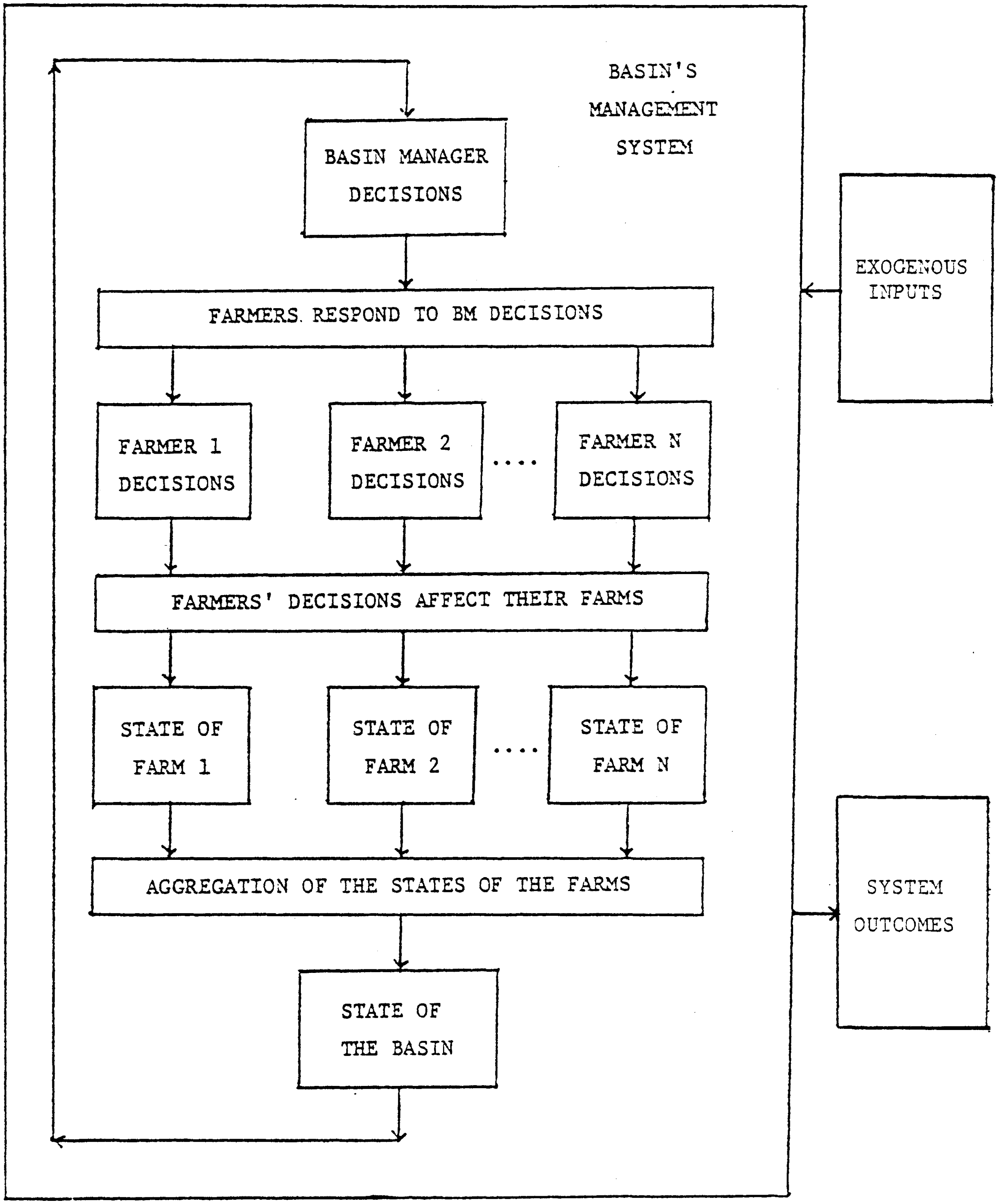
Figure 4, which presents an overall management model of an irrigation system, shows that these objectives are interrelated. Indeed, when the basin manager makes one of the decisions discussed in Chapter 2 (on land assessments, user charges, groundwater restrictions, etc.) each farmer in the basin adjusts his own decision variables (acreage, crop mix, irrigation intensity) to maximize his own expected utility under the new conditions (agency's decisions and exogenous inputs). These decisions affect both the output from these farms (profits) and the state of the basin (groundwater levels, storage in reservoirs). When the basin manager perceives these changes, and possible changes in the exogenous inputs, he re-evaluates his policy. Typical exogeneous inputs are the hydrologic conditions of the basin (surface and groundwater levels) and decisions by political entities which have some jurisdiction over the operation of local irrigation agencies.

Thus, the overall model consists of the following parts:

1. A submodel for the decision making of the basin manager (irrigation institution).
2. A submodel for the decision making of individual farmers.
3. A simulation model that links the decisions of the farmers and the basin manager to the state of the basin.
4. Exogenous inputs to the system.

The first part constitutes the focus of this work; the second is being studied by Arntzen (1980). As Figure 4 shows, farmers respond to the actions of the basin manager (BM) in making their decisions. They may respond by:

Figure 4: General Framework for Conjunctive Management of Surface and Groundwater



1. Changing croping patterns,
2. buying a different amount of surface water,
3. pumping a different amount of groundwater,
4. drilling new wells, and
5. changing their irrigation practices.

Arntzen (1980) proposes to model farmers' behavior by the use of probabilistic choice models which explicitly account for uncertainty, risk aversion and the existence of discrete alternatives. Specifically, he develops a sequential decision model, which combines an Elimination by Aspects Model (Tversky, 1972) with a Boolean utility model. Thus, these two studies pave the way for a comprehensive study of the conjunctive use of surface and groundwater.

The third component of an overall model, a simulation model, is not studied either in this study or in Arntzen's work, Section III. Many simulation models are presented in the studies reviewed in Chapter 1, but the discussion in this chapter shows that more sophisticated models may be needed if realistic representations of the decision-making process of local irrigation agencies is used.

The fourth component, exogenous inputs, needs to be examined to determine the effects of policies by the state and federal governments on the operation of local irrigation institutions, decisions of farmers and state of the basin.

4.2 Model of a Political System

The submodel of the basin manager can be examined in detail in the context of a general model of a political system. One such general model, proposed by Easton (1965), is presented in Figure 5. While the terms used by Easton: demands, support, outputs, feedback are commonly used in systems theory, they have specific meanings in political models.

4.2.1 Demands

Demands are those wants which members of a political system would like to see implemented through political outputs. A demand can be defined as an expression of opinions that an authoritative allocation with regard to a particular subject matter should or should not be made by those responsible for doing so.

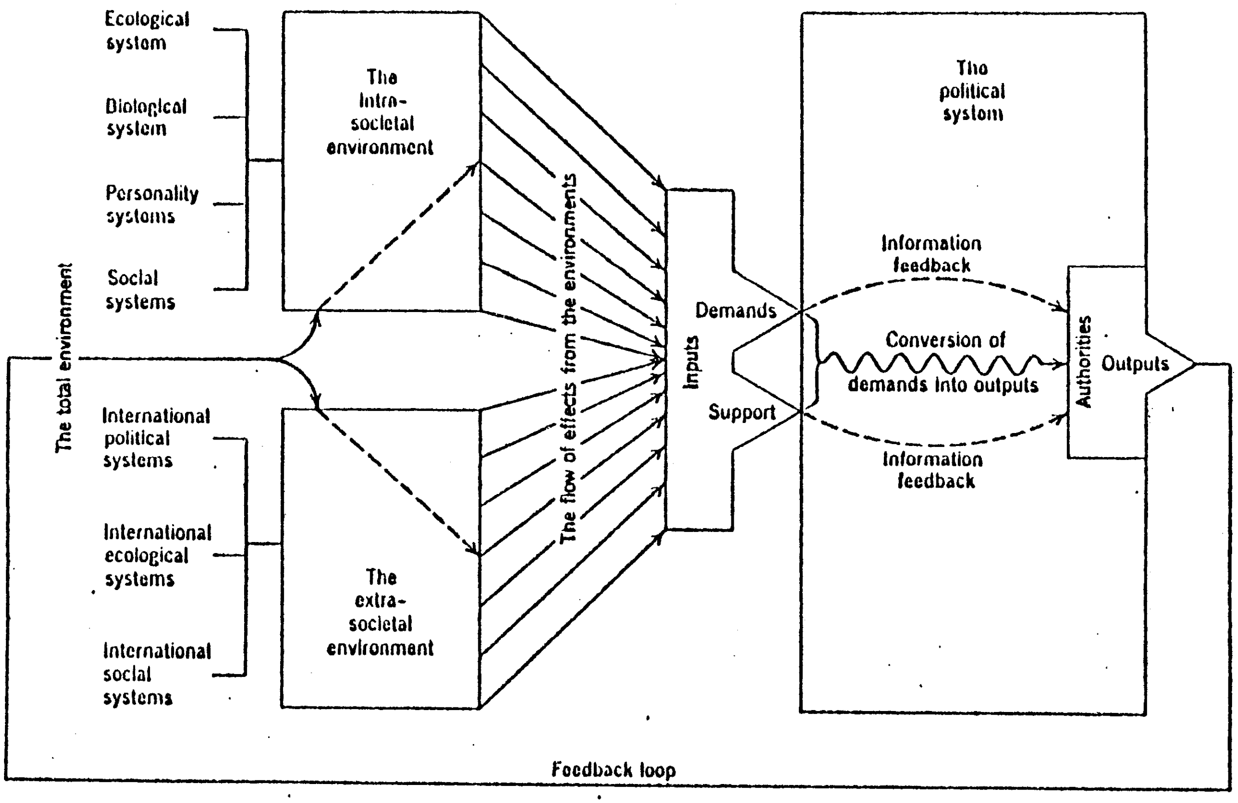
4.2.2 Support

The significance of support in a political system is explained in Section 3.3.2. One important function of a political system is to ensure that the resources and energies of society are mobilized and oriented toward the pursuit of common goals. This responsibility can only be fulfilled successfully if the system is able to marshal the support of its members.

4.2.3 Outputs

Outputs are a stream of activities which flow from the authorities of a system. They constitute the means by which those persons who occupy the special roles of authority in a system are able to exercise some control over the other members of the system. It is important to understand the difference between the terms "outputs" and "outcomes". The latter are the consequences of the farmer. Therefore, the overall

Figure 5: A Dynamic Response Model of a Political System



conjunctive management model requires a simulation submodel to relate the actions of the basin manager (outputs) and farmer to the state of the basin (outcome).

In general, outputs may be authoritative or associated statements or performances. The differences between these types of outputs are illustrated in Table 4 (Easton, 1965). Authoritative statements take the form of verbal indications that are to guide the performance of tasks. They are decisions on the part of authorities that certain actions should or will be taken and are important even when separated from direct actions. Thus, while it may prove impossible to implement a certain decision, or the decision-maker may lack the political will to do so, the verbal output by itself may affect the attitude of the members of the political system. Authoritative performances may be either tangible (money, physical facilities, goods and services) or intangibles (prestige, recognition).

Associated outputs are statements and performances that are connected in some way to authoritative outputs and which could not have the consequences they have unless they were so associated. Examples of associated statements are broad policies (the authoritative statement constitutes a small portion of the policy). Associated performances are services or favors that those in positions of authority provide to individuals or groups within their system. These outputs are unrelated to the major responsibilities of the political authority.

Table 4: Types of Outputs of Political Institutions

	Modes	
Qualities	Statements	Performances
Authoritative	Binding decisions, laws, decrees, regulations, orders, judicial decisions	Binding Actions
Associated	Policies, rationales and commitments	Benefits and Favors

4.2.4 Feedback

Under optimal conditions, the authorities of a system attempt to match outputs to demands. The effectiveness of these authorities is directly related to the amount and kinds of information they have about the general state of the system and its environment and about the effects of outputs from the system. Therefore, they rely on a feedback loop to provide them with information on the effects of their actions.

In general, the term "feedback loop" refers to two interlocked processes:

1. The regulative outputs of a system and the consequences of these outputs; these represent the way in which authorities adjust to the situation in which they find themselves.
2. The information itself that is fed back about the state of the system and consequences flowing from whatever regulative or adjusting actions are undertaken by the authorities.

4.3 A Hypothetical Example

A detailed analysis of the systems model described in Section 4.2 is best undertaken as part of a case study of a particular irrigation institution. Indeed, it is difficult to determine what typical demands, support, authoritative and associated statements and associated performances might be. These may depend on local custom, state laws, hydrologic characteristics of the basin, socioeconomic characteristics of the farmers, etc. Therefore, the hypothetical example presented in this section deals only with one component of the Easton (1965) study: authoritative performances. However, it should be clear that a case study which only considers this type of output, and ignores the other components defined by Easton (1965) is, by definition, an incomplete one.

In this hypothetical example, suppose that the irrigation agency with jurisdiction over a given region, is faced with falling groundwater levels which raise pumping costs, force farmers to install deeper wells and threaten the financial survival of farmers who rely heavily on groundwater. The policy alternatives available to a given type of agency are discussed in detail in Chapter 2. The full range of options presented in Chapter 2 includes the following:

A. Do nothing.

B. Refuse to grant permits for the construction of new wells.

C. Require the installation of meters and restrict the amount of groundwater that can be pumped from each well.

D. Obtain an additional supply of surface water and finance the purchase through increases in both the land assessment and user charges.

E. Obtain a long-term supply of water from, for instance, a federal agency or other suppliers and finance it exclusively through an increase in water charges.

Section 2.2.3 shows that a public irrigation district involved primarily in supplying water would have to choose among alternatives A, D and E. Section 2.2.4 demonstrates that a typical groundwater management district would choose among alternatives A, B and C and a groundwater management district with the power to engage in surface water transactions among all five alternatives. Finally, Section 2.3.3 shows that a mutual irrigation company would be limited to choosing between alternatives A and E (since it cannot levy land taxes).

Clearly, alternatives C, D and E define a full range of options, but for the purposes of this discussion, only one option (a given quantity of outside water purchases, a given pumping restriction, etc.) will be considered for each alternative. Also, it is assumed that the objectives of each agency are those presented in Chapter 3: maximization of aggregate profits, local control, conflict resolution, equity and maximization of "internal" utility.

Naturally, an agency using a formal model as a decision aid would want to know the impact of each of the policies which it has the power to implement on each of its objectives and would then use this information to select its preferred policy.

The different methods that may be used to evaluate the impacts of each policy alternative or the objectives of an agency are best discussed in the context of a specific case study. As a first step, suitable criteria to measure the objectives need to be defined. These criteria can either be precise mathematical measurements of the objective or appropriate surrogates. For example, aggregate profits could be measured directly, conflict might be measured by a surrogate such as groundwater levels (since falling levels could lead to conflicts among adjacent irrigators), local control by the percentage of dependence of water supplied by outside agencies and of investments by outside agencies in facilities within the basin, etc.

Probably, the two economic objectives would be measured with the aid of an economic simulation model which would provide the responses of farmers acreage planted, crop mix, level of irrigation, etc. to actions of the irrigation agency. A mechanism by which farmers respond to such actions is proposed by Arntzen (1980).

Although a full discussion of the choice of a preferred alternative cannot be provided in the context of this study, the methodology to be used is illustrated by reference to a hypothetical matrix of criteria vs. alternatives. In this matrix, presented in Table 5, aggregate profits are measured in $100,000 units, and the other four objectives by means of a subjective scale, where 1 and 5 represent the low and high ends of the scale, respectively. A crude justification for the levels chosen in Table 5 is presented below. The following discussion also shows that a rough idea of the impact of various policies may be obtained without resorting to complex simulation models.

4.3.1 Aggregate Profits

Table 5 shows that aggregate profits are lowest for the "do-nothing" option and highest for the alternative in which additional water provided from outside the system and where the sale is financed solely through increased user charges. If no action is taken, the groundwater will rise and farmers might find it necessary to install deeper wells. The loss in benefits could be reduced in part by restricting the granting of new permits, but this measure would probably not be strong enough to halt the further groundwater decline. Limiting the amount of groundwater pumped from each well would maintain the groundwater table at an acceptable level and save the higher costs associated with pumping deeper water, but it would also lead to water shortages that would be reflected in lower crop yields. By bringing outside water into the region, the public irrigation district could halt the overuse of

Table 5: Criteria vs. Alternatives for a Hypothetical Example

Alternatives	A	B	C	D	E
				Augment Supply	
Measures of Effectiveness	No Action	Restrict New Permits	Restrict Quantity Pumped	Charges & Taxes	Charges
1. Aggregate Profits *	12	13	15	16	17
2. Local Control **	4	4	4	3	3
3. Equity **	4	3	2	4	4
4. Conflict Resolution **	2	3	2	3	4
5. Internal "Prestige" **	1	2	4	4	4

Scales * In $100,000 units

** Subjective Scale:
1 = Very Bad
2 = Bad
3 = Fair
4 = Good
5 = Very Good

groundwater if it were able to secure this water at a price lower than the marginal pumping cost. However, some of the efficiency of this scheme would be lost if the agency decided to finance the purchase through both user charges and an increase in the land assessment. In this case, the farmers would perceive this water to have a price lower than its true cost and would use an amount greater than that which would be economically optimal.

4.3.2 Conflict Resolution

Both the "do-nothing" and the pumping restriction policies would lead to important conflicts among water users. The first alternative would produce squabbles between adjacent irrigators, the second, a host of complaints and requests for exemptions from the regulations. On the other hand, restricting the granting of new permits and raising the land tax rate would lead to conflict between the irrigation agency and its constituency.

4.3.3 Local Control

Local control would be hampered, to a certain extent, by capacity expansion, since the irrigation district would have to sign long term contracts with a wholesaler. The discussion in 3.3.1 shows that these contracts would lead to interference from the wholesaler. The other policy options do not affect local control appreciably, although they could present problems if dissatisfied users brought up their grievances with the sate or county governments.

4.3.4 Equity

Restrictions on groundwater pumping would reduce overall equity, since they would penalize farmers who relied primarily on groundwater more heavily than those whose main source of supply was surface water. While it is true that some more equitable restriction schemes could be devised, it is unlikely that any given solution would encounter wide acceptance.

4.3.5 Internal Utility

The internal "prestige" of the agency would be enhanced by actions interpreted as being drastic. In contrast, its prestige would suffer it it gave the appearance of ignoring the crisis. Therefore, in this example, the internal utility of each measure is roughly proportional to its severity.

4.4 Choice of a Preferred Alternative

Table 5 presents a general list of policy alternatives. Naturally, in a case study of a given agency, only those alternatives available to that agency would be included in a matrix of criteria vs. alternatives. In any event, to use this model as a decision aid, an irrigation agency needs to reduce its set of policy options to a single preferred alternative. The process of elimination of undesirable alternatives consists of two parts:

1. Elimination of dominated alternatives, and
2. elimination of non-dominated alternatives.

4.4.1 Elimination of Dominated Alternatives

Definition 1: Alternative a_k dominates alternative a_j if, and only if,

$$V_{rk} \geq V_{rj} \quad \forall_r$$
and
$$V_{rk} > V_{rj} \quad \text{some } r$$

where V_{rk} is the value of criterion (measure of effectiveness) r for alternative k.

In Table 5, alternative E dominates alternative D. Hence, the latter option will not be chosen by a rational decision-maker. Figure 6 shows that all other alternatives are non-dominated.

4.4.2 Choice Among Non-Dominated Alternatives

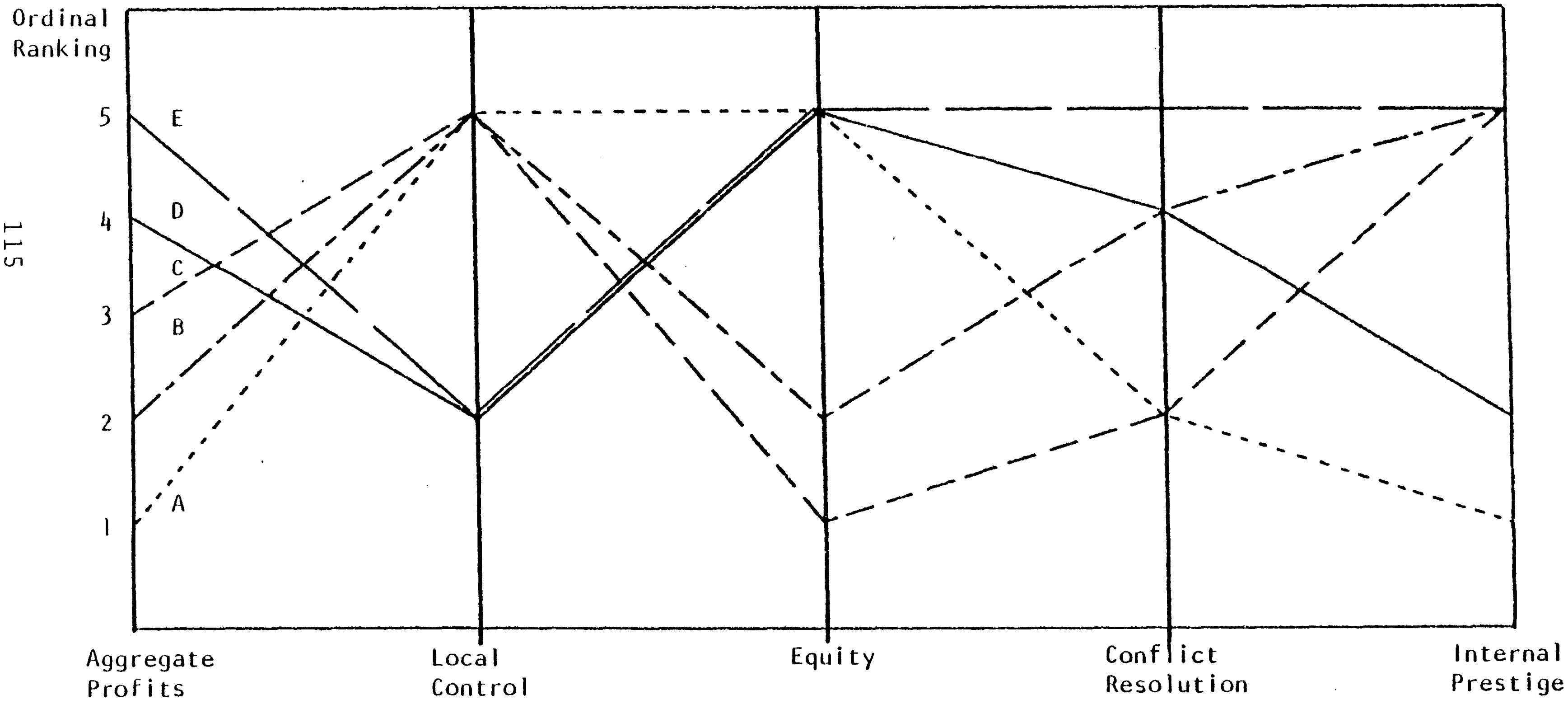
Having eliminated the dominated alternatives, the irrigation agency can proceed in two ways:

1. It can make a holistic judgement among the remaining alternatives, or
2. it can ask a systems analyst to choose a preferred alternative by means of a multi objective programming technique.

Multi objective programming techniques are used extensively in water resource planning. These techniques are classified, reviewed and evaluated by Cohon and Marks (1975). In their paper, these techniques are classified as follows:

1. Generating techniques,
2. techniques which rely on prior articulation of preferences, and

Figure 6: Ordinal Ranking of Alternatives vs. Criteria



3. techniques which rely on progressive articulation of preferences.

Generating techniques were the first multi objective solution procedures developed since they follow directly from the Kuhn-Tucker conditions for non-inferior solutions. These techniques indentify the non-inferior solutions and therefore provide all of the information one can extract from a multi-objective model. They do not require preference information from decision makers. The vector optimization problem can be converted into a scalar optimization problem by weighing the components of the original vector-valued objective function.

Generating techniques are desirable in that they explicitly present the tradeoffs among objectives, but they are computationally inefficient. The computational burden can be reduced considerably by a prior articulation of preferences on the part of the decision maker. In one such technique, goal programming, the decision maker chooses targets for each goal and the objective function seeks to minimize the sum of the weighted deviations from these targets.

Finally, some techniques rely on a progressive articulation of preferences. These techniques consist of the following steps:

1. Find a non-inferior solution,
2. obtain the decision maker's reactions to the solution and modify the problem accordingly, and
3. repeat the previous steps until satisfaction is attained or until some other termination rule may be applied.

The choice of a particular multi objective technique depends on the characteristics and complexity of the problems being analyzed. For example, if few objectives are considered, generating techniques may be desirable. In contrast, if many objectives are used, they may prove computationally burdensome. Thus, the technique used should be chosen with care in planning a case study of a particular irrigation institution.

4.5 Descriptive Model

The discussion of Sections 4.3 and 4.4 focuses on the use of a mathematical model as a decision aid for the local irrigation agency. However, a descriptive model can also be constructed. A model of this type is of particular use to a higher level decision maker (state government, federal government, etc.) interested in projecting into the future the state of a basin managed by a local irrigation agency. A descriptive model differs from one used as a decision aid (prescriptive) in this example in that:

1. The choice of policy alternatives needs to be done in a way that reflects the local agency's <u>own</u> perceptions about the measures it can adopt.
2. The multi objective decision making model used should reflect the decision making process of the agency as perceived by the higher level decision maker, (a survey of behavioral decision models is provided by Slovic et al., 1977).

4.6 Summary

This chapter combines the main findings of Chapter 2 (that local irrigation agencies have limited powers) and Chapter 3 (that these agencies consider more than one objective in ranking alternatives) to provide a blueprint for the construction of a detailed mathematical model of the decision-making process of an agency of this type. The couplings between this component and the generalized framework of the management system of problems of conjunctive use of surface and groundwater illustrate how the inputs and outputs of the agency affect the general functioning of the system.

Chapter 5

Conclusion

This study provides some answers to the questions posed in Chapter 1. First, a systematic analysis of the literature on the conjunctive management of surface and groundwater reveals five serious deficiencies. Second, two of these deficiencies are analyzed in depth. Chapter 2 shows that the assumption of centralized control does not accurately describe the operation of local irrigation agencies, since the powers of these institutions are limited to very specific areas. Ironically, the recent formation of National Resources Districts (NRD) in Nebraska might herald a transition to more centralized control. Indeed, these Natural Resources Districts replace all existing special purpose public districts in the state and have the power to supply surface water and to declare groundwater control areas (Axthelm, n.d.). However, even these districts do not conform to the descriptions provided by most engineering studies because they do not have complete control over groundwater withdrawals. Chapter 3 shows that single objective functions in general, and aggregate profit maximization in particular, are not successful at explaining the decisions of irrigation agencies. In addition, it identifies other important objectives: local control, equity, conflict resolution, maximization of "internal utility" but points out that a comprehensive list of objectives can be elucidated only through a case study of a particular irrigation agency.

Third, this study shows how the knowledge obtained from studying the nature and objectives of irrigation agencies can be used to build a prescriptive or descriptive model of such an agency. Chapter 4 also discusses the ways in which a model of this type can be incorporated into an overall decision model used to study problems involving the conjunctive management of surface and groundwater. The hypothetical example presented in Section 4.3 illustrates which alternatives may be available to a particular agency to deal with declining groundwater levels and how agencies might assess the impact of their policies on their objectives.

The central contributions of this report are that it shows that:

1. Institutional problems need to be studied in any overall examination of the conjunctive management of surface and groundwater.
2. Reasonably complex multi objective organizational models may be incorporated with relative ease into these studies.
3. The term "conjunctive management of surface and groundwater" is actually misleading because in most cases, an irrigation agency can only regulate groundwater withdrawals by indirect methods.
4. Most of the components of the model of a political institution discussed by Easton and the multi objective technique used to find a preferred alternative should be defined to be compatible with the case study being planned.

5.1 Suggestions for Further Research

This study has discussed some areas in detail, outlined other and hinted at the importance of yet others. Thus, it opens up countless opportunities for further research. First, a case study of either a public irrigation district would illustrate the methods to elucidate objectives and rank alternatives presented in this paper. Second, a model of an irrigation agency could be incorporated to an existing study of conjunctive use of surface and groundwater. The study best suited for this attempt is that of Young and Bredehoeft (1972) because it recognized that farmers, and not a centralized agency, make most of the groundwater withdrawal decisions. In any event, the study used should be one which employs linking as the method for combining hydrologic and economic models. Embedding models should not be used because they cannot account for the physical behavior of overdeveloped aquifers. Response function models cannot be used because it is not possible to derive precise mathematical expressions linking surface and groundwater levels with the degree of attainment of the various objectives. In the more distant future, this study should be coupled with works on farmer demand for surface and groundwater currently in progress (Arntzen, 1980).

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Final Report

Conservation in Long Term Conjunctive Use: Irrigation Demands Using Disaggregate Choice Models

Section III

Predicting the Acceptance of Water Conservation Policies by High Plains Irrigators: An Application of Probabilistic Choice Modelling

by

Bruce C. Arntzen, Roman Krzysztofowicz
David H. Marks and John Wilson

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Section III

Predicting the Acceptance of Water Conservation Policies by High Plains Irrigators: An Application of Probabilistic Choice Modelling

Abstract

This study addresses the groundwater depletion problem in the Ogallala aquifer beneath the High Plains and examines the suitability of probabilistic choice models for predicting the acceptability of alternative water conservation policies to the irrigators. The nature of the policy acceptance problem is discussed and the social, institutional, and legal environments present on the High Plains are described. An overview of choice models and behavioral factors of individual information processing is presented. Use of the Elimination by Aspects (EBA) model and the Luce choice model is explored in the context of prediciting the degree of acceptance of alternative water conservation policies by irrigators. The existing and proposed policies of the groundwater management districts on the High Plains are reviewed and their characterization in terms of aspects is proposed. These alternatives are then used in an experimental application of the EBA and Luce choice models. Two laboratory experiments are conducted to examine the performance of these models in the context of predicting water conservation policy acceptance. The experiments confirm the validity of the regularity and moderate stochastic transitivity assumptions (EBA model) and the multiplicative inequality (both models) but do not confirm

the validity of the similarity hypothesis (EBA model), or the constant ratio rule and strong stochastic transitivity (Luce's model). In the experiments, the EBA model was a more accurate predictor of the choice probabilities than Luce's model. Furthermore, use of the EBA model appears to be most appropriate for problems characterized by many feasible alternatives which can be described by many concrete aspects which are easily recognized by the decision makers. Recommendations are made concerning field applications of the EBA model and future research needs of predictive choice modelling.

CHAPTER 1

INTRODUCTION

1.1 Objectives of the Research

This study addresses the problem of declining groundwater levels in the High Plains area of the United States and attempts to develop a probabilistic choice model to predict the acceptability of alternative water conservation policies. Groundwater use for irrigated agriculture in this region has caused the depletion of the Ogallala aquifer to the point where some wells are now dry. Although there are many technically feasible policy alternatives available to district managers for controlling water demands, many of these would fail for the lack of popular support. Whether any will work depends on the nature of the policy acceptance problem, the attitudes of the users, and the specific policy.

Although the practice of policy-making is as old as civilization itself, the science of predicting which alternative policies will be the most acceptable to those being governed is quite young. The large data needs and aggregate nature of traditional regression models make them inappropriate for predicting policy acceptance. Similarly, normative decision aids such as those offered by operations research techniques are not useful because of the highly subjective nature of policy acceptance and the failure of such models to fully account for non-economic values. Because policy acceptance depends on individuals' subjective and often random preferences, behavioral decision theory offers much promise for providing such a predictive tool. This study presents an overview of behavioral decision theory and experimentally tests the predictive ability of two probabilistic choice models, the Elimination By Aspects (EBA) Model (Tversky, 1972a) and Luce's Model (Luce, 1959).

The goals of this research are:

A. To develop an understanding of the nature of the water conservation policy acceptance problem.

B. To investigate the suitability of and to classify behavioral decision methods for predicting policy acceptance.

C. To examine the social, institutional, and legal setting of the policy acceptance problem in the High Plains.

D. To conduct a laboratory test of the EBA and Luce models in predicting policy acceptance within the High Plains scenario.

The seven chapters that follow address these objectives in the above order. Chapter One builds an understanding of the physical and socioeconomic nature of the groundwater depletion problem in the High Plains. Chapter Two describes the institutions involved in water management and discusses the interactions between the institutions and the irrigators. The need and the possibility of coordinating supply alternatives (such as water importation) with demand alternatives (such as controls on water use) is also discussed. Chapter Three reviews the models which could be used to predict policy acceptance and also discusses the psychological basis of choice theory. Tversky's Elimination By Aspects (EBA) choice model is selected for further investigation. Chapter Four describes the EBA model and Chapter Five interfaces the Ogallala problem with the EBA model. In Chapter Six the EBA model is tested via two separate experiments and recommendations for future field applications are made. Finally, Chapter Seven summarizes the study and brings forth the major findings.

1.2 Motivation for the Research

The High Plains of the United States lie above a vast supply of underground water, the Ogallala Aquifer. Although it receives very little recharge, the Ogallala is being pumped and depleted at an ever increasing rate to provide water for irrigation. The declining groundwater levels and rising pump irrigation costs cause increasingly adverse economic and social impacts on the High Plains communities. It is anticipated that local, state, and perhaps even federal agencies will attempt to intervene in order to mitigate these problems. Several large scale water importation plans were proposed in the 1960's but they proved to be expensive and politically infeasible. Currently, the technical and economic feasibility of many supply-side and demand-side alternatives is being investigated. Clearly, there is a need for a planned solution to the problem which coordinates the supply policies with the demand policies, and which integrates all water demands into one overall management structure. Furthermore, it is paramount to assure that the supply and demand policies are efficiently implemented through the local groundwater management districts which enjoy the most popular support.

Water conservation policies for irrigators will be an important component in any solution to the problem. This thesis proposes an analytic tool to be used by the appropriate agencies to identify those water conservation policies which are the most acceptable to the irrigators. The remainder of this chapter describes the Ogallala problem including its causes and proposals for solving it, and summarizes past attempts to model policy acceptance.

1.2.1 Depletion of the Ogallala Aquifer: An Overview

Physical Description of the Ogallala and the High Plains. The High Plains and the Ogallala Formation are nearly coterminous and cover portions of Nebraska, Kansas, Colorado, New Mexico, Oklahoma, Texas, South Dakota and Wyoming (see Figure 1.1). This flat, dry, and nearly treeless region would resemble a desert without the Ogallala.

About 70 to 90 million years ago, volcanic pressure began to force upward the sheets of sedimentary rock left behind when ancient oceans retreated. The heat and pressure transformed much of this rock into granite and thus gave rise to the Rocky Mountains. As the mountains weathered, rivers flowing east toward the Mississippi or the Gulf of Mexico carried boulders, gravel, sand, silt and clay from the mountains and deposited them on the flat lands below the hills. These river deposits formed a porous "apron" of loose debris up to 500 feet thick on the plains east of the Rocky Mountains. Later, erosion served to cut off the apron on both the east and west sides, leaving an 800 mile long north-south belt of sand and gravel now called the Ogallala. Later deposits buried the Ogallala; today it lies from 0 to 300 feet below the surface (Bittinger and Green, 1980).

The High Plains are semi-arid for two main reasons. First, they receive an average of only 15 to 20 inches of rain a year. Fortunately for the farmers, most of the annual rainfall does occur during the growing season from May to September. However, there is so much variability in the year to year and week to week distribution of rainfall that it

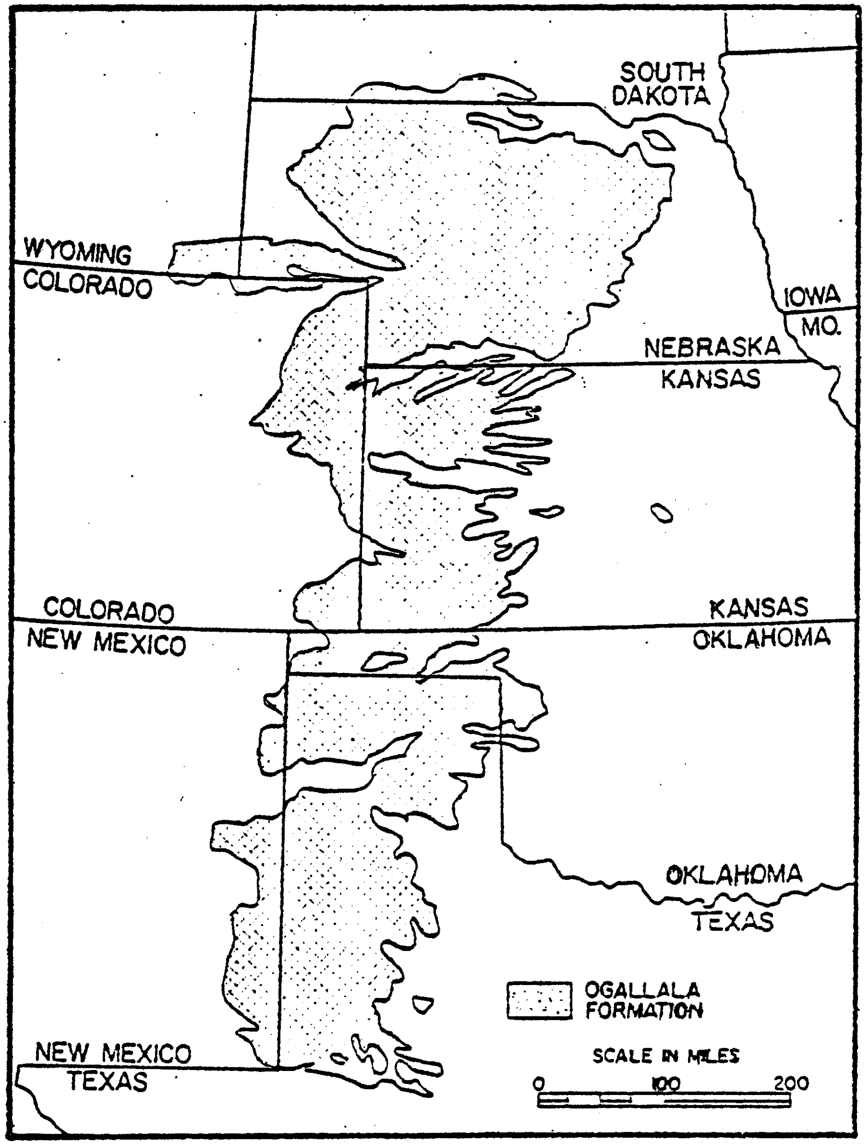


FIGURE 1.1 Eight States Area Covered By the Ogallala Formation.

cannot be counted upon by farmers to water their crops. For instance, having only one storm in an entire month is common. Second, much of the precipitation evaporates before it has a chance to run off or infiltrate. High winds help to keep the plains dry as well.

Since the Ogallala is cut off from the Rockies on the West, it receives no recharge from the mountains. Before man intervened, the Ogallala was saturated with water and when a storm came, the runoff would quickly flood the stream beds. Soon after the storm, the streamflow would shrink to the base flow provided by the Ogallala. As man lowered the ground water level, he created a situation where the base flow of many streams has disappeared and storm runoff is lost through the streambeds to the aquifer. Many reservoirs were built on the High Plains to provide flood control and a more continuous and dependable water supply for irrigators downstream. However, with the groundwater levels depressed by well pumping, the flow of water into the reservoirs is greatly reduced and the reservoirs themselves leak water into the Ogallala. The result is that the Ogallala does receive some additional recharge, i.e., via leakage from reservoirs, canals, and laterals, but not enough to keep pace with the pumping.

History of Development. The idea of trying to control the development of groundwater in the High Plains is recent because nearly all of the groundwater development has occurred since 1950. Through most of history, most thought the region had no potential for development. In 1859, Horace Greely declared the High Plains a desert and offered several colorful theories to explain this dry, windy region. As the railroads moved west, the demand for water grew, not only for the steam engines, but also for the many new towns and stockyards which sprang up all along its route. The first major cattle drive, from Texas to Sedalia, Missouri, occurred in 1866 (Webb, 1971).

While domestic water users were able to use the Eastern-style wells which raised water in a bucket on a rope, ranchers and railroads needed a faster, less labor-intensive means of raising water. The American-style windmill was developed between 1854 and 1867 and perfected by a young mechanic, Daniel Halladay. These windmills, once a common sight on the High Plains, were about 6 to 10 feet in diameter and solved the water pumping problem for the stockmen and railroads by delivering a fairly constant and reliable supply of water. The Homestead Act of 1862, which gave away up to 160 acres of public land free to settlers, the Desert Land Act of 1875, which sold up to 640 acres to settlers for $1.25/acre, and the invention of barbed wire combined with the new windmills to populate the High Plains (Bittinger and Green, 1980).

North America, like other large continents, has what is called a "plow line." On one side of the line, the climate is humid enough to permit dryland farming, and on the other side it is too dry. Although year to year variations in climate cause the position of this line to shift, the 98th meridian is its average position. Each series of wet years allowed the settlers to push further west and the following series of dry years would move the plow line back to the east. In the words of Simons (1906)

> ...every such wave left behind it a mass of human wreckage in the shape of broken fortunes, deserted farms, and ruined homes.

> From the 98th meridian west to the Rocky Mountains there is a stretch of country whose history is filled with more tragedy...than perhaps any other equal expanse of territory within the confines of the Western Hemisphere.

As recently as the 1930's a variation in climate caused the human calamity known as the Dust Bowl where dry winds blew dust and sand into drifts like snow on High Plains farms.

Until about 1920-1925 wells were dug by hand and centrifugal pumps were placed below the surface, next to the water table. However, by 1930 two technological advances were made which set the stage for rapid groundwater development. First was the invention of the deep-well turbine pump which is installed on the surface and can deliver water at over 1000 gallons per minute. Second was the invention of the reverse-rotary drilling method where the drilling fluid flows down the outside of the drill pipe and then rapidly carries the cuttings up through the inside (Bittinger and Green, 1980). The introduction of siphon tubes (1940's) and, later, gated pipes reduced the labor requirement for furrow irrigation and helped precipitate rapid groundwater development in the High Plains. The first major surge in well drilling occurred in the High Plains of Texas, where approximately 34,000 wells were installed between 1950 and 1960 (New, 1978). Incredibly, this tremendous expansion of groundwater development was later dwarfed by another invention: the center pivot.

The center pivot irrigation machine consists of about 7 to 10 towers spaced about one hundred feet apart on large rubber or steel wheels which suspend a water pipe and sprinklers about 10-15 feet above the ground. The towers move around the center of the field in a circle spraying water, fertilizer, pesticides, and herbicides on the field during its 12 to 72 hour traverse. They usually are designed to water a quarter section (130 of 160 acres, omitting the corners). While furrow irrigation requires nearly flat, gently sloping fields, center pivots can roll over small hills and thus permit vast amounts of previously non-irrigable land to be farmed. In Nebraska alone, the number of center pivots increased from less than 3000 in 1972 to 17,000 in 1978 with a corresponding increase in the number of wells needed to supply them (Nebraska Conservation and Survey Division, 1979).

Present Water Situation. By now (1980) there are between 140,000 and 200,000 wells pumping water out of the Ogallala and irrigating over 16 million acres of food and fiber crops on the High Plains. It is estimated that since 1950 irrigated agriculture has increased at an average annual rate of approximately 7.5 percent (Frederick, 1976). Whereas the U.S. as a whole relies on groundwater for 20 percent of its water needs, High Plains rely on groundwater for about 2/3 of their needs: Oklahoma, 61%; Nebraska, 68%; and Kansas, 86%. Although there is between 1 and 2 billion acre feet of water stored in the Ogallala, some areas, particularly where the aquifer is thin, will go dry within 10 years while other areas will last more than fifty years. Water levels have declined up to 75 feet near Guyman, Oklahoma (Wickersham, 1980). Before the aquifer actually goes dry (or nearly dry) pumping lifts will probably make irrigation too expensive. For instance, if electricity costs 6¢ per kilowatt hour, kwh, then a drop in the water table of 75 feet increases the cost of providing one-quarter section (160 acres) of land with 18" of water by about \$1650. Similarly, if the water table is 150 feet below the surface (typical in the High Plains), a one cent per kwh price increase causes a \$550 increase in the farmer's pumping cost for a quarter section.

1.2.2 Problem Causes and Legislative Actions

Reviewing the history of development of the High Plains, it is tempting to say that the problem was "bound to happen." The causes of the problem can be categorized as follows.

1. Population pressure. There was a strong desire by many settlers to farm this dry area west of the plow line.
2. Free land. The Homestead Act and the Desert Land Act made High Plains land available to settlers.
3. Technological advances. Deep-well turbine pumps, reverse-rotary drilling, siphon tubes, gated pipes and finally center pivots made irrigation possible.
4. Ogallala itself. Although the aquifer has little recharge it is so big that it was once considered inexhaustible.

To an economist, this is a Tragedy of the Commons. To a hydrologist it is a Common Pool Problem. In this situation, where each individual farmer fends for himself, each has a strong incentive to use up as much of the common resource as he can, before his neighbor beats him to it. If no organization of enlightened individuals intervenes to halt this rapid exploitation of the resource, then the tragedy of the commons proceeds to its unfortunate end where the resource is gone and the individuals are financially ruined.

In the northern part of the Ogallala (Sand Hills of Nebraska) the aquifer receives about 8 inches of natural recharge yearly which is enough to balance the withdrawals. Thus in the north the classic solution to the Tragedy of the Commons, attaining a sustained yield, is possible. However, in the southern part of the aquifer, withdrawals cause an annual decline in the groundwater table of 2 to 5 feet while recharge is estimated to be from only 0 to 2 inches. Most irrigators and water officials in the south ignore this tiny amount of recharge and consider the water supply in the Ogallala to be a finite resource. Therefore, this is not a Tragedy of the Commons in the traditional sense since attaining a sustained yield is not thought possible. Still, cooperation among the users is highly desirable to make this finite supply last as long as possible.

For the most part, state legislatures were very slow to act to control groundwater depletion. Some states have realized the problem and have enacted new legislation to deal with it. The 1975 Nebraska Groundwater Management Act, the 1972 Kansas Groundwater Management District Act, and the 1973 Oklahoma Groundwater Management Legislation are examples of recent attempts to deal with the problem. Unfortunately, it is probably too late now because once development occurs it is very hard to undo. For instance, suppose a farmer has purchased a section, drilled 4 wells and now grows irrigated corn with 4 center pivots. Can the legislature even consider a policy forcing the farmer to abandon 2 wells and incur the loss on his investment? Would such a policy be fair and efficient from the social and economic standpoint?

It seems that a better approach would have been to limit the development in the first place rather than to attempt to phase it out later on.

There were a number of reasons why the state legislatures took so long to act. First, each state contains several aquifers which have different characteristics. Second, the legislatures were used to considering renewable surface water supplies, not exhaustible groundwater. Third, groundwater hydrology was generally misunderstood and its connection to surface water was unknown. Finally, and most importantly, the farmers did not want any controls (Bittinger and Green, 1980). The farmers did not then and do not now want any "bureaucrats" telling them what to do. For many years farmers did not feel the consequences of this myopic philosophy since the groundwater in the Ogallala declines slowly. However, now they are beginning to feel the pinch in the form of increased pumping costs and reduced stream flows.

Three different groundwater doctrines are used by High Plains states:

1. Common law or absolute ownership rule permitting unlimited withdrawals as in Texas (applies to "percolating" groundwater),
2. Reasonable use - Nebraska,
3. Prior appropriation as part of a permit system - Kansas, New Mexico, Oklahoma (Clark, 1978).

Colorado follows a modified appropriation system where the previous appropriations within a 3-mile radius are considered when determining the appropriation for a new well. New Mexico has done the best job of controlling the development by strictly following its prior appropriation doctrine. The New Mexico Supreme Court faced the problem of defining the rights of a prior appropriator on a non-renewable resource (the Ogallala). It determined that they are to be protected from a too rapid depletion, with a 40-year life being the goal. Similarly, one groundwater management district in Kansas has stated that no new wells will be permitted in an area if the depletion will exceed 40% in 25 years, and another district has said that none will be permitted if more than 50% depletion has occurred since 1950. Colorado also uses the "40% depletion in 25 years" rule to decide on new wells. An Oklahoma law effective July 1, 1973, stated that appropriations of groundwater will be based on a life of 20 years (Oklahoma Water Resources Board, 1977). Nebraska and Texas have not yet addressed the question of how many years they would like to stretch their water supplies. The Sand Hills region of Northern Nebraska gets a substantial amount of recharge and thus that area alone still has a chance of holding groundwater development down to the sustained yield of the aquifer. Texas, on the other extreme, which was the first state to begin depleting the Ogallala, has done very little to correct the situation and hence now faces the most severe decline of groundwater levels.

An in-depth case study of the causes and consequences of the groundwater depletion problem was done near McCook, Nebraska. This area is interesting because the old irrigation districts (using surface water from reservoirs) are now suffering greatly because of the recent "invasion" of center pivots. Under Nebraska state law, groundwater users are permitted to pump without restriction, regardless of the consequences, i.e., the connection between groundwater levels and surface flows is not legally acknowledged. The case is described in detail in Appendix I.

1.2.3 Solving the Ogallala Problem

Who Can Solve It? It is by definition that each individual acting alone cannot solve the Tragedy of the Commons. In the absence of any groundwater controls or management structure, the optimal behavior for each individual is to use up the common resource as fast as he can. If he does not, his neighbors will. Only an organized group of all individuals can solve the Tragedy of the Commons; perhaps the government. Which government? If one county severely curtailed its use of groundwater but all the surrounding counties did not, the controlled county would eventually lose its supply to its neighbors. The logical approach is to bring all groundwater users in the High Plains together under one government to solve the problem. Since this involves many states there is some support for the Federal government to solve the problem.

The concept of gathering all the groundwater users under one government has already been partially accomplished by the formation of the Groundwater Management Districts Association (GMDA). As of 1980, this association consists of 34 member Groundwater Management Districts (GWMD's) and 22 of the 29 GWMD's which lie above the Ogallala have joined. Although the association has no authority, their annual conferences and published proceedings provide a forum for the exchange of ideas and information about surface and groundwater conservation and new, water-saving farming practices. Such a forum of enlightened GWMD managers is extremely valuable in developing a regional view of the problem and thus preventing the Tragedy of the Commons.

With the exception of establishing various Federally reserved water rights (e.g., surface water flows for Indian Reservations, National Parks), the Federal government has allowed states to enact their own water laws and control their own water. This practice of Federal non-involvement in water laws developed around renewable surface water supplies and until recently has carried over into groundwater as well.

However, in the mid-1970's, Texas with the help of Oklahoma, convinced the U.S. Congress to appropriate $6 million for a study. The Six-State High Plains-Ogallala Aquifer Study is to investigate and evaluate the supply-side (water importation) and the demand-side (conservation alternatives) of the problem. The proposed solutions which range from simple allocation rules to fascinating schemes for importing water from Alaska, are described below.

Alternatives. The Six-State High Plains-Ogallala Aquifer Study is evaluating the following six general types of alternatives:

1. Initiate no new public action of deliberate change, but instead continue trends in current practices of water and agriculture management in both public and private sectors.
2. Voluntarily reduce water use by providing incentives designed to encourage technological change and improved water and agricultural management practices at the farm level.
3. Provide incentives for voluntary and mandatory reductions of water use by regulating water use or restricting new irrigation development.

4. Require management of water supplies and reductions of water use by augmentation of local area water supplies through weather modification, artificial recharge and other means, and through alterations in cropping practices.
5. Subregional water importation systems (provided long-term surpluses are available) as well as voluntary and mandatory management of water supplies and demands.
6. Regional and large-scale interbasin water transfer systems.

Alternatives 2, 3, and part of 5 include implementing water conservation measures, the focus of this study. Alternative 1 is the "do nothing" option and alternatives 4, 5, and 6 are "supply-side alternatives" whereby pipelines and canals are constructed to import water. Several large-scale structural alternatives were proposed during the 1960's to supply water to the High Plains from as far away as Alaska. Appendix II illustrates and discusses these plans as well as the current, small-scale, importation alternatives.

Summary. It is fitting to conclude this description of the policy acceptance problem by putting it in its proper perspective from both national and local viewpoints. It is also necessary to identify the research needs of the problem.

The use of the Ogallala has turned the semi-desert of the High Plains into productive farmland. Presently, the High Plains produce about 10% of the U.S. total cash crop receipts. Without irrigation, production would drop to about 3%. How much of an effort should be put forth by the Federal government to save this 7% of U.S. cash crop production once the Ogallala is depleted? There is no easy solution to the problem. All water importation plans are very expensive and encounter stiff opposition. Water conservation laws which dictate to the farmers how much groundwater they can pump are very unpopular. Nevertheless, there are many advantages to a planned reduction of groundwater use as opposed to the abrupt dewatering of the aquifer. The baseline projection is that groundwater irrigation on the High Plains will eventually be abandoned with some areas running out of water long before other areas. This can lead to particularly inequitable financial hardships. For example, near Culbertson, Nebraska, surface water irrigators who have been farming for 90 years are being ruined by center pivot irrigators who moved in less than 10 years ago.

Enacting the strict, tough water conservation policies needed to either reduce withdrawals to the sustained yield or even to make the supply last 50 years requires a tremendous effort on the part of the local, state or Federal agencies involved. Since there are many possible conservation policies to choose from, farmers can be expected to be more adamantly opposed to some plans than to others. Different policies have different impacts and the effects will vary from farmer to farmer and from policy to policy. This research investigates and classifies behavioral decision methods for predicting policy acceptance. A particular model, EBA, is presented in detail and its worth as a method to predict the farmers' acceptance of alternative water conservation policies is tested via a laboratory experiment. The results of the tests give insight into the use of the EBA model for the policy acceptance problem in the High Plains and into the future research needs of behavioral decision theory. Such predictive models, when perfected, are intended to aid policy makers in identifying more acceptable policies and eliminating undesirable ones.

1.3 Previous Studies on Policy Acceptance

Although many studies have dealt with the acceptance of new policies in many fields, none were found to include a predictive model for policy acceptance. For example, in Nebraska (Welch and Kissel, 1979) and South Dakota (Wagner and Dimit, 1975) public opinion polls have been conducted concerning agricultural water use. Also, public policy literature is filled with case studies where the difficulties in implementing a new policy are discussed and the short-sightedness of policy makers is expounded. A famous example in water resources is the immense study by the National Commission on Water Quality describing the impacts of Public Law 92-500 (Federal Water Pollution Control Act Amendments of 1972) on each industry. Existing policies of all sorts are constantly being critiqued after they have been enacted, but that is not the problem addressed in this study.

Other highly technical studies address the engineering and economic feasibility of implementing proposed guidelines such as those promulgated by the EPA. An example is the reply to the EPA's Proposed § 304 Guidelines and § Standards of Performance For Steam Electric Powerplants by the Edison Electric Institute and a consortium of 150 electric utility companies in the United States. The problem faced in this study deals with public opinion and political acceptability of groundwater conservation regulations, not so much technical or economic feasibility.

Multiattribute utility (MAU) theory has been used by Keeney and Raiffa (1976) and many others as a decision aid to evaluate various policy alternatives for decision makers who are concerned with multiple objectives. However, MAU models are most frequently used as normative decision aids, not as predictive models. They are deterministic and use lumped parameters in contrast to much decision behavior which is better described as probabilistic and conceptual.

Elmore (1980) proposed the concept of "backward mapping" from the individual being affected, through all the intervening agencies, back to the policy maker to help design better laws and programs. Similarly, Chase (1979) examined the task of implementing a human services program in New York City's prisons. He attempted to elucidate all possible problems of implementation and then design strategies and manpower and materials requirements for the program around the list of contingencies. Chase's purpose was to design a human services program that would work well, not to choose among several alternative programs.

Choice models, specifically Logit models, have been used frequently by transportation engineers to predict the public's response to new facilities (roads, bridges, etc.) and new services (bus routes, subway lines, etc.). Much work has been done in forecasting travel demand by Ben-Akiva and Lerman (1977), residential choice by McFadden (1978), and destination choice by Koppelman and Hower (1978) to name a few. Gensch (1980) proposed calibrating choice models using data from observed, committed behavior, not choices from posed, hypothetical situations, to predict the public response to new transportation policies. Gensch's study is quite close to the theme of this study since choice models (although different ones) are used in both and both predict public response to new policies. However, new transportation policies are usually the offering of a new service which the consumer may or may not use as he chooses. This is a big difference from imposing strict mandatory groundwater conservation regulations which will immediately and significantly affect the farmers. After a rigorous literature search, no previous attempts to model policy acceptance were found.

CHAPTER 2

IRRIGATION MANAGEMENT SYSTEM

To understand the nature of the policy acceptance problem it is crucial to know where policies originate and how they are implemented. Water policy alternatives must interface with the existing framework of users, institutions and water laws to be feasible, and must enjoy the support of users and the institutions to be successful. This chapter discusses western state water laws (surface and ground water), the institutions which play a role in water management, and the interactions between the farmers and the managers. Water management agencies exist at all levels of government, ranging from the U.S. Water Resources Council to the groundwater management districts. It seems that the more regional the organization, the less popular support, and the more local the agency, the more popular support. It is probably true that the high level agencies (Federal and State) have the best idea about what ought to be done, but the local agencies have the best idea about what can be done. Thus, policy implementation can best be accomplished through the local groundwater management districts (GWMD's) which both enjoys the support of and reflects the attitudes of the irrigators. Policy oriented Federal and State agencies must win the confidence of the GWMD's. Therefore, it is important for agencies at all levels to pursue policies which are acceptable to the users.

Water management decisions in irrigated regions are made by irrigation districts, groundwater management districts, irrigation companies, with occasional input from local, state, and federal agencies.

Together, these institutions make up a decision component of a management system for an irrigated region. Each institution possesses management objectives and, according to them, makes water policy decisions and reacts to water use decisions made by the farmers. The individual farmers make up another decision component of the management system. Each farmer responds to institutional water policies by using a different quantity of water and possibly even seeking another source of water.

2.1 Institutions and Water Laws

During the settlement and development of the West, a legal framework grew up around the ownership and use of water. In most western states, the doctrine of prior appropriation is applied to surface water allowing water to be treated as property with seniority being given to earlier claims. The first water rights were filed about the time of the Civil War, 1860's, and by 1920 most of the reliable flows of western rivers had been claimed. Water rights claims have continued, but the most recently acquired rights guarantee water only during very high flows. Each western state has enacted legislation which addresses the following questions: 1) Which doctrine is to be followed? 2) Is water private or public property? 3) How can water rights be acquired? 4) How can water rights be lost? 5) May changes be made in the point of diversion, the place of use, and/or the nature of use of a water right? 6) Can the location or the nature of water use be changed by the individual water rights owner? 7) How are water rights administered? 8) How are conflicts resolved? The western states' surface water laws are summarized in

Table 2.1 (Colette, 1976).

In those regions of the High Plains where significant streamflows exist another kind of institution arose: the irrigation company. Irrigation companies, also called ditch, canal, or reservoir companies, districts, or associations, serve to fulfill several objectives of farmers: local control, conflict resolution, economic growth, and the equitable distribution of income (Maass and Anderson, 1978). Typically, an irrigation company acquires water rights from farmers who trade in their water rights in exchange for shares in the company. In return the company provides water at a price to any user in its service area. Such an arrangement gives water users much more flexibility in transferring water than is possible through the state courts. If water was distributed strictly according to the Appropriation Doctrine, the economic returns to water (marginal value of water) would vary considerably from one user to another because of differences in the land, equipment, farming practices, etc. This inefficiency is largely eliminated through the water rental markets set up by the irrigation companies. This is especially true of Colorado but not of Nebraska where the water right is legally fixed to the land thus preventing transfers and rental markets. Note that in a perfect market where all farmers are both buyers and sellers of water the price of water delivered would reach an equilibrium value based on the quantity available, and would equal the true marginal value of water which would be the same for all users.

Irrigation companies exist in three major types: private, public and mutual. Private irrigation companies were responsible for the early development of irrigated agriculture, especially in Cali-

Table 2.1 Western State Surface Water Laws

	Summary of state water doctrines, concepts of water as public or private property, methods of acquiring water rights and causes of loss of water rights.													Legal Authorities vested in individual water rights holders.			Administration of water rights and legal structures for resolution of conflicts.							
	Doctrine			Ownership		Acquire water rights				Lose water rights				Individual authorized to change:			Administration of rights by:				Conflict resolution by:			
	Riparian	Appropriative	Permit	Public	Private	Buy Land	Buy Right	Appropriation	Permit	Sell Land (a)	Sell Right	Misuse	Non-Use	Point of Diversion	Place of Use	Nature of Use	Agency	Commissioner	State Engineer	State Court	Agency	Commissioner	State Engineer	State Court
Arizona		X		X		X	X		X	X	X	X	X	X	X	X		X				X		X
California	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X				X			X
Colorado		X		X		X	X			X	X	X	X	X	X	X			X					X
Idaho		X		X		X	X		X	X	X	X	X	X	X	X			X[h]					X
Kansas		X		X		X	X		X	X	X	X	X	X	X	X			X				X	
Montana		X		X		X	X	X		X	X	X	X	X	X	X				X				X
Nebraska	X	X		X		X	X		X	X	X	X	X	c	c	c	X				X			
Nevada		X		X		X	X		X	X	X	X	X	X	X	X			X				X	X
New Mexico		X		X		X	X		X	X	X	X	X	X	X	X			X				X	X
North Dakota		X		X		X	X[b]		X	X	X[b]	X	X	d	d	d		X	X				X	X
Oklahoma	X	X		X		X	X		X	X	X	X	X	X[e]	X[e]	X[e]	X							X
Oregon		X		X		X	X		X	X	X	X	X	X	X	X			X				X	X[i]
South Dakota		X	X	X		X	X		X	X	X	X	X	X	X	X[f]	X							X
Texas	X	X		X		X			X	X		X	X	X	X	X	X				X			X
Utah		X		X		X	X		X	X	X	X	X	X	X	X			X				X	X
Washington		X		X		X	X		X	X	X	X	X	X	X	X	X					X[j]		
Wyoming		X		X		X			X	X		X	X	g	g	g	X		X		X			X

(a) Conveys only those water rights appurtenant to the land. (b) Can be severed for beneficial use only upon approval of the State Engineer. (c) Applies to irrigation rights on a fully appropriated stream only. Other uses under permit follow different rules. (d) Cannot be changed except upon approval of the State Engineer. (e) May be changed upon approval of the Water Resources Board. (f) Holds for irrigation rights unless water cannot be used benefically in irrigation. Nature of use may be changed if the right is issued under the permit system. (g) Cannot be changed except for preferential use. (h) Director of the Department of Water Administration. (i) Review of decree or for appeal only. (j) Director of the Department of Ecology.

Source: Colette, 1976.

fornia and somewhat in the High Plains. These developers acquired huge tracts of land, constructed canals to convey water to the land, and then sold the land as farms to hundreds of settlers. In other areas, local governments went into the business of operating public irrigation companies, with more concern for social welfare than was displayed by the private companies. Finally, groups of farmers organized themselves into mutual irrigation companies to increase their efficiency and resolve their water conflicts. Many irrigation companies operate in the western states. Anderson (1961) reports that along an approximately 100 mile stretch on the South Platte River in Colorado there are about 100 irrigation companies, mostly mutual, including 12 major firms (100 to 300 stockholders).

Government agencies also participate in water policy decisions. At the federal level, the U.S. Water and Power Resources Service, formerly the Bureau of Reclamation, has constructed numerous reservoirs and canals and has entered into long-term contracts to provide water to various organizations of water users. Other Federal agencies, including the EPA, the Bureau of Indian Affairs, and the National Park Service, represent Federal interests in specific aspects of water policy. In addition, most western state governments have a State Engineer and a Division of Water Rights to administer control of surface waters. Finally, many states have set up Natural Resources Districts (NRD's) or Groundwater Management Districts (GWMD's) which are given the authority to make and enforce local water policies.

The NRD's or GWMD's were set up by the states in order to provide local control over local problems, something which is demanded by the farmers. An NRD or GWMD usually has an elected board of 5-15 members which meet regularly to set policies. They employ a full-time manager, secretary and laborers to transact the daily business. In some states (Nebraska, Kansas, Colorado) controlling the decline of groundwater levels has been left almost entirely up to the local water users, via the NRD's or GWMD's. In other states (Montana, New Mexico) the state government controls the decline of groundwater levels. Finally, several states (Texas, Oklahoma) have state laws according to which groundwater has a property right and is immune to institutional controls by GWMD's. However, GWMD's do exist in Texas to promote farming practices which conserve water.

Since groundwater had usually been developed as a secondary source of irrigation water, its legal and institutional framework emerged much later than that of surface water and is still changing. While the scarcity of surface water has long been acknowledged, the mining of groundwater was either not occurring or at least was not perceived as a problem in most areas until recently (since 1950). At first, drilling wells and pumping groundwater were not regulated, and farmers used this source on their own volition. As groundwater levels began to decline and to interfere with surface flows, states responded with administrative controls on drillers and farmers. These controls include requiring permits before drilling, establishment of groundwater rights, adopting a doctrine of control and other measures. A summary of the western states' groundwater laws is given in Table 2.2.

Nine of the western states provide for the establishment of groundwater conservation districts. Four of the states allow farmers

Table 2.2 Western State Groundwater Laws

	GW[1] Conservation Districts or District Advisory Boards are formed.	Permits Required for all GW withdrawals except domestic, stock and lawn watering.	Permits required in controlled or critical areas only.	Administrative control of GW in aquifers only; percolation GW is not controlled.	Doctrine of Reasonable Use applies with or without Doctrine of Prior Appropriation.	Pre-existing GW rights are recognized by the current GW legislation.	Legislative provision for issuing permits to pre-existing users.	Control and licensing of well drillers.	Drillers must file reports of their activities	GW linked to surface flow is controlled via surface water rights.	No mining of GW is allowed.	Domestic, stock, etc., wells exempted from driller licensing and permit requirements.
Arizona			X		X				X	X		X
California	X			X	X							
Colorado	X	X				X		X		X		X
Idaho		X						X	X			X
Kansas	X	X				X	X	X	X			
Montana			X			X		X	X		X	
Nebraska	X		X		X				X			X
Nevada	X	X				X		X	X			X
New Mexico	X	X				X	X	X	X		X	
North Dakota		X				X		X				
Oklahoma		X			X	X		X				X
Oregon		X				X	X	X	X			X
South Dakota		X				X	X	X	X			X
Texas	X				X				X			
Utah	X	X				X		X	X			
Washington		X				X	X	X				X
Wyoming	X	X	X			X	X		X			

[1] GW = Groundwater

to use groundwater freely until the level begins to decline at which time a "critical area" is declared and pumping is restricted.

In conclusion, there are many institutions which have an influence on local water policy. These institutions make decisions concerning water supplies, tax rates, and user charges. Since these decisions indirectly determine the district's productivity and economic performance, this collection of institutions is viewed herein as an acting Basin Manager. An examination will be made concerning how the Basin Manager interacts with the users of the water, the irrigators.

2.2 Interactions Between Managers and Farmers

The interactions between the Basin Manager and the farmers are more interesting where the groundwater is controlled by NRD's or GWMD's which are elected by the farmers than when a State Engineer is in charge. In states without GWMD's or NRD's, the mechanism for local control and participation by individual users in water policy decisions is absent. Often, upon election to an NRD or GWMD board, a farmer gets a much broader, more regional and longer range view of this tragedy of the commons than the myopic viewpoint held by each individual farmer. The board members often realize advantages of limiting groundwater depletions which are not recognized by the individual irrigators. Therefore, nearly all GWMD's conduct campaigns to educate the farmers about the problem and better farming practices, and publicize their board meetings via newspapers, radio and even television. At the board meetings, the NRD or GWMD decides tax rates or user charges to raise revenues and policies concerning surface water use, groundwater use, and farming practices.

Farmers make their water use decisions based in part on the policies set forth by the district management. Farmers respond to these policies by:

1) changing their irrigation technology and farming practices,
2) changing cropping patterns and crop mixes,
3) changing the quantity of water applied,
4) changing the quantity of surface water obtained, (if possible),
5) changing groundwater pumping rates, and
6) drilling new wells.

Options 1, 2 and 3 involve changing the amount of water used and options 4, 5 and 6 constitute changes which affect the sources used to obtain water.

Old farms, within irrigation districts, which are lucky enough to lie above a thick part of the Ogallala have two very different sources of supply. Surface and groundwater differ in 1) costs, 2) reliability, 3) spatial distribution, 4) laws governing their use, 5) quality, 6) managing institutions, and 7) degree of direct control by the user. For most of the last century (1880 to present) surface water laws have existed and surface water has been controlled by irrigation companies and government agencies. More often than not, the farmer was forced to rely on someone else (companies or agencies) to provide the water. Traditionally, this dependence was tolerated by farmers since drilling wells and pumping groundwater was more expensive than buying surface water. However, farmers realize that when the rivers go dry or when their access to surface supplies is blocked by a lack of seniority, they can still find the water they need by drilling wells. Only recently has the groundwater begun to be controlled.

In a review of the hydrology of the South Platte Basin, Hurr, Schneider, and Minges (1975) note the following:

> The effects of several actions which affected the installation of irrigation wells are shown by the graph in Figure (2.1b). The sharp increase in the number of wells drilled in 1954 and 1955 was the direct result of the deficient surface-water supply during those years (compare with Figure [2.1a]). From 1956 through 1962 the number of wells drilled annually was low because of decreased need for new wells and because the surface water supply was normal to slightly above normal. The increase in well installation during 1963-1965 is believed by the authors to be the result of both a decreased surface-water supply during part of the period and an anticipated change in Colorado's groundwater law which would regulate the drilling and use of wells. The small number of wells drilled after 1965 is the result of the implementation of the law.

In other areas of the High Plains such as Texas and Oklahoma, surface water irrigation never existed so the development of groundwater use occurred earlier and was spurred on by droughts and advances in well and pump technology.

The water management institutions, the farmers, and the interactions between them can be viewed as components of an irrigation management system. A strict systems analysis structuring of the problem includes definitions of a time scale, a state space, an input set, a decision set, an output set, state transition functions, strategies, output functions and probability distributions of the inputs. Further development of this system is reserved for future research.

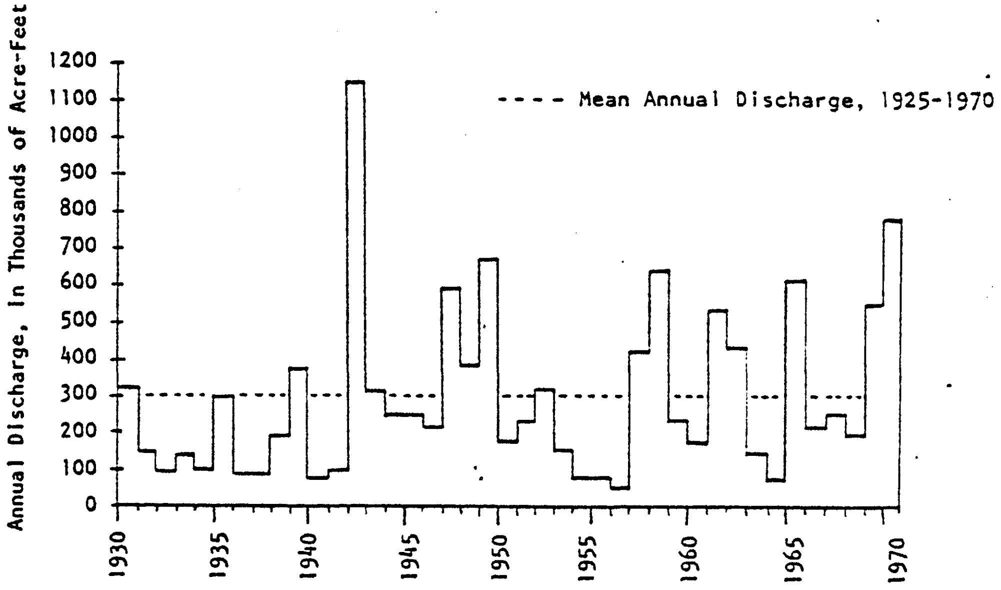


Figure 2.1a Annual Streamflow of South Platte River at Julesburg, Colorado. (Hurr, Schneider, and Minges, 1975).

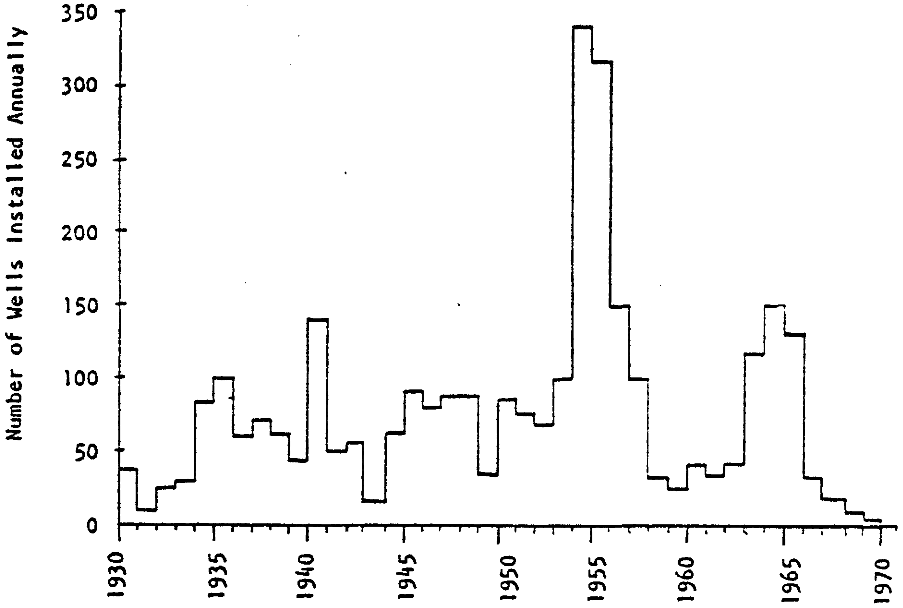


Figure 2.1b Annual Installation of Large-capacity Irrigation Wells in the South Platte Basin, Colorado. (Hurr, Schneider, and Minges, 1975).

CHAPTER 3

MODELLING TECHNIQUES

Chapters One and Two describe the policy acceptance problem and identify the need for developing a predictive model to aid the process of design and selection of water conservation policies. Such a model is needed to determine which feasible conservation policies will encounter the least opposition from the water users and will thus have the best chance for successful implementation. This chapter examines and compares several types of predictive models, in general, and then describes and categorizes the various types of choice models. Finally, there is a discussion of modelling techniques from the point of view of modern behavioral decision theory. This includes the psychological basis of choice theory, popular heuristics, common biases, elimination procedures, theories about thresholds and fuzziness, and the sequencing of models and heuristics.

3.1 Predictive Models: An Overview

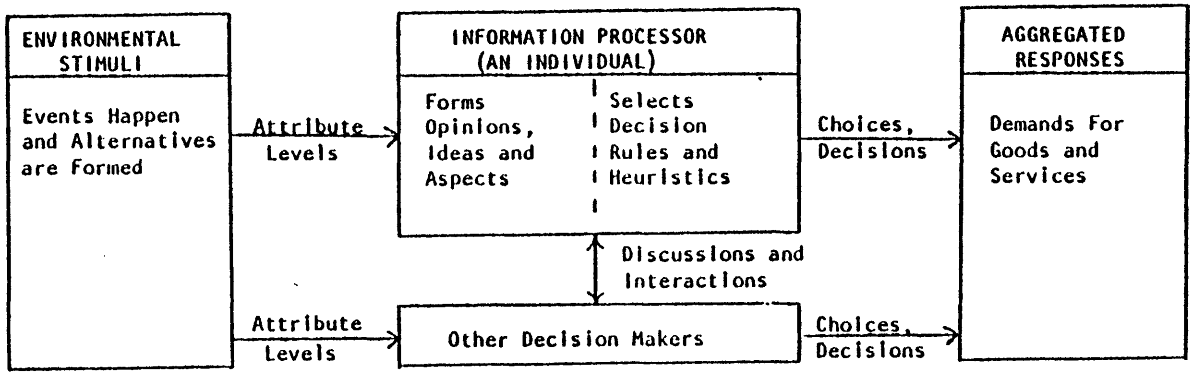
The first predictive models to be used (e.g. regression models) were developed from statistical relationships, correlations, between historical values of the predictors and the unknown (to be predicted) variable. The assumption was made that the relationships between the known and unknown variables would continue in the future to be the same as in the past. This allowed projections of future values of variables to be made. Regression models are still used extensively, especially for making predictions in disciplines where the underlying scientific, social, economic, or behavioral mechanism is insufficiently understood to itself be incorporated into a predictive model. However, in other fields, attempts have been made to create predictive models which incorporate the scientific theory about the process being modelled. These new predictive models have different inputs and outputs and are designed to model different stages of the decision process. An attempt will be made below to briefly list, describe and compare the various sorts of predictive models.

To better examine the differences between the many models which try to predict human activity, a framework of this activity is hypothesized as follows. The framework consists of six components: 1) Environmental stimuli, 2) Attribute levels, 3) Individual's state of mind, 4) Decision rules, 5) Choices of individuals, and 6) Aggregate response. Environmental stimuli include all events that occur and all alternatives that are formed which initiate a decision process. Quantitative scales used to measure or rate the alternatives are called "attributes." Examples are cost (dollars), size (feet), duration (days), and speed (meters per second). An individual's state of mind refers to his opinions, preferences, ideas and his own unwritten definitions of such qualitative aspects such as beautiful, good tasting, inexpensive, reliable and fair. An individual's state of mind is influenced by environmental stimuli, which are measured in attribute levels, and by discussions with other individuals. Decision rules refer to any of a number of heuristic procedures for analyzing information in order to make a choice among alternatives. For instance, selecting the alternative which performs the best on the most important attribute is a very simple and common decision rule.

It is assumed that every model of human decision making behavior requires at least one of the above components as an input and predicts or describes another component(s) as an output. Therefore, a quick way to compare different models is to examine their inputs and their outputs (see Figure 3.1).

Early models, such as regression models, required attribute levels as inputs and used trends found in time series and cross-sectional data to output predictions of aggregate responses thus ignoring the intervening decision stages including opinions, heuristics, and choices. These "black box" models make predictions solely on the basis of past data and are used in many fields when the underlying process is not sufficiently well understood to be modelled in detail. A step back from this large span from inputs to outputs occurred later when Multiattribute Utility Models, Linear Programming Models, and Choice Models were developed. These models, which use attribute levels as inputs and output individual choices, include explicit assumptions about human decision behavior (e.g. utility maximization).

Recently attempts have been made to model the decision process one step at a time to increase the accuracy of each step. Beginning with an input of environmental stimuli, several "one step" models would be linked together to finally output aggregated responses. Physical models require events as inputs and output attribute levels. Satisficing and Fuzzy Set Models require attribute levels as inputs and predict an individual's opinions and ideas. Unfortunately a "Processing Model," which can predict which heuristics or decision rules will be used given a person's state of mind and the nature of the decision problem, has only been alluded to in the literature (Svenson, 1979, and Slovic, 1977) and does not yet exist. Therefore, predicting an individual's choice given his state of mind



Model	Events	Attribute Levels	Opinions, Ideas, and Aspects	Decision Rules, & Heuristics	Choices, Decisions	Demands For Goods and Services
Physical Models	Input	Output				
Multiatt Util. Mod.		Input			Output	
Satisficing Model		Input	Output			
Fuzzy Set Model[1]		Input	Output			
Heuristic Models[2]			Input		Output	
Aggregation Models					Input	Output
Linear Prog. Models		Input			Output	
Regression Models		Input			Output[3]	Output[4]
Choice Models		Input			Output	
Processing Model[5]			Input	Output		

Figure 3-1. Comparison of Predictive Models by their Inputs and Outputs.
1) As described by Yager and Basson, (1975). 2) Models, such as EBA, which assume a priori that the decision maker will follow a particular heuristic 3) Regression model calibrated for an individual 4) Regression model calibrated for a population 5) Does not yet exist but alluded to by Svenson (1979) and Slovic (1977).

is currently done by choosing a priori a popular decision rule and then assuming that it is followed by the decision maker. Finally, aggregation models are used to predict societal choices given individual choices.

The interactions between individual decision makers are predicted by the theories of polarization (Meyers and Lamm, 1975), group utility (Keeney and Raiffa, 1976), game theory (Blackwell and Girshick, 1954; Bartos, 1967), and "groupthink" (Janis, 1975). Each uses individual choices or preferences as inputs and predicts what the group's choices or preferences will be after group discussions have been conducted. Although these interaction models do not appear in Figure 3.1 because their input and outputs are usually in the same column, the final aggregate responses are indeed influenced by such interactions.

Because choice models (including heuristic models) incorporate more behavioral postulates than other models, and because they require only limited and individual data which can be easily collected, they were selected to be used for the policy acceptance problem. A description of choice models appears below including a discussion of their assumptions, strengths and weaknesses.

3.2 Choice Models

3.2.1 Types of Choice Models

Choice models can be divided into two classes: 1) Prescriptive (optimization) models which prescribe the best choices for the decision maker, and 2) Descriptive (simulation) models which describe the choices made by the decision maker. Descriptive models can be further classified into 1) lumped parameter models versus conceptual models, and 2) deterministic models versus probabilistic models. A taxonomy of choice models appears in Figure 3.2. Several types of choice models are explained below.

The notation used in defining the models is as follows. Sets of alternatives are denoted by capital letters, such as A, and alternatives are denoted by small letters, such as x. $P(x;A)$ is the probability of choosing x from set A. $P(x;y)$ is an abbreviation for $P(x;\{x,y\})$, the probability of choosing x from the set $\{x,y\}$.

Utility Functions. Utility theory postulates that there is a utility function, U, defined on the set of alternatives $A = \{x,y,z,\ldots\}$. The chosen alternative is the one with the largest utility, i.e.,

$$P(x;A) = \begin{cases} 1 & \text{if } U(x) > U(y) \text{ for all } y \varepsilon A-x \\ 0 & \text{if otherwise.} \end{cases}$$

Note that traditional utility theory purports that as long as two alternatives, x and y, are indeed different, $x \neq y$, then they have different utilities, i.e., $P(U(x) = U(y)) = 0$.

Multiattribute utility (MAU) theory assumes that the alternatives are described by a set of quantitative attributes (such as price, length, etc.) and then seeks to define a utility function on the set of alternatives in terms of the attributes. For example, a simple additive MAU function can be written as

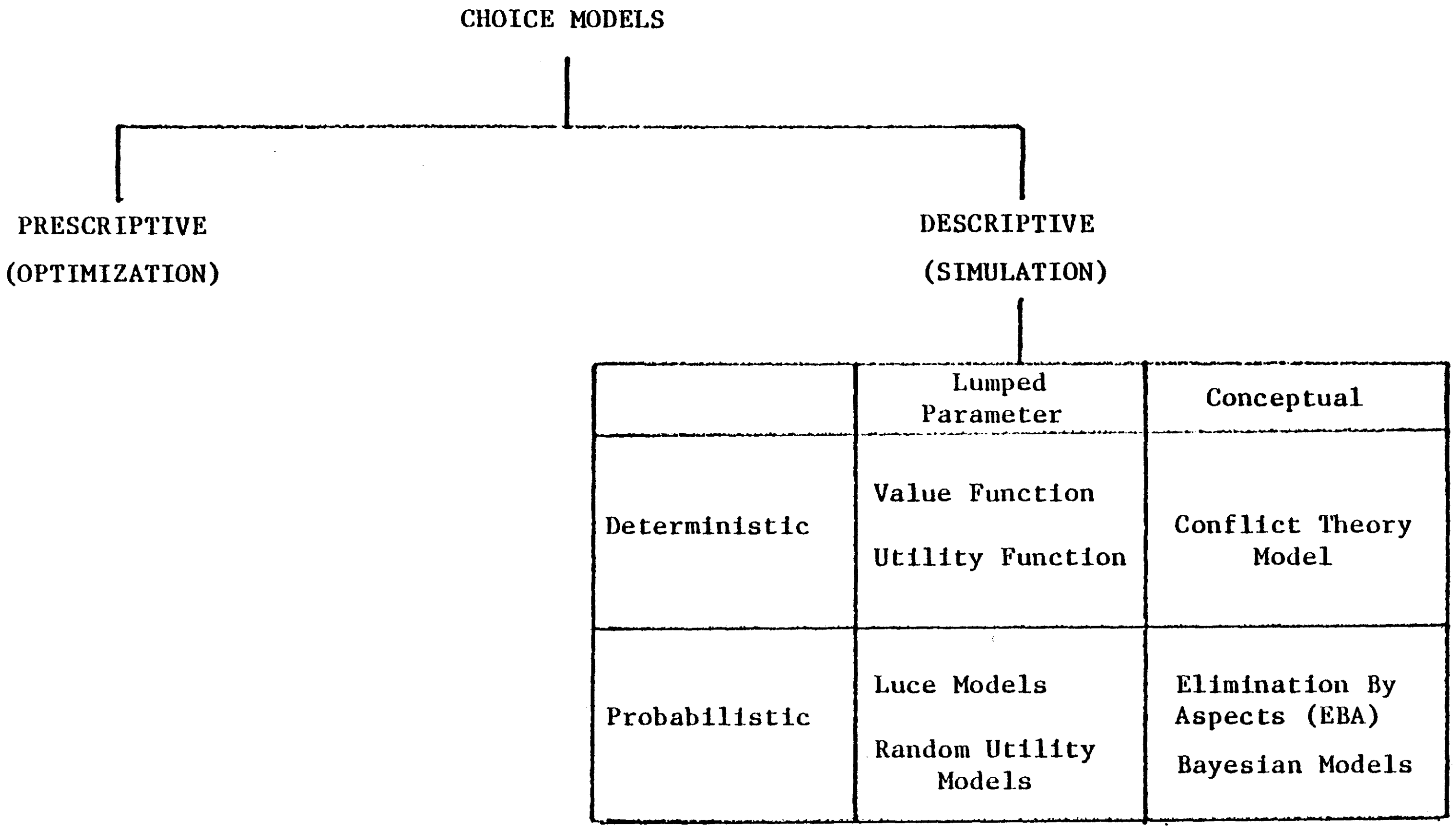
$$U(x) = k_a u_a(a_x) + k_b u_b(b_x) + \ldots$$

where $U(x)$ is the utility of alternative x,

$A'' = \{a,b,c,\ldots\}$ is the set of attributes,

$k_a, k_b, k_c, \ldots$ are coefficients of the attributes, and

$a_x, b_x, c_x, \ldots$ are the values of alternative x on attributes a,b,c,...



	Lumped Parameter	Conceptual
Deterministic	Value Function Utility Function	Conflict Theory Model
Probabilistic	Luce Models Random Utility Models	Elimination By Aspects (EBA) Bayesian Models

Figure 3.2 Taxonomy of Choice Models (from Krzysztofowicz, 1980).

$u_a(a_x)$ is the utility of a_x.

Research in MAU theory has dealt with assessing individuals' preferences in order to define the functional forms of u and to identify the coefficients, k. MAU models are then deterministic and use lumped parameters.

Random Utility Models. Random utility models attempt to explicitly account for the inconsistencies and intransitivities of human preference behavior by treating the utilities as random variables. The end result is that no longer does the model predict which alternative will be chosen but instead determines a probability with which each alternative will be chosen:

$$P(x;A) = P[U(x) \geq U(y)] \quad \text{all } y \varepsilon A-x.$$

This again assumes that $P[U(x) = U(y)] = 0$. Random utility models are then probabilistic and have lumped parameters.

General Random Utility Models. A simple relaxation of the $U(x) \neq U(y)$ restriction such that $P[U(x) = U(y)] > 0$ leads to a more general random utility model which has many interesting properties (Corbin and Marley, 1974). For instance, the decision process is considered to be sequential. At the first step, the decision maker subconsciously selects a utility function at random and then uses it to assign a utility to each alternative. He then rejects those alternatives which have less than the maximum utility and retains those which have tied for the maximum utility for further consideration. He then repeats the process, eliminating more alternatives until only one remains. The recursive choice probability equation is:

$$P(x;A) = \sum_{\phi \subset B \subseteq A} Q_A(B) \cdot P(x;B)$$

where $A = \{x,y,z...\}$ the set of alternatives,

B = a nonempty subset of A, and

$Q_A(B)$ = transition probability of moving from set A in one stage to subset B in the next stage, which equals the probability that the utilities of all elements of B are equal to each other and larger than the utilities of all elements of A-B.

Luce Models. A very intuitively appealing and simply stated probabilistic choice model was proposed by Luce (1959). He stated that the probability of choosing an alternative is directly proportional to the utility of the alternative relative to the utilities of all the alternatives, i.e.,

$$P(x;A) = \frac{U(x)}{\sum_{y \varepsilon A} U(y)} .$$

Several different forms of Luce's model can and have been developed which only differ in their definition of U. Three of these models, Logit, Probit, and Dogit, are presented below.

Logit models assume the following:

1. Additive Disturbances: $U_{nx} = V_{nx} + E_{nx}$

   where U_{nx} = utility of alternative x to individual n,
   V_{nx} = mean utility, observed,
   E_{nx} = random disturbance.

2. Linear and additive scales: $V_{nx} = \sum_{i=1}^{m} k_{in} a_{ix}$

   where m = number of attributes or "scales,"
   k_{in} = coefficient of scale i in individual n's utility function,

a_{ix} = value of alternative x on scale i.

3. Independent and Identically Distributed E_{nx} (iid) (for mathematical tractability).

4. E_{nx}'s have a Weibull (extreme value) Distribution: $P(E \leq w) = \exp(-\exp(-(\alpha+w)))$ with $\alpha = 0$.

The Logit model is then defined by

$$P_n(x;A) = P(U_{nx} \geq U_{ny}) \qquad x \neq y, \quad x,y,\varepsilon A .$$

Substitution of assumptions 1-4 above gives the final form

$$P_n(x;A) = \frac{e^{V_{nx}}}{\sum_{z \varepsilon A} e^{V_{nz}}} .$$

The Probit model employs assumptions 1-3 but assumption 4 states that the errors, E_{nx}, have a normal distribution, $E_{nx} \sim N(0, \sigma_n^2)$. For the two alternative case, define

$$U_{nx} = V_{nx} + E_{nx} \quad \text{and} \quad U_{ny} = V_{ny} + E_{ny}$$

also define

$$D_n = U_{nx} - U_{ny} \quad \text{and} \quad \Delta V_n = V_{nx} - V_{ny} .$$

Therefore D_n is distributed $N(\Delta V_n, \sigma_n^2)$. The Probit model is then defined as

$$P_n(x;y) = P(U_{nx} \geq U_{ny}) = P(U_{nx} - U_{ny} \geq 0)$$

$$= P(D_n \geq 0) = 1 - P(D_n < 0) .$$

Since D_n is normally distributed,

$$P_n(x;y) = 1 - \Phi(\Delta V_n/\sigma_n)$$

where

$$\Phi(z) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{z} e^{-(x^2/2)} dx.$$

The Dogit model (Gaudry and Dagenais, 1979) was developed from the Logit model in an attempt to avoid a major weakness of all Luce models, Independence from Irrelevant Alternatives, IIA (IIA is explained below in Section 3.2.3). Consequently, it is not a Luce model in the purest sense. The same assumptions, 1-4, are employed as in the Logit model but the functional form of the model is slightly different:

$$P_n(x;A) = \frac{e^{V_{nx}} + \theta_x \sum_{y\varepsilon A} e^{V_{ny}}}{(1 + \sum_{y\varepsilon A} \theta_y) \sum_{y\varepsilon A} e^{V_{ny}}}$$

A new coefficient θ_x is introduced and must be estimated.

Boolean Utility Models. A utility function which assigns a value of 0 or 1 to all alternatives is a Boolean Utility function. Consider such a function defined over each scale (attribute) used to measure the alternatives; V_i is the Boolean utility function for scale i. If a_{ix} is the value of alternative x on scale i, then

$$V_i(a_{ix}) = \begin{cases} 1 \text{ if } a_{ix} \text{ is within the acceptable range on scale i} \\ 0 \text{ if otherwise} \end{cases}$$

For instance, on scale i the acceptable range might be between 0 and a_i^*. A random Boolean utility model would then attempt to account for any randomness in the critical value, a_i^* which denotes the limit of the acceptable range. A distribution of a_i^* would be determined to define the Boolean utility:

$$P(V_i(a_{ix}) = 1) = P(a_{ix} \leq a_i^*).$$

Elimination By Aspects (EBA). According to the EBA model (Tversky, 1972a) each alternative is viewed as a set of aspects. At each stage in the decision process, the decision maker selects an aspect according to a given probability law and eliminates from further consideration all the alternatives which do not possess that aspect. The process continues until all alternatives but one are eliminated. The probability of selecting an aspect is proportional to the utility of the aspect. The model is expressible purely in terms of the choice alternatives without any reference to specific aspects. (Tversky, 1972a). The EBA model is thoroughly explained in Chapter 4.

3.2.2 Discussion of Choice Models

The first predictive models were regression models which used aggregate data to predict future levels of aggregate behavior. The models were often called "black box" models since they did not attempt to simulate the decision process, only fit the data with the best possible curve. The recent trend is toward 1) using disaggregate (individual) data, 2) accounting for the randomness of the utility functions, and 3) developing conceptual models of human decision making behavior. Slovic *et al*. (1977) in their review of behavioral decision theory state:

> Whereas past descriptive studies consisted mainly of rather superficial comparisons between actual behavior and normative models, research now focuses on the psychological underpinnings of observed

behavior.

In this research, the EBA model is selected since it accounts for the randomness of utility functions and presents a conceptual model of decision making behavior.

Different types of choice models have different data requirements and would be expected to perform better under different decision circumstances. It is postulated that Luce's model is best at predicting holistic decisions rather than sequential decisions made by following some heuristic. Other models, such as EBA, assume _a priori_ that a particular heuristic will be used and generate predictions based on that assumption. Theoretically, this class of heuristic choice models (as opposed to holistic choice models such as Luce, Logit, Probit, and Dogit) can be applied to problems when there is at least one decision maker, at least two alternatives, and at least two aspects which belong to the alternatives. However, if there are very few decision makers (farmers in this study), a predictive model is usually not needed. Similarly, one would suspect that while decision makers might rely on heuristics to quickly narrow down a large field of alternatives, they would be less likely to choose between a very small number of alternatives without doing a more complex tradeoff procedure. Finally, in order to use the heuristics, the decision makers need to know a substantial amount of information about the alternatives, i.e. such as which alternatives possess which aspects. Therefore the true power of heuristic choice models as predictors of human decision behavior occurs when there are:

1) many decision makers,
2) many distinct alternatives, and
3) many distinct and easily defined aspects of the alternatives.

It is therefore postulated that under these circumstances heuristic choice models perform the best and are the most valuable as an aid in decision making.

3.2.3 Problems of Application

Mixed Continuous and Discrete Variables. A necessary condition for using probabilistic choice models is that the decision variables be discrete, not continuous, so that distinct choices are available to the decision maker. When continuous alternatives do exist, they are subjectively discretized to create distinct choices. Also some of the alternatives may not be mutually exclusive. For instance, a GWMD may institute several groundwater policies such as well spacing, allocation, and pumping rotation as well as various surface water and farming policies simultaneously. Choice models can predict the acceptance of each policy individually or any combination of policies although the very large number of possible combinations of policies greatly increase the computations necessary to solve the models. Usually, therefore, a subset of all these possible alternatives would be examined instead. However, this approximation is not without some psychological basis. When faced with actual decisions, people frequently make similar truncations to restrict the number of alternatives they are faced with in order to simplify complex tasks.

Independence from Irrelevant Alternatives (IIA). IIA is a major weakness of the class of choice models called Luce models (see Section 3.2.1). Recall that according to Luce's model

$$P(x;A) = \frac{U(z)}{\sum\limits_{z \varepsilon A} U(z)} \text{ and } P(y;A) = \frac{U(y)}{\sum\limits_{z \varepsilon A} U(z)}.$$

The ratio of $P(x;A)/P(y:A) = U(x)/U(y)$. This ratio only depends on the utilities of x and y and not on any other alternatives. This means that if x is preferred to y in one context, it must be preferred to y in any other context. For a counter example, define the alternatives

x = allocation per irrigable acre

y = moratorium on new wells

and assume that $P(x;y) = .60$ and $P(y;x) = .40$ so that the ratio $P(x;y)/P(y;x) = 1.5$. Now if another additional alternative

z = allocation per irrigated acre

was available, models exhibiting IIA would still predict that the ratio $P(x;y,z)/P(y;x,z) = 1.5$. However, it is more likely that introducing alternative z would diminish x's chances but not y's. Therefore, one would expect something like $P(x;y,z) = .30$, $P(y;x,z) = .40$, and $P(x;y,z) = .30$. This leads to a ratio $P(x;y,z)/P(y;x,z) = .75$, contrary to IIA.

Choice modelling today is in a transition from the purely empirical models of the past to the highly behaviorally based models of the future. Choice theory, as represented by the models described above, has not yet achieved its final form. In an attempt to capture decision behavior in mathematical statements these models have entrained some weak assumptions (e.g., IIA and simple scalability). However clumsy, this transition is needed if decision theorists are ever to successfully incorporate the psychological basis of information processing into usable choice models. It is interesting to take a look at the current trend of developments in behavioral decision theory. Below is a discussion of information processing including an explanation of popular heuristics, biases, and their potential uses.

3.3 Information Processing

3.3.1 Psychological Basis of Choice Theory

Choice theory is in the process of maturing from the early days when MAU models were the state of the art. Slovic *et al.* (1977, p. 7) in their review of behavioral decision theory comment on the frustration of researchers attempting to discover the laws of preferential choice:

> The sense of frustration is understandable when one reviews recent research of choice. The field is in a state of transition, moving away from the assumption that choice probability is expressible as a monotone function of the scale values or utilities of the alternatives. Present efforts are aimed at developing more detailed, molecular concepts that describe choice in terms of information-processing phenomena. Researchers appear to be searching for heuristics or modes of processing information which are common to a wide domain of subjects and choice problems. However, they are finding that the nature of the task is a prime determinant of the observed behavior.

3.3.2 Popular Heuristics

When attempting to select the best alternative, decision makers frequently employ one or more simple decision rules or "heuristics." The purpose of these is to establish an efficient procedure for quickly reaching an easily defendable decision without relying on computations or complex tradeoffs. Although these heuristics often lead to suboptimal decisions, that sacrifice is constantly being made by decision makers in order to avoid the pressure and aggravation associated with making decisions. Svenson (1979) compiled a listing of decision rules which appears in Table 3.1.

3.3.3 Biases

Tversky and Kahneman (1974) examined many of the heuristics people use to simplify decisions and revealed a number of misconceptions and biases caused by these heuristics.

Representativeness. Under this heuristic, people judge the probability that object (event) A belongs to class B based on the degree to which A resembles B. If A is highly representative of (i.e., similar to) B then the probability that A belongs to class B is judged to be high. This leads to the following biases:

1) Insensitivity to prior probability of outcomes. In other words, base rate probabilities are neglected.
2) Insensitivity to sample size. Intuitive judgments are dominated by the sample proportion even though a small sample may have little statistical significance.
3) Misconceptions of chance. Chance is thought of as a self-correcting process whereby a deviation in one direction induces a deviation in the other direction to restore equilibrium.
4) Illusion of validity (overconfidence). The confidence people have in a prediction depends primarily on the degree of representativeness with little regard for factors that limit predictive accuracy.

Table 3.1 Popular Heuristics (Svenson, 1979)

Dominance Rule. Alternative A should be chosen over B if A is better than B on at least one attribute and not worse than B on all other attributes.

Conjunctive Decision Rule. At each stage, a set of thresholds is specified on the attributes each alternative must meet or exceed. Those which do not meet all the thresholds are dropped. The process continues until only one alternative remains.

Disjunctive Decision Rule. The mirror image of the Conjunctive Decision Rule, a chosen alternative must exceed the thresholds on at least one attribute while all other alternatives only equal or subceed the criteria.

Lexicographic Decision Rule. The chosen alternative is the most attractive on the most important attribute. In the case of a tie, the next most important attribute is considered, etc.

Elimination By Aspects Rule. At each stage, an aspect is selected and those alternatives which do not possess that aspect are eliminated. The process continues until only one alternative remains.

Minimum Difference Lexicographic Rule. This works the same as the lexicographic rule but a minimum difference, D_i for attribute i, is established. Differences between alternatives of less than D_i are ignored.

Maximizing Number Of Attributes With Greater Attractiveness Rule. The alternative with the largest number of favorable attributes is chosen.

Elimination By Least Attractive Aspect Rule. At each stage, the alternative with the worst overall aspect is eliminated.

Choice By Most Attractive Aspect Rule. The alternative with the overall most attractive aspect is chosen.

Choice By Greatest Attractiveness Difference Rule. The decision maker finds the attribute with the greatest attractiveness difference and then chooses the alternative which is the best on this attribute. This rule may be seen as an analog to the minimax regret principle in game theory.

Addition Of Utilities Rule. The alternative with the greatest summation of the utilities of its aspects is chosen.

Addition Of Utility Differences Rule. The decision is based on the differences between the utilities of different alternatives on the same attributes. The alternative with the greatest sum of these is chosen.

Subjective Expected Utility Rule. When summing the utilities of the aspects, each is weighted by the subjective probability of its occurrence and the alternative with the greatest expected utility is chosen.

(From: Svenson, O., Process Descriptions of Decision Making, Organizational Behavior and Human Performance, (23), p. 86-112, 1979).

5) Misconceptions of regression. People do not recognize regression toward the mean in situations where it is bound to occur (such as the intelligence of the child of two very intelligent parents) and when they are faced with it they often invent spurious causal explanations for it.

<u>Availability</u>. Following this heuristic, people judge the probability of an event by the ease with which occurrences can be brought to mind. If all classes of events were equally likely to be remembered then the availability heuristic would produce unbiased judgments. Since availability is affected by things other than probability and frequency, the following biases occur.

1) Biases due to the retrievability of instances. Vivid memories receive a higher probability of occurrence than equally likely, but forgotten memories.
2) Biases due to the effectiveness of a search set. Events which can be readily identified by an efficient search procedure are judged to be more likely than events which are harder to identify.
3) Biases of imaginability. The likelihood of occurrence of events which are hard to imagine (do not come into mind) is underestimated. Since risks in many undertakings are assessed by imagining contingencies with which the project is not equipped to cope this bias is very prevalent in peoples' perception of safety or danger.
4) Illusory correlation. Overestimating the correlation

between two events biases upward the subjective probability of occurrence of such events.

Anchoring and Adjustment. Often people make estimates by starting with an initial value and making adjustments. The initial value could be suggested by the problem itself or simply be their "first guess." The typical result is that the adjustments are insufficient, hence this phenomenon of "anchoring" leads to the following biases.

1) Insufficient adjustment. Different initial values lead to different final estimates.
2) Biases in evaluating conjunctive and disjunctive events. People tend to overestimate the probability of conjunctive events and underestimate the probability of disjunctive events.
3) Anchoring in the assessment of subjective probability distributions. People (weathermen excepted) typically grossly underestimate the size of the tails of distributions.

The biases caused by various heuristics and the inability to predict which heuristic(s) will be followed by the decision maker complicates the task of modelling information processing behavior. Choice models must be flexible enough to correctly predict behavior over a wide range of decision rules and biases. Sequential elimination models show promise for having this necessary flexibility.

3.3.4 Elimination Procedures

Several probabilistic choice models have been invested based on a sequential decision process. At each stage the decision maker eliminates one or more alternatives from the available set according to some decision rule and this process continues until only one alternative remains. Three such elimination models are the EBA model, the General Random Utility Model (GENRUM), and the Discard Model. EBA and GENRUM are explained above in Section 3.2.1. The Discard Model (Marley, 1965) is based on the regularity condition whereby the probability of choosing an alternative from any set is at least as great as the probability of choosing it from any of its supersets; i.e., regularity holds if

$$P(x;A-\{y\}) \geq P(x;A) \quad \text{all } x,y \varepsilon A,\ y \neq x.$$

The Discard model holds if there exists a set of discard probabilities, $Q_A(y)$, such that the probability of choosing an alternative from a set equals the weighted sum of the probabilities, $P_{A-\{y\}}(x)$, of choosing it from subsets generated by discarding single alternatives from the given set A:

$$P(x;A) = \sum_{y \varepsilon A-\{x\}} Q_A(y)\ P(x;A-\{y\})$$

where $Q_A(y)$ is the probability of discarding alternative y from set A. Note that $\sum_{y \varepsilon A} Q_A(y) = 1$. These discard probabilities serve as the weighting factors in the recursive choice probability equation.

3.3.5 Thresholds and Fuzziness

A drawback of traditional utility theory is the assumption that a precise utility function exists which can assign each unique alternative a unique utility value, i.e., $U(x) \neq U(y)$ if $x \neq y$. Trying to assess such precise utility functions researchers often found grey areas of indecision and outright inconsistencies among their subjects. This lead to view the utilities as random variables and hence the development of random utility models. Other researchers decided to break away from the strict, traditional view of utility and created models which allow the decision makers to have less precise (not less accurate) utility functions, i.e., $P[U(x) = U(y)] > 0$ for $x \neq y$. Four different models which allow for some slack in the utility functions are summarized below.

General Random Utility Model. As previously described in Section 3.2.1, this model (Corbin and Marley, 1974) allows for non-unique utilities. At each stage of the sequential decision process, those alternatives tied for having the highest utility are retained and the rest are eliminated. In this model, different alternatives may have equal utility.

Threshold of Indifference. Krishnan (1977) used a different approach by retaining the traditionally precise utility functions but changing the definition of indifference. Two alternatives can receive different utilities but the decision maker is indifferent between them unless the difference exceeds some "minimal perceivable difference, MPD." Krishnan introduced this MPD criterion into a conventional binary logit model and noted significantly better predictive capabilities.

Choice Between Equally Valued Alternatives. Slovic (1975) acknowledged the possibility that two or more alternatives may be of equal value to the decision maker and proposed and tested a decision rule whereby the alternative which performs the best on the most important attribute is chosen. His results verify this hypothesis and lend further support to Tversky's (1972a) theory that people follow choice mechanisms (like EBA) which are easy to explain and justify in terms of a priority ordering on the aspects (Slovic, 1975).

Fuzzy Set Theory. A major premise of utility theory is that the many different attributes which describe alternatives can be incorporated into a single function which assigns a utility value. Zadeh's (1973) "Principle of Incompatibility" states that as the complexity of a situation increases it becomes more difficult to make both precise and significant statements about it until precision and significance are almost mutually exclusive. When the goals and/or constraints of a choice problem are vague and ill defined the Theory of Fuzzy Sets is useful in modelling the decision (Yager and Basson, 1975). Consider the set of alternatives $A = \{x,y,z\}$. A fuzzy subset, $\bar{a}$, of A is characterized by a membership function $U_{\bar{a}}(A)$ where $U_{\bar{a}}$ maps A to the set of Real numbers $[0,1]$. $\bar{a}$ could be considered to be an attribute such as efficiency. The larger $U_{\bar{a}}(x)$, the stronger the degree of membership of alternative x in $\bar{a}$. If x, y, and z had efficiencies of 50%, 75%, and 20% respectively, then a possible fuzzy subset $\bar{a}$ could be

$$\bar{a} = \{\frac{.2}{x}, \frac{.5}{y}, \frac{0}{z}\}.$$

Note that any functional form of $U_{\bar{a}}$ can be used as long as it does not change the ordinal relationship of the alternatives. Suppose another membership function, $U_{\bar{b}}$, representing the attribute of reliability gave another fuzzy subset

$$\bar{b} = \{\frac{.7}{x}, \frac{.3}{y}, \frac{.5}{z}\}.$$

If the goal was to choose the alternative with both efficiency and reliability then a set $\bar{c}$ would be created from $\bar{a}$ and $\bar{b}$ where

$$U_{\bar{c}}(A) = U_{\bar{a} \cap \bar{b}}(A) = \min[U_{\bar{a}}(x),\ U_{\bar{b}}(x)] \quad \text{all } x \varepsilon A.$$

Therefore

$$\bar{c} = \bar{a} \cap \bar{b} = \{\frac{.2}{x}, \frac{.3}{y}, \frac{0}{z}\},$$

and alternative y would be chosen since it has the strongest degree of membership in set $\bar{c}$. This is similar to a maxi-min principle.

Consequently if the goal was to select an alternative which was efficient or reliable, then a set $\bar{d}$ could be created where

$$U_{\bar{d}}(A) = U_{\bar{a} \cup \bar{b}}(A) = \max[U_{\bar{a}}(x),\ U_{\bar{b}}(x)] \quad \text{all } x \varepsilon A.$$

Therefore

$$\bar{d} = \bar{a} \cup \bar{b} = \{\frac{.7}{x}, \frac{.5}{y}, \frac{.5}{z}\}$$

and alternative x is chosen (Yager and Basson, 1975).

3.4 Sequencing of Models and Heuristics

The future of predictive modeling lies not just in identifying the above heuristics and biases, but also in determining when they are used. One reason why assessing utility functions and designing choice models is a difficult task is that people often employ several different heuristics and schemes and switch back and forth between them in mid-decision. Wright and Barbour (1977) postulated that a decision process initially consists of a screening phase where a conjunctive rule may be used, followed by a second phase where any one of a number of decision rules may be employed. Svenson (1979) found that the decision maker may use different decision rules in arriving at a decision but may also use the same rule repeatedly while changing the criterion levels during the information search. Research is now being done to draw correlations between the nature of the decision problem (i.e., how many attributes, how many alternatives, the importance of the decision, time constraints, etc.) and decision rules used by the decision maker. Therefore, one future development in choice theory may well be the linking of heuristics in succession to model human decision making behavior. Finally, the future development of processing models as described in Section 3.1 will help analysts to link several "one step" models together to more accurately predict human behavior.

CHAPTER 4

EBA CHOICE MODEL

4.1 Explanation of Tversky's EBA Model

Tversky (1972a) designed the EBA model around several fundamental hypotheses concerning human information processing and choice behavior. First, humans think of alternatives in terms of various aspects which each alternative may or may not possess. In this study, aspects are defined as qualities of alternatives such as affordability, or convenience, or beauty, and each alternative is considered by the decision maker to either have or not have a particular aspect.

For example, consider the following groundwater policy alternative which a district manager is considering to adopt: A specific groundwater allocation per well for a 1-year time period such that the groundwater supply lasts 40 years. This alternative may be considered by the farmers to possess the aspects such as:

α_1 no additional uncertainty about water availability is created by the policy,

α_2 the policy is effective in stretching the existing water supply,

α_3 compliance is inexpensive,

α_4 the policy permits old farming practices to continue.

But this alternative may not be considered by the farmers to possess the aspects such as:

α_5 the policy is fair and treats all farmers equally,

α_6 the policy is effective in halting groundwater mining,

α_7 compliance is convenient,

α_8 no invasion of the privacy of the farmer by meter readers or inspectors will result,

α_9 the policy will not reduce short-term farm outputs.

Second, some of the aspects are more important than others. Third, when a human is to choose one alternative from a set of alternatives, he first selects one aspect and eliminates from further consideration all alternatives which do not possess that aspect. He then selects another aspect and eliminates those alternatives which do not possess that aspect. The process continues until only one alternative remains. If an aspect is common to all the alternatives, then no alternative can be eliminated for not possessing it. Therefore, only aspects which are not possessed by all alternatives influence the decision.

Define the following notation which will be used to develop the EBA model:

T = Set of all alternatives.

$A = \{x_1, x_2, .., x_g, .., x_m\}$ = Set of alternatives available to the decision maker. Note $A \subseteq T$.

$A' = \{\alpha_1, \alpha_2, .., \alpha_i, .., \alpha_n\}$ = Set of aspects possessed by alternatives in A.

A^o = Set of aspects common to all alternatives in A.

$A\alpha_i$ = Set of all alternatives in A which possess aspect α_i.

x_g' = Set of aspects possessed by alternative x_g.

V_g = Possession function defined on each alternative.

$$V_g(\alpha_i) = \begin{cases} 1 \text{ if alternative } x_g \text{ possesses aspect } \alpha_i, \\ \text{i.e., if } \alpha_i \epsilon x_g', \\ 0 \text{ if otherwise.} \end{cases}$$

B_k, B_ℓ, and B_o = Proper subsets of alternatives.

g,h = Subscripts for alternatives.

i,j = Subscripts for aspects.

k,ℓ,o = Subscripts for subsets of alternatives.

m = Number of alternatives in A.

n = Number of aspects in A'.

$u(\alpha_i)$ = The importance of aspect α_i (also called the utility of aspect α_i).

It is presumed that the decision maker selects an aspect according to a given probability law. The probability of selecting an aspect is proportional to the relative importance of that aspect:

$$P(\alpha_i;A'-A^o) = \frac{u(\alpha_i)}{\sum_{\alpha_j \epsilon A'-A^o} (\alpha_j)}$$

The recursive choice probability equation for the EBA model is:

$$P(x_g;A) = \frac{\sum_{\alpha_i \epsilon x_g'-A^o} u(\alpha_i)\ P(x_g;A\alpha_i)}{\sum_{\alpha_j \epsilon A'-A^o} u(\alpha_j)}$$

where $P(x_g;A)$ is the probability of selecting alternative x_g from the set of available alternatives, A.

Using the same definitions the Luce model of choice probabilities for $x_g \epsilon A$ is:

$$P(x_g;A) = \frac{\sum\limits_{\alpha_i \varepsilon x'_g} u(\alpha_i)}{\sum\limits_{x_h \varepsilon A} \sum\limits_{\alpha_j \varepsilon x'_h} u(\alpha_j)}$$

Figure 4.1 provides a simple example problem in order to graphically explain the EBA and Luce models. Notice that according to the EBA model, the probability of choosing alternative x_1 or x_2 does not depend at all on their common aspect, α_2. However, in Luce's model, aspect α_2 is a factor in the decision.

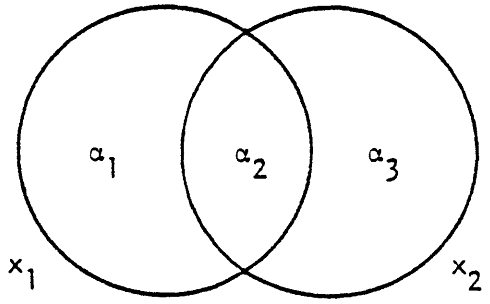
Tversky's EBA model does not necessarily have to be formulated in terms of the utility function, u, defined over the set of aspects. The EBA model can be formulated purely in terms of subsets B_k and B_ℓ where $B_k \subset T$ and $B_\ell \subset T$. If B_k is a subset of T, then define $\bar{B}_k$ as the set of aspects unique to subset B_k, i.e., which belong to every alternative in B_k and to no other alternatives. The major premise of the EBA model is that the decision maker distinguishes between alternatives solely on the basis of differences in the sets of aspects they possess and that the selection of an alternative is based on its "unique advantages." The unique advantage of a set of alternatives, B_k, is defined as the sum of the utilities of the aspects included in $\bar{B}_k$:

$$U(\bar{B}_k) = \sum_{\alpha_i \varepsilon \bar{B}_k} u(\alpha_i)$$

The recursive choice probability equation of the EBA model can therefore be expressed purely in terms of alternatives as (Tversky, 1972a):

$$P(x_g;A) = \frac{\sum\limits_{B_k \supseteq A} U(\bar{B}_k) \cdot P(x_g;A \cap B_k)}{\sum\limits_{B_\ell \cap A \neq A, \phi} U(\bar{B}_\ell)}$$

Example Problem:



EBA Model

In the Example:

$$P(x_1;x_2) = \frac{u(\alpha_1)}{u(\alpha_1)+u(\alpha_3)}$$

$$P(x_2;x_1) = \frac{u(\alpha_3)}{u(\alpha_1)+u(\alpha_3)}$$

In General:

$$P(x_g;A) = \frac{\sum_{\alpha_i \varepsilon x'_g - A^o} u(\alpha_i)\ P(x_g;A\alpha_i)}{\sum_{\alpha_j \varepsilon A' - A^o} u(\alpha_j)}$$

Luce Model

In the Example:

$$P(x_1;x_2) = \frac{u(\alpha_1)+u(\alpha_2)}{u(\alpha_1)+2u(\alpha_2)+u(\alpha_3)}$$

$$P(x_2;x_1) = \frac{u(\alpha_2)+u(\alpha_3)}{u(\alpha_1)+2u(\alpha_2)+u(\alpha_3)}$$

In General:

$$P(x_g;A) = \frac{\sum_{\alpha_i \varepsilon x'_g} u(\alpha_i)}{\sum_{x_h \varepsilon A} \sum_{\alpha_j \varepsilon x'_h} u(\alpha_j)}$$

Where:

$u(\alpha_i)$	The importance (utility) of aspect α_i.
$A = \{x_1, x_2, .., x_3, ... x_m\}$	Set of alternatives.
$A' = \{\alpha_1, \alpha_2, .., \alpha_i, ... \alpha_n\}$	Set of aspects of alternatives in A.
A^o	Set of aspects common to all alternatives.
$A\alpha_i$	Set of alternatives which contain α_i.
x'_g	Set of aspects belonging to alternative x_g.
$P(x'_g;A)$	Probability of choosing alternative x_g from the set A.

Figure 4.1 Explanation of EBA and LUCE Models.

4.2 Distinctions Between the EBA and Luce Models

4.2.1 Assumptions About the Locus of Uncertainty

Tversky (1972b) classifies models into 1) random utility models, 2) constant utility models, and 3) elimination models. Random utility models assume that the utility of each alternative is subject to random fluctuations and that the alternative which has the highest utility at the time of the decision is chosen. Constant utility models assume that the utility of each alternative is known to the decision maker and does not fluctuate randomly. The uncertainty is then attributed to the process by which the decision maker uses this information to reach a decision. Elimination models propose processes in which the decision maker proceeds through a sequence of decision stages, drawing on his preferences at each stage in order to move to the next stage. Uncertainty in elimination models is attributed to random fluctuations in preferences which determine the transition from one decision stage to the next.

These different assumptions about the locus of uncertainty lead directly to different psychological interpretations of the decision process. In a constant utility model, it is assumed that repeated assessments of an individual's utility function would yield the same result (constant utility). Therefore, the decision maker's choice is probabilistic only because it is uncertain how he uses this information to reach a decision, i.e., he may not follow a utility maximizing decision rule. Random utility models assume that the decision maker does always choose the alternative with the highest utility but that he may change his mind about which alternative that is. Elimination models attempt to avoid the uncertainty as to which decision rule is used to process the preference information by adopting one rule and assuming that that is the one followed by the decision maker. Their predictive accuracy is then dependent on the extent to which the decision maker actually follows that decision rule.

4.2.2 Assumptions About the Structure of Alternatives

A second distinction between the EBA and Luce models is that only aspects which are not common to all alternatives enter the EBA model. Luce's model includes these common aspects since each alternative is judged on its total utility, not just its unique advantage. Because of this distinction care must be taken when applying choice models to structure the alternatives to fit the model desired or choose a model compatible with the given alternatives. Figure 4.2 presents a comparison of the EBA and Luce models to illustrate this distinction. The top figure depicts two alternatives with no aspects in common in which case the choice probabilities are the same for both models. As the alternatives begin to have more aspects in common, the EBA model increases the probability of choosing x_1, the alternative with the largest unique advantage. In the bottom figure, alternative x_2 is totally dominated by alternative x_1, i.e., only x_1 has a unique advantage. The EBA model now predicts that the probability of choosing x_1 is 1.00 and the probability of choosing x_2 is 0.00 which is what one would expect the true probabilities to be. However, the choice probabilities predicted by Luce's model have not changed throughout. Clearly this property of Luce's model restricts the applicability of the model and

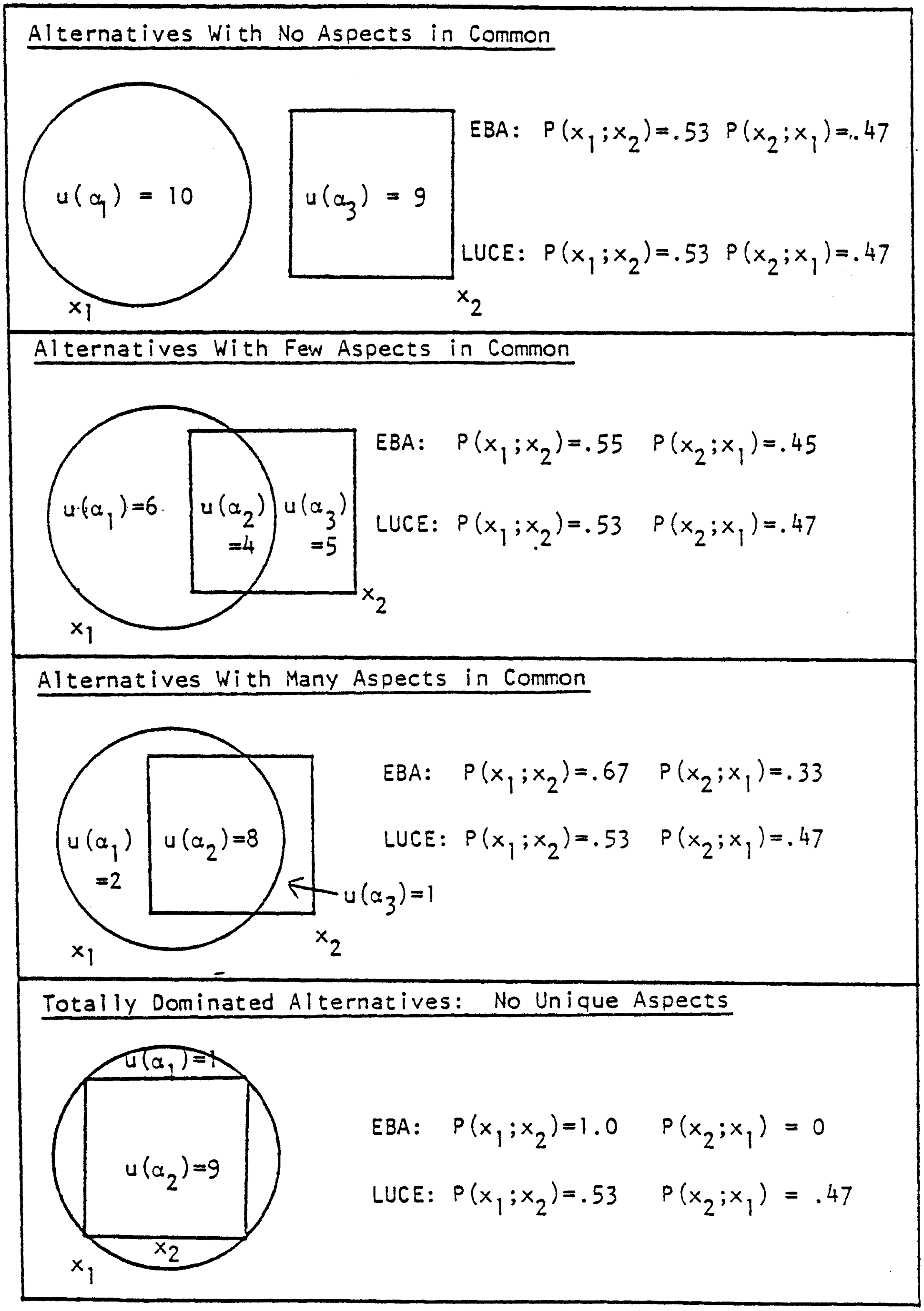


Figure 4.2 Comparisons of EBA and LUCE Models.

care must be taken to keep the alternatives as distinct or different as possible when applying Luce's model. In Figure 4.2, Luce's model is appropriate only in the top figure, where the alternatives have no aspects in common.

Obtaining accurate predictions with Luce's model requires that the alternatives be unitary entities, which are aspect-wise disjoint (distinct and non-overlapping). The choice process corresponding to Luce's model is then elementary (holistic), i.e., the decision is not decomposed into a sequence of sub-decisions. Instead, a single alternative is selected and all others are eliminated simultaneously. On the other hand, the EBA model corresponds to choices from among composite alternatives which are aspect-wise conjoint (share the same aspects). The EBA choice process then assumes that the decision is complex and is decomposed into a series of sub-decisions which are made in a probabilistic sequence until a single alternative is chosen (Krzysztofowicz, 1980).

4.2.3 Simple Scalability versus Regularity

Underlying most of the theoretical work in choice theory (including Luce's) is the assumption of "simple scalability," whereby alternatives can be scaled so that the choice probability of each is expressible as a monotone function, F_m, of the scale values of the respective alternatives, i.e.,

$$P(x_g;A) = F_m[u(x_1),u(x_2),\ldots,u(x_g),\ldots,u(x_m)]$$

where F_m is strictly increasing in the first argument and strictly decreasing in the remaining m-1 arguments provided $P(x_g,A) \neq 0,1$. A strong testable consequence of the simple scalability assumption is:

For every $x_1, x_2 \varepsilon A$, $P(x_1;x_2) \geq 1/2$ iff $P(x_1;A) \geq P(x_2;A)$

provided $P(x_2;A) \neq 0$.

In other words, the ordering of x_1 and x_2 by choice probability is independent of the offered set. Therefore if x_1 is preferred to x_2 in one context, then x_1 is preferred to x_2 in any context. Simple scalability is a general formulation of the notion of Independence from Irrelevant Alternatives (Tversky, 1972a).

Luce's model is a special case of the simple scalability assumption which displays Independence from Irrelevant Alternatives. Recall that according to Luce's model,

$$\frac{P(x_1;A)}{P(x_2;A)} = \frac{u(x_1)}{u(x_2)}$$

whereby the ratio of the choice probabilities of x_1 and x_2 is independent of all other alternatives. In fact the ratio is assumed to be a constant. This "constant ratio rule" is an easily testable consequence of Luce's model and is widely objected to in the literature (Debreu, 1960; Chipman, 1960; Krantz, 1967; Tversky, 1972a) even by those who have employed Luce's model in their research (Gaudry and Dagenais, 1979; Ben-Akiva, 1977; McFadden, 1978). In contrast to the constant ratio rule of Luce's model, the EBA model is founded on the assumption of regularity and implies a stronger form called the similarity hypothesis. Regularity states that:

For all $x_1 \varepsilon A \subseteq B$, $P(x_1;A) \geq P(x_1;B)$.

That is, the probability of choosing an alternative cannot be increased by enlarging the offered set. (Regularity will be discussed more later.) An implication of the elimination by aspects decision process is that if one alternative is eliminated because it does not possess the selected aspect, then other, similar alternatives, are also likely to be eliminated, i.e., similar with respect to which aspects they possess. Therefore, EBA predicts that similar alternatives diminish each others' chances of being chosen, i.e., the similarity hypothesis.

Since simple scalability and the constant ratio rule do not hold in general, care must be taken to only use Luce's model when the alternatives are not similar but are instead distinctly different (aspect-wise disjoint). The EBA model is not limited by this restriction but allows the alternatives to be comprised of many aspects which may be shared by several alternatives. In the next chapter, it is proposed that there are at least nine aspects of the water conservation policy alternatives. Several of these aspects are shared by many of the alternatives and several are shared by very few alternatives. Hence the EBA model should be better suited to model water conservation policy acceptance than the Luce model.

4.3 Adapting the EBA Model

A problem faced by every modeler of human decision making is to devise a method to incorporate the decision maker's opinions and preferences into a quantitative, mathematical model, especially when those opinions are often fuzzy and undergo random fluctuations. The EBA model requires that the alternatives be viewed as collections of aspects.

Although many possible definitions exist for "aspects," it is herein assumed that aspects are defined simply as desirable qualities possessed by alternatives, such as fairness or convenience. Since the meaning of fairness or convenience or any other aspect is quite subjective, the analyst cannot always determine which aspects are characteristic of which alternatives. This is highly a matter of opinion, and a survey of the population being modelled or interviews with experts are necessary to resolve this problem. In adapting the EBA model, a "Possession Function," V_g, is introduced such that

$$V_g(\alpha_i) = \begin{cases} 1 \text{ if alternative } x_g \text{ possesses aspect } \alpha_i, \\ \quad \text{i.e., if } \alpha_i \in x_g' \\ 0 \text{ if otherwise.} \end{cases}$$

In adapting and simplifying the EBA model, the set of all alternatives, T, is considered irrelevant and is ignored. Only the set A, all alternatives available to the decision maker is used. Thus, where Tversky (1972a) defined $B_k \subset T$, it is now defined as $B_k \subset A$. The possession function for a set of alternatives B_k, where $x_g \in B_k \subset A$, is constructed from the possession functions of the alternatives in the set:

$$V_{ik} = \prod_{x_g \in B_k} V_g(\alpha_i)$$

Notice that the possession function, V_{ik}, of a set $B_k \subset A$ is one if and only if the possession functions of all $x_g \in B_k$ are also one for aspect α_i.

The relative importance or weight of each aspect is then defined by the farmer through an assessment procedure:

$u(\alpha_i)$ = importance to the farmer of an alternative possessing aspect α_i (also called the utility of aspect α_i).

For instance, if α_i was an aspect representing fairness, then $u(\alpha_i)$ could be interpreted to mean: the importance which the farmer attaches to the aspect of fairness. Similarly, the importance of all other aspects is defined by their respective weights. With V_g and u defined it is possible to formulate an additive utility function for the set A:

$$U(x_g) = \sum_{i=1}^{n} u(\alpha_i)\cdot V_g(\alpha_i) \quad \text{for all } x_g \varepsilon A$$

A simple Luce model can be constructed using this additive utility function:

$$P(x_g;A) = \frac{U(x_g)}{\sum\limits_{X_h \varepsilon A} U(x_h)} = \frac{\sum\limits_{i=1}^{n} u(\alpha_i)\cdot V_g(\alpha_i)}{\sum\limits_{h=1}^{m} \sum\limits_{i=1}^{n} u(\alpha_i)\cdot V_h(\alpha_i)}$$

The numerator in this Luce model sums up the weights of all aspects possessed by alternative x_g whether or not they are unique to x_g or shared by some or all other alternatives. In Tversky's EBA model, all such "common" (shared by all alternatives) aspects are ignored. The possession function defined on the alternatives and the weights assigned to the aspects can be combined in such a way as to use only the unique advantages in the calculation of the choice probabilities. If $U(\bar{B}_k)$ is defined to be the unique advantage of the subset $B_k c A$, then

$$U(\bar{B}_k) = \sum_{i=1}^{n} u(\alpha_i)\cdot K_{ik}$$

where

$$K_{ik} = V_{ik}\cdot \prod_{B_\ell \not\subset B_k} (V_{ik}-V_{i\ell}).$$

Note

$$K_{ik} = \begin{cases} 1 \text{ if and only if aspect } \alpha_i \text{ is unique to subset } B_k \\ 0 \text{ otherwise.} \end{cases}$$

Since $B_k \subset A$, $U(\bar{B}_k)$ represents the conditional unique advantage of subset B_k given the offered set A. As one proceeds through the EBA strategy, i.e., through the recursive equation, the value of $U(\bar{B}_k)$ changes as the offered set shrinks. Recall that in Tversky's model, (Section 4.1), $B_k \subset T$ thus $U(\bar{B}_k)$ is constant. The recursive equation for choice probabilities for this adapted EBA model can be presented as:

$$P(x_g;A) = \frac{\sum\limits_{B_k \subset A} U(\bar{B}_k)\cdot P(x_g,B_k)}{\sum\limits_{B_\ell \subset A} U(\bar{B}_\ell)}$$

Although it is expressed slightly differently, this adapted EBA model yields the same choice probabilities as Tversky's EBA model (Section 4.1).

4.4 Assumptions and Consequences

Tversky's original model encompasses two major assumptions: general scalability and the EBA strategy. In addition it is herein assumed that the possession function can be defined for each alternative.

General scalability is the representation of choice alternatives in terms of subsets of T, the total set of alternatives. General scalability is said to hold if there exists a scale U defined on 2^T (i.e., the set of subsets of T) and functions F_m, $2 \leq m \leq t$, such that for all $x_g \varepsilon A \subseteq T$,

$$P(x_g;A) = F_m(U[p(x_g;A,1)],U[p(x_g;A,2)],\ldots,U[p(x_g;A,2^t)]),$$

where m and t denote, respectively, the cardinality of A and T, and $p(x_g;A) = [p(x_g;A,1),\ p(x_g;A,2),\ldots,p(x_g;A,2^t)]$ is a permutation of 2^T.

It is further assumed that, for all $p(x_g;A) \neq 0,1$, (i) F_m increases in each argument $U[p(x_g;A,i)]$, $i=1,\ldots,2^t$, such that $A \cap p(x_g;A,i)$ is $\{x_g\}$ (ii) F_m decreases in each argument such that $A \cap p(x_g;A,i)$ is nonempty and does not include $\{x_g\}$ and (iii) F_m is constant in each argument such that $A \cap p(x_g;A,i)$ is either empty or equal to A.

Translated into the language of aspects the above assumption states that F_m increases with the value of aspects that belong to x_g and to no other alternative of A; F_m is independent of aspects that do not belong to any of the alternatives of A, or belong to all of the alternatives of A. Thus, general scalability asserts that any choice probability $P(x_g;A)$ is expressible as a function F_m of the scales values associated with the subsets of T. Note that F_m takes as arguments all the scale values of the subsets of T; x_g and A enter into the equation by determining a permutation $P(x_g;A)$ of 2^T, i.e., an ordering of the arguments of F_m.

If F_m is further constrained so that it depends only on subsets containing a single alternative, then general scalability reduces to simple scalability (Tversky, 1972b).

Several consequences of the EBA model are the following:

1. Regularity and the Similarity Hypothesis,
2. Moderate Stochastic Transitivity,
3. Multiplicative Inequality.

Regularity:

For all $x_g \varepsilon A \subseteq C \subseteq T$, (Tversky, 1972a)

$P(x_g;A) \geq P(x_g;C)$

Define A_k, $B_k \subset A$ and A_ℓ, $B_\ell \subset C$.

Proof:

$$P(x_g;A) = \frac{\sum\limits_{B_k \subset A} U(\bar{B}_k)P(x_g;B_k)}{\sum\limits_{A_k \subset A} U(\bar{A}_k)}$$

and

$$P(x_g;C) = \frac{\sum\limits_{B_\ell \subset C} U(B_\ell)P(x_g;B_\ell)}{\sum\limits_{A_\ell \subset C} U(\bar{A}_\ell)}$$

Examining the numerators, note that

$$\{B_k\colon B_k \subset A\} \subseteq \{B_\ell\colon B_\ell \subset C\} \quad \text{since } A \subseteq C$$

Define $D = C-A$

Therefore $\{B_\ell\colon B_\ell \subset C\} = \{B_k\colon B_k \subset A\} \cup [\{B_\ell\colon B_\ell \subset C\} \cap D]$

and

$$\sum_{B_\ell \subset C} U(\bar{B}_\ell)P(x_g;B_\ell) = \underbrace{\sum_{B_k \subset A} U(\bar{B}_k)P(x_g;B_k)}_{k_1} + \underbrace{\sum_{B_\ell \subset C} U(\bar{B}_\ell)P(x_g;B_\ell \cap D)}_{k_2}$$

Examining the denominators, note that

$$\{A_k\colon A_k \subset A\} \subseteq \{A_\ell\colon A_\ell \subset C\} \quad \text{since } A \subseteq C.$$

Therefore $\{A_\ell\colon A_\ell \subset C\} = \{A_k\colon A_k \subset A\} \cup [\{A_\ell\colon A_\ell \subset C\} \cap D]$

and

$$\sum_{A_\ell \subset C} U(\bar{A}_\ell) = \underbrace{\sum_{A_k \subset A} U(\bar{A}_k)}_{k_3} + \underbrace{\sum_{A_\ell \subset D} U(\bar{A}_\ell)}_{k_4}$$

Combining the numerators and denominators, $P(x_g;C) = \dfrac{k_1+k_2}{k_3+k_4}$.

Examining k_2 recall that $x_g \varepsilon A$ and that A and D are disjoint, i.e.,

$$A \cap D = \phi \text{ and } \{x_g\} \cap D = \phi.$$

Therefore, $P(x_g;B_\ell \cap D) = 0$ and $k_2 = 0$.

Finally, compare $P(x_g;A)$ with $P(x_g;C)$:

$$P(x_g;A) = \frac{k_1}{k_3} \text{ and } P(x_g;C) = \frac{k_1}{k_3 + k_4}.$$

Therefore, $P(x_g;A) \geq P(x_g;C)$ since k_4 is never negative.

QED.

<u>Similarity Hypothesis</u>:

If $P(x_1;A) = P(x_3;A)$ where $x_1,x_3 \varepsilon A$, and if alternative x_2, $x_2 \not\varepsilon A$, is more similar to x_1 than to x_3, then $P(x_1;A \cup \{x_2\} < P(x_3;A \cup \{x_2\})$.

As explained above, the similarity hypothesis predicts that the addition of another alternative will decrease the choice probability of those alternatives most similar to it much more than those least similar to it. Notice that according to the constant ratio rule of Luce's model,

$$P(x_1;A \cup \{x_2\}) = P(x_3;A \cup \{x_2\}).$$

The similarity hypothesis, which is implied by the EBA process, is a stronger statement than regularity; the similarity hypothesis implies regularity.

Proof: The similarity hypothesis states that if $A = \{x_1,x_2,x_3\}$, and if x_1 and x_2 are similar and x_3 is dissimilar, then (from Tversky, 1972a)

$$P(x_1;x_3) > P_{x_2}(x_1;x_3)$$

and

$$P(x_2;x_3) > P_{x_1}(x_2;x_3)$$

where

$$P_{x_2}(x_1;x_3) = \frac{P(x_1;x_2,x_3)}{P(x_1;x_2,x_3) + P(x_3;x_1,x_2)}$$

and

$$P_{x_1}(x_2;x_3) = \frac{P(x_2;x_1,x_3)}{P(x_2;x_1,x_3) + P(x_3;x_1,x_2)} .$$

Regularity states that

$$P(x_1;x_3) \geq P(x_1;x_2,x_3)$$

and

$$P(x_2;x_3) \geq P(x_2;x_1,x_3).$$

Recall that

$$P(x_1;x_2,x_3) = \frac{P_{x_2}(x_1;x_3) \cdot P(x_3;x_1,x_2)}{1-P_{x_2}(x_1;x_3)}$$

and

$$P_{x_2}(x_3;x_1) = 1-P_{x_2}(x_1;x_3)$$

therefore

$$P(x_1;x_2,x_3) = \frac{P_{x_2}(x_1;x_3) \cdot P(x_3;x_1,x_2)}{P_{x_2}(x_3;x_1)} .$$

Similarly

$$P(x_2;x_1,x_3) = \frac{P_{x_1}(x_2;x_3) \cdot P(x_3;x_1,x_2)}{1-P_{x_1}(x_2;x_3)}$$

and

$$P_{x_1}(x_3;x_2) = 1-P_{x_1}(x_2;x_3)$$

therefore

$$P(x_2;x_1,x_3) = \frac{P_{x_1}(x_2;x_3) \cdot P(x_3;x_1,x_2)}{P_{x_1}(x_3;x_2)} .$$

Substituting the regularity condition gives

$$P(x_1;x_3) \geq \frac{P_{x_2}(x_1;x_3) \cdot P(x_3;x_1,x_2)}{P_{x_2}(x_3;x_1)}$$

and

$$P(x_2;x_3) \geq \frac{P_{x_1}(x_2;x_3) \cdot P(x_3;x_1,x_2)}{P_{x_1}(x_3;x_2)} .$$

Recall

$$\frac{P(x_3;x_1,x_2)}{P_{x_2}(x_3;x_1)} = \underbrace{P(x_3;x_1,x_2) + P(x_1;x_2,x_3)}_{P'} \leq 1$$

and

$$\frac{P(x_3;x_1,x_2)}{P_{x_1}(x_3;x_2)} = \underbrace{P(x_2;x_1,x_3) + P(x_3;x_1,x_2)}_{P''} \leq 1.$$

Therefore regularity can be restated as

$$P(x_1;x_3) \geq P_{x_2}(x_1;x_3) \cdot P'$$

and

$$P(x_2;x_3) \geq P_{x_1}(x_2;x_3) \cdot P''$$

where

$$P', P'' \leq 1.$$

Notice that if

$$P(x_1;x_3) > P_{x_2}(x_1;x_3)$$

as the similarity hypothesis implies, then

$$P(x_1;x_3) \geq P_{x_2}(x_1;x_3)$$

and

$$P(x_1;x_3) \geq P_{x_2}(x_1;x_3)\cdot P'$$

where

$$P' \leq 1.$$

Similarly, if

$$P(x_2;x_3) > P_{x_1}(x_2;x_3)$$

then

$$P(x_2;x_3) \geq P_{x_1}(x_2;x_3)\cdot P''$$

where

$$P'' \leq 1.$$

QED.

Moderate Stochastic Transitivity (MST):

$P(x_1;x_2) \geq 1/2$ and $P(x_2;x_3) \geq 1/2$ imply

$P(x_1;x_3) \geq \min\,[P(x_1;x_2),\ P(x_2;x_3)]$. (Tversky, 1972b)

Proof: (from Tversky, 1972b)

Let $A = \{x_1, x_2, x_3\}$ and $U(\bar{x}_1)=a$, $U(\bar{x}_2)=b$, $U(\bar{x}_3)=c$, $U(\bar{x}_1\bar{x}_2)=d$, $U(\bar{x}_2\bar{x}_3)=e$, and $U(\bar{x}_1\bar{x}_3)=f$. See Figure 4.3.

According to the EBA model, $P(x_1;x_2) = \dfrac{a+f}{a+f+b+e}$

$$P(x_2;x_3) = \frac{b+d}{b+d+c+f}$$

and $P(x_1;x_3) = \dfrac{a+d}{a+d+e+c}$

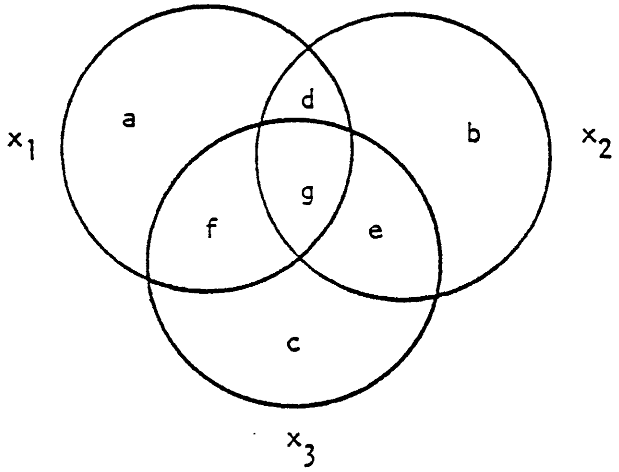


Figure 4.3 Graphical explanation of notation for the proofs of Moderate Stochastic Transitivity and Multiplicative Inequality.

If either $P(x_1;x_2)$, $P(x_2;x_3)$, or $P(x_1;x_3) = 1$ then MST must follow. Therefore, suppose they are all less than one. This being the case, it is sufficient to show that if

$$\frac{P(x_1;x_2)}{P(x_2;x_1)} = \frac{a+f}{b+e} = 1+u \text{ and } \frac{P(x_2;x_3)}{P(x_3;x_2)} = \frac{b+d}{c+f} = 1+v$$

for some $u, v \geq 0$, then $\dfrac{P(x_1;x_3)}{P(x_3;x_1)} = \dfrac{a+d}{c+e} \geq 1+w$ where $w = \min(u,v)$.

Since by the above assumption $c+e > 0$, then

$$\begin{aligned}
\frac{a+d}{c+e} &= \frac{(a+f)+(b+d)}{c+e} - \frac{b+f}{c+e} \\
&= \frac{(1+u)(b+e) + (1+v)(c+f)}{c+e} - \frac{b+f}{c+e} \\
&= 1+u\left[\frac{b+e}{c+e}\right] + v\left[\frac{c+f}{c+e}\right] \\
&\geq 1+w\left[\frac{b+e}{c+e} + \frac{c+f}{c+e}\right] \\
&\geq 1+w
\end{aligned}$$

QED.

Multiplicative Inequality (MI):

$$P(x_1;x_2,x_3) \geq P(x_1;x_2)\cdot P(x_1;x_3)$$

Proof: (from Tversky, 1972b)

Using the same notation as above,

$$P(x_1;x_2,x_3) = \frac{a+d\cdot P(x_1;x_2) + f\cdot P(x_1;x_3)}{a+b+c+d+e+f}$$

Note: $P(x_1;x_2) = \frac{a+f}{a+f+b+e}$ and $P(x_1;x_3) = \frac{a+d}{a+d+c+e}$.

Substituting: $P(x_1;x_2,x_3) = \frac{a+d(a+f)/(a+f+b+e)+f(a+d)/(a+d+c+e)}{a+b+c+d+e+f}$

$$\geq \frac{(a+f)(a+d)}{(a+f+b+e)(a+d+c+e)} = P(x_1;x_2)P(x_1;x_3)$$

"which follows after some algebra. Q.E.D." (Tversky, 1972b)

MI states that the probability of choosing x_1 from $\{x_1,x_2,x_3\}$ cannot be smaller than the probability of choosing x_1 from both $\{x_1,x_2\}$ and $\{x_1, x_3\}$ in two independent choices. Furthermore, Tversky purports that the EBA model implies a much stronger, more general form of MI, namely:

$P(x_g;A \cup B) \geq P(x_g;A)P(x_g,B)$.

The multiplicative inequality property is also shared by Luce's model.

Proof: From the notation in Figure 4.3 define

U_1 = a+d+f+g = utility of x_1 $(U_1 \geq 0)$

U_2 = b+d+e+g = utility of x_2 $(U_2 \geq 0)$

U_3 = c+e+f+g = utility of x_3 $(U_3 \geq 0)$

Luce's model states that $P(x_1;x_2,x_3) = \frac{U_1}{U_1 + U_2 + U_3}$,

$P(x_1;x_2) = \frac{U_1}{U_1 + U_2}$, and $P(x_1;x_3) = \frac{U_1}{U_1 + U_3}$.

Substitution gives

$$P(x_1;x_2)\cdot P(x_1;x_3) = \frac{U_1^2}{U_1^2 + U_1U_3 + U_1U_2 + U_2U_3}$$

which can be rearranged to (provided $U_1 \neq 0$)

$$\frac{U_1}{U_1 + U_2 + U_3 + \frac{U_2 + U_3}{U_1}} \quad .$$

Notice that

$$U_1 + U_2 + U_3 \leq U_1 + U_2 + U_3 + \frac{U_2 + U_3}{U_1}$$

and

$$\frac{U_1}{U_1 + U_2 + U_3} \geq \frac{U_1}{U_1 + U_2 + U_3 + \frac{U_2 U_3}{U_1}} \quad .$$

Therefore

$$P(x_1;x_2,x_3) \geq P(x_1;x_2) \cdot P(x_1;x_3)$$

QED.

4.5 Data Needed and Survey Requirements

With regard to policy acceptance, the individuals judging the acceptability of policies (i.e., the irrigators) are the decision makers. The EBA model can be calibrated to predict a single decision maker's responses by obtaining the following data:

1. $A = \{x_1, x_2, .., x_g, .., x_m\}$ the set of alternatives offered to the decision maker. In this study, A includes conservation policy options being considered by NRD's, GWMD's, state agencies or Federal agencies.
2. $A' = \{\alpha_1, \alpha_2, .., \alpha_i, .., \alpha_n\}$ the set of aspects possessed by the alternatives in set A can be suggested by the analyst and confirmed by farmers or local water officials.

3. V_g the possession function for each alternative can be estimated by the analyst and confirmed via an interview with local water experts.
4. $u(\alpha_i)$ the relative importance of each aspect must be determined via interviews with the decision makers, i.e., water users.

Since the data to calibrate the model is collected from individual decision makers and the goal is to predict responses of a larger population of decision makers, more data and an aggregation methodology are needed. Basically aggregation models attempt to first segregate the population into homogeneous fractions, then calibrate the model for each fraction and finally recombine the model results based on what percentage of the population each fraction represents. For this procedure socioeconomic and geographic data is necessary. The aggregation methodology for the EBA model must also reconcile differences in the V_g's (possession functions) and $u(\alpha_i)$'s (relative importance of aspects) as defined by different decision makers in the survey. For example, all farmers who already own wells may think that a moratorium on new well construction is a fair policy. The opposite opinion is probably held by those farmers who have not yet drilled wells. Therefore, well ownership may be a good criterion for segregating the population into homogenous groups. Aggregating individual's ratings of aspects, $u(\alpha_i)$, can be done simply by arithmetic averaging. However, aggregating their possession functions, V_g, requires inventing a criterion for determining a group possession function. For instance, one such rule states that the group's possession $V_g(\alpha_i)$ equals 1.0 (i.e., alternative x_g possesses aspect α_i) if and only if a majority of the group members' individual possession functions also assigned $V_g(\alpha_i) = 1$. Otherwise $V_g(\alpha_i)$ (group) equals zero. The experiments discussed later in Chapter 6 compare this and other aggregation schemes on the basis of their accuracy and ease of implementation. Chapter 6 also includes recommendations for a field application of the EBA model.

CHAPTER 5

WATER CONSERVATION POLICY ALTERNATIVES AND ASPECTS

5.1 Existing Conservation Policies

Each state containing a significant portion of the Ogallala aquifer has legislation enabling the formation of GWMD's or NRD's to manage groundwater and other natural resources. Twenty-eight such self-governing districts now exist on the High Plains and cover about 85% of the formation. Only Oklahoma has been unable to organize a GWMD although an attempt was made from 1976 until 1978 in Texas County. Each district publishes a small pamphlet containing the rules and regulations which apply in that district concerning the use, development and conservation of groundwater. It is logical that conservation practices such as controlling tailwater runoff, evaporation and new well development are much less controversial (and less effective) than groundwater policies which restrict withdrawals. Hence nearly all NRD's and GWMD's have active conservation programs and a few (especially in Texas) make a strong effort to educate the people about conservation. However, only seven of the districts have as yet restricted groundwater withdrawals and none have attempted to attain a sustained yield. A listing of all the NRD's and GWMD's on the Ogallala, their locations, number of existing wells, and their groundwater policies (if any) appears in Table 5.1.

Table 5.1 Groundwater Policies of Natural Resources Districts and Groundwater Management Districts in the High Plains.

District	Number of wells	Groundwater Policy [1]
Middle Niobrara NRD Valentine, Nebraska	483[2]	none[3]
Lower Niobrara NRD Butte, Nebraska	1433[2]	none[3]
Upper Elkhorn NRD O'Neil, Nebraska	2516[2]	none[3]
Upper Loup NRD Thedford, Nebraska	642[2]	none[3]
Lower Loup NRD Ord, Nebraska	6521[2]	none[3]
South Platte NRD Sidney, Nebraska	1000	none[3]
Twin Platte NRD North Platte, Neb.	1777[2]	none[3]
Central Platte NRD Grand Island, Neb.	14,000	none[3]
Upper Big Blue NRD York, Nebraska	9550	1. Well spacing of 1000 feet.[4] 2. Meters required on all wells. 3. Allocation of 16"/year, 3-year period with some carryover allowed.
Upper Republican NRD Imperial, Nebraska	2700	1. Well spacing of 3300 feet. 2. Allocation of 23"/year/irrigable acre, 5-year period with some carryover allowed.
Middle Republican NRD Curtis, Nebraska	2200	none[3]
Tri-Basin NRD Holdrege, Nebraska	3504	none[3]
Lower Republican NRD Alma, Nebraska	2465	none[3]

Table 5.1 Continued

District	Number of wells	Groundwater Policy [1/]
Little Blue NRD Davenport, Nebraska	4400	none[3/]
Arikaree GWMD Kirk, Colorado	N/A	1. Well spacing of 1/2 mile .[6/] 2. Maximum appropriation/well is 30" per year per irrigated acre. 3. New permits cannot cause more than 40% depletion in 25 years within a 3-mile radius circle from new site.
Frenchman GWMD Holyoke, Colorado	470	same as above [6/]
Sand Hills GWMD Wray, Colorado	496	same as above [6/]
Marks Butte GWMD Holyoke, Colorado	155	same as above [6/]
W-Y GWMD Yuma, Colorado	N/A	same as above [6/]
Plains GWMD Burlington, Colorado	N/A	same as above [6/]
Central Yuma Co.GWMD Wray, Colorado	505	same as above plus[6/] 4. Meters are required on all wells. 5. No new development if saturated thickness is less than 50 feet within 3 miles of the new site.
Western Kansas GWMD #1 Scott City, Kansas	2900	1. No new wells in areas of over 50% depletion. 2. Well spacing is based on the % depletion since 1950.
Southwest Kansas GWMD #3 Garden City, Kansas	8000	1. Well spacing based on well capacit 2. Allocation based on maximum depletion of 40% in 25 years.
Southern High Plains GWMD's (7 Divisions) Walsh, Colorado	N/A	1. Well spacing of 1/2 mile.[6/] 2. Maximum annual appropriation of 42" per irrigated acre per year.

Table 5.1 Continued

District	Number of wells	Groundwater Policy 1/
Northwest Kansas GWMD #4 Colby, Kansas	3600	1. Allocation based on a maximum depletion of 40% in 25 years. 2. Well spacing based on well capacity. 3. In control area, allocation is the lesser of a per well and a per acre amount.
Texas County Irrigation Association 5/ Guymon, Oklahoma	N/A	none
High Plains GWMD #1 Lubbock, Texas	50,000	1. Well spacing based on well capacity.
North Plains GWMD #2 Dumas, Texas	5636	1. Well spacing based on well capacity.
Panhandle GWMD #3 Whitedeer, Texas	N/A	1. Well spacing based on well capacity.

Notes:

1/ Rules and regulations concerning surface water and farming practices are not included. Also, small or domestic wells are usually exempt from the rules.

2/ Estimated as of September 30, 1978.

3/ A minimal well spacing of 600' to prevent interference between wells is a part of Nebraska State Water Laws.

4/ Rules and Regulations pertain to the groundwater control area within the NRD.

5/ Unsuccessful attempts have been made to change this into a GWMD.

6/ The Colorado Groundwater Commission promulgated policy guidelines concerning well spacing, maximum depletion rates, and maximum per acre allocation leaving the districts authority to require well meters and to make stricter regulations if they so desire.

5.2 Water Conservation Policy Options

Conservation policies pertain to three major issues: Surface Water, Groundwater, and Farming Practices. Many specific conservation programs exist within each category which can be implemented to achieve the goals set forth by the regulatory agency. Figure 5.1 presents a hierarchy of 1) General Policy Options, 2) Specific Conservation Programs, and 3) the Expected Results of actions taken to address the problem of declining groundwater.

5.2.1 Surface Water Policies

Several fairly simple measures to make more efficient use of surface water supplies could be implemented quickly once the necessary changes have been made to state water laws.

In-farm Transfers would allow farmers to transfer water allotted for one field to another within a contiguous farm. In areas of diminishing supply, this would allow the farmers to grow irrigated crops on at least part of their farms. That is, an irrigator could reduce his irrigated acreage without reducing his application rate. Currently this practice is illegal in Nebraska where water rights are fixed to the land with no transfers permitted.

Water Rental Markets now operating in Colorado provide a much more efficient distribution of the limited surface supplies than did the original water rights system. An inefficient operator, or one with poor soil, is better off to lease his water to a better farm where the economic return for the water is higher.

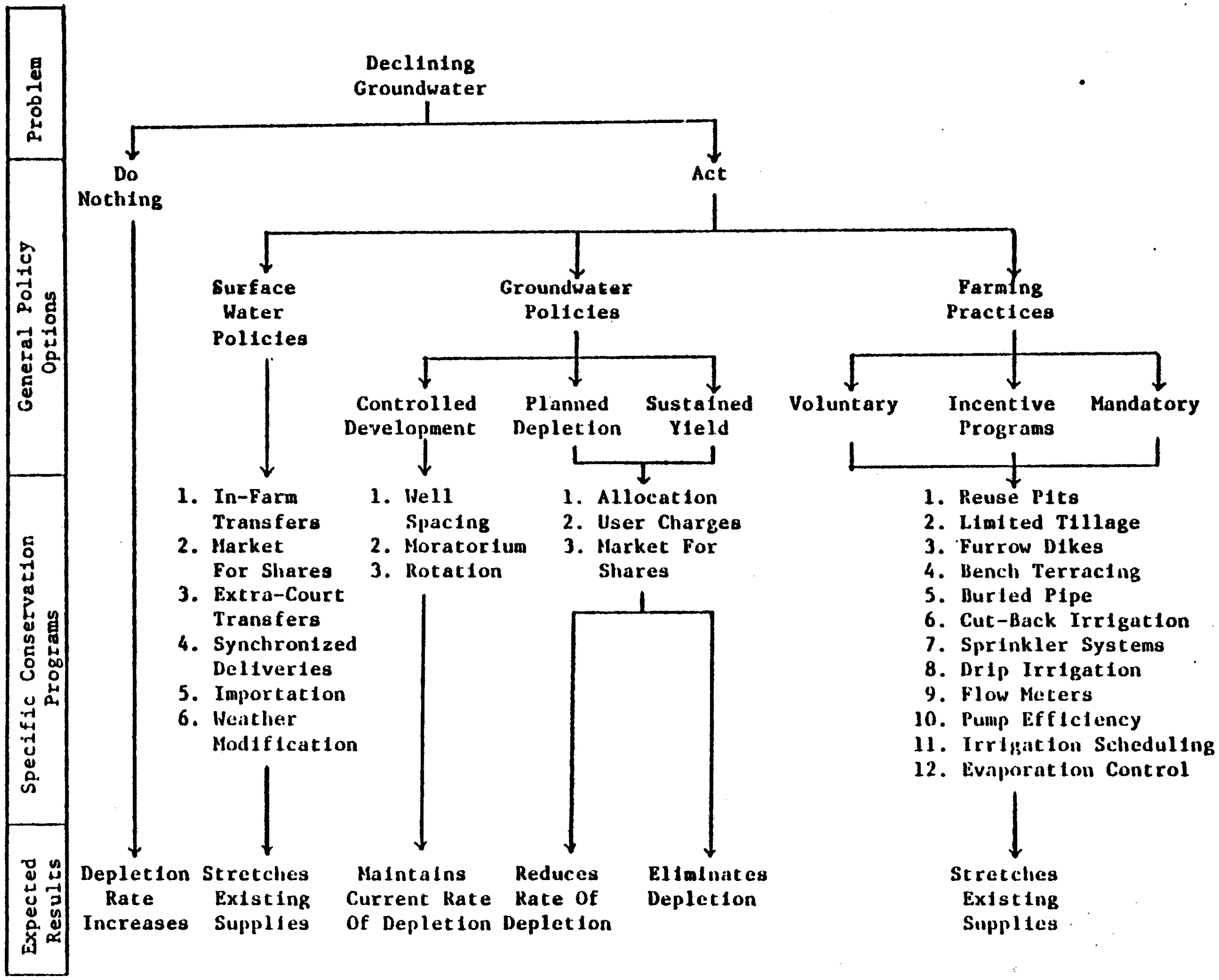


Figure 5.1 A hierarchy of 1) General Policy Options, 2) Specific Conservation Programs, and 3) the Expected Results of actions taken to address the problem of declining groundwater.

Extra-Court Transfers of Water Rights would also improve the economic return to water since it would allow water to be redistributed to more productive users. Currently, the courts incur a large transactions cost and thus block many otherwise Pareto-optimal tranfers. A standard transfer procedure would have to be devised in each state and approved by the state justice department so that transfers can proceed smoothly.

Synchronized deliveries to water users served by the same canal would greatly reduce seepage and evaporation losses presently incurred by "On Demand" canal delivery systems which must keep the entire canal primed to serve the most distant user.

Water Importation schemes, as discussed in Chapter 1, are more costly but have the advantage of bringing new water into the area instead of simply stretching existing supplies.

Weather Modification via cloud seeding can, when successful, provide additional water to help fill the void left by the disappearing groundwater.

Many of these surface water policies can be followed simultaneously to reduce the demand for groundwater, but none can directly and unequivocably control the depletion of the groundwater.

5.2.2 Groundwater Policies

Farmers who have for years drilled wells and pumped groundwater freely will most certainly be opposed to any restriction of these privileges. Therefore, groundwater management districts in Kansas, Nebraska and Colorado are following a logical and natural sequence of ever stricter groundwater controls. The first step is to slow down or stop the drilling of new wells. The next step is to establish a planned depletion schedule for the district and to restrict withdrawals to meet the schedule. The final step is to further restrict withdrawals to attain a sustained yield from the aquifer. If no action is taken withdrawals would still be reduced to the sustained yield by the eventual depletion of the aquifer. In most of the High Plains there is so little recharge that any withdrawal rate significant for irrigation would deplete the aquifer. However, in areas with substantial recharge, such as Nebraska's Sand Hills, if this were to occur then 1) there would be no base flow in surface streams, 2) only users atop the greatest thickness of the aquifer would still find water, and 3) pumping lifts for these remaining users would be at their absolute maximum. All three of these problems can be avoided by attaining a sustained yield quickly by management, i.e., before it is imposed naturally.

Controlled Development is the phase most groundwater management districts were in at the time of this writing. Well spacing limits the number of wells which can be developed in an area and helps reduce the interference between adjacent wells. A moratorium on new drilling stops all new development but also restricts the use of groundwater to the present well owners, a consequence which will surely be tested in the courts. Finally, rotation schedules which allow pumping only every other week, for instance, are a nuisance to the irrigators and do little to diminish the overall depletion of the aquifer. These three measures to control development have the effect of either maintaining the current depletion rate or at least slowing down the increase in the depletion rate; a first step toward effective groundwater policies.

Planned Depletion schedules which are considerably more restrictive, reduce the rate of depletion, and can be accomplished through several different programs. One purpose of planned depletion schedules is to insure that the groundwater supply will last long enough for irrigators to pay off their investments in wells and equipment. Schemes which allocate the amount of water each farmer can pump are described on the basis of three variables:

1. Horizon of Allocation - The horizon is the number of years that the groundwater supply is planned to last. This varies from 40 years for some states to infinity implying a sustained yield.
2. Basis of Allocation - The quantity to be pumped can be calculated per well, or per irrigable acre, or per irrigated acre, or per crop.
3. Period of Allocation - This can vary from a single year allocation to a multi-year allocation where the user is permitted to carry unused allotments over into the next year.

An example of a planned depletion allocation program would be: Horizon - 40 years, Basis-Irrigable Acres, and Period - 5 years. The administrative agency must determine which areas qualify as irrigable within its jurisdiction.

Another method to enforce a planned depletion schedule which also redistributes the water to the most productive users is via user charges. The administrative agency simply begins with a small fee/unit pumped and each year continues to raise the fee until the demand is reduced to the desired amount. Although simple in theory and appealing to economists, this scheme would be vehemently opposed by farmers who already complain of excessive taxation.

Finally, the administrative agency could issue one share of stock for every acre-foot of groundwater that they will allow to be withdrawn from the aquifer. Initially, the shares would be auctioned off to water users and the proceeds could be used to subsidize conservation practices. Subsequent transactions involving these water shares would occur through a free market. Such a market would redistribute the groundwater to the most efficient users but it would also be greatly opposed by the farmers. User charges and a market for groundwater shares produce efficient solutions but they also cause the farmers to pay very high premiums above and beyond their current pumping costs. Allocation schemes do not incur such a premium.

Sustained Yield programs are identical to those outlined above for planned depletion with the only difference being the quantity of water withdrawn from the aquifer. Since withdrawals from the aquifer are limited to its natural recharge, each user would be allowed to pump considerably less groundwater. A sustained yield allocation scheme such as: Horizon-Forever, Basis-Irrigable Acres, Period-5 years, would permit some yearly withdrawals to exceed the recharge rate provided the cumulative 5-year withdrawals do not exceed the cumulative 5-year recharge.

User charges higher than those for planned depletion would be required for that program and fewer shares would be issued for a market program.

5.2.3 Farming Practices

Many farming practices can be used to conserve water thus stretching existing supplies. As with groundwater policies, farming practices which save water can be implemented voluntarily at first, followed by incentive programs and finally they can be made mandatory. Currently, many groundwater management districts are actively engaged in programs which educate and encourage farmers to adopt some of the following water-saving practices.

Reuse Pits are located in the lowest corner of an irrigated field to collect tailwater so it can be recycled through the irrigation system.

Limited Tillage is the reduction of cultivation by eliminating plowing. This leaves the stubble from the previous crop to suppress evaporation. An extension of this idea is no tillage where chemicals are used to control weeds and the new crop is planted (drilled) in the remains of the previous crop.

Furrow Dikes, also called Basin-Tillage, is a method of cultivating whereby mounds of soil are mechanically placed at regular intervals across the furrows to form small basins in the furrow. Rainfall is thus impounded on the field for infiltration rather than being lost as runoff.

Bench Terracing can be used on sloping ground to create level fields to prevent runoff and increase infiltration on the field. A modification of this idea, called conservation bench terracing involves leveling and cropping only the bottom one-third of the field and using the upper part of the field as a rainfall collector. Although terracing programs are supposedly profitable (Jones and Shipley, 1975), they require a much larger initial capital outlay than the previously mentioned conservation practices.

Buried Pipe to replace open, unlined canals, ditches and laterals can greatly reduce evaporation and seepage losses of the water during conveyance. The cost of installing buried pipe appears to be more than offset by the value of the water saved. (High Plains Underground Water Conservation District, No. 1, 1979.)

Cut-Back Irrigation on furrow irrigated fields involves sending an initial surge of water down each furrow to wet it to the end of the field and then reducing the flows to save water. A problem encountered with irrigating too little is that of insufficient leaching, i.e., a damaging salt buildup occurs at the surface of the soil. However, if an application is made after the growing season at a time of low demand it will bring the soil to the proper moisture level for the next season, and leach the salts from the soil.

Sprinkler Systems can provide an even distribution of water over the entire field, thereby avoiding the problem of overwatering the top end of the field while underwatering the bottom end as is common with furrow irrigation. Recently in southwestern Nebraska, furrow irrigators required from 22 to 28 inches of water while center pivot irrigators needed only 14 to 18 inches, a savings of 36% (Milner, 1970).

Drip Irrigation consists of a distribution system of small-diameter plastic pipes which have tiny holes that allow water to drip out of the pipe onto the ground next to each plant. Although it greatly reduces distribution and evaporation losses, the high installation costs and filtration requirements of drip irrigation limit its use to orchards.

Flow Meters installed on wells supplying irrigation systems allows farmers to accurately determine how much water they are actually using, and to determine the efficiency of his pump and irrigation system.

Pump Efficiency improvements do not conserve water per se but they do stretch the feasibly available groundwater supply by reducing the pumping costs. Recently, the development of low pressure irrigation systems also save money, energy, and reduce wind evaporative losses.

Irrigation Scheduling based on crop needs and continuous monitoring of the moisture content of the soil profile by electrical resistance blocks, or neutron probes or tensiometers, results in exactly the right amount of water being applied at exactly the right time. Far from scientific, most farmers rely on their "gut feelings" to decide when to irrigate. Agricultural Research Service studies estimate that those farmers often waste more than 25% of their water (Heermann, 1977).

Evaporation Control by leaving the wheat residue on the fields after harvest is very effective in conserving water. A rotation system can be established whereby corn, sorghum, or cotton can be planted directly in the undisturbed bed of the previous wheat crop to control evaporation.

These farming practices, with the exception of increased pump efficiency, have the effect of increasing the efficiency of water use and thus reducing the demand for groundwater.

5.3 Desirable Aspects of Conservation Policies

5.3.1 Subjective Nature of Desirability

Prior to undertaking the subjective task of listing the desirable qualities of water conservation policies several words of caution are in order. First, it is important for the analyst to define desirability from the farmers' point of view and not bias the study with his own normative ideas. It may seem obvious to experts that a particular policy is in the farmers' best interests but this should not be misconstrued as public acceptance. Second, policies which are desirable for the short term may not be for the long term and vice-versa.

To be concerned with only short term farm profits is to continue the practice followed up until the last few years. In areas where the Ogallala provides the base flow for streams and where there is appreciable recharge of the aquifer there is a sharp difference between what is a good long term use of the aquifer and what is a good short term use of the aquifer. For instance, expanding irrigated acreages via center pivots may be profitable in the short run but since it has eliminated forever the base flow of streams it is a bad long run use of the aquifer.

However, the distinction between long and short run strategies is not so clear in areas where there are few streams and no (or very limited) natural recharge to the aquifer. Such is the case in the High Plains of Texas and New Mexico. The resource is nearly finite and thus it becomes a question of how to deal with the economic contraction of the region when the supply is exhausted. Since the size of the agricultural industry is directly proportional to the rate at which the water is mined, Texas could face a larger economic collapse and sooner than New Mexico which is conserving the water assuming no importation of water to either region. Effective groundwater conservation and allocation programs could greatly mitigate and delay this unavoidable result.

5.3.2 Aspects

The following is a list of desirable aspects which are possessed by at least some conservation policies.

1. The policy does not create additional uncertainty about the future availability of water.
2. The policy is fair; all farmers are treated equally.
3. The policy is effective in halting the mining of groundwater.
4. The policy is effective in stretching the existing water supply over a long time.
5. It is inexpensive for the farmers to comply with the policy.
6. It is convenient for the farmers to comply with the policy.
7. The policy permits farmers to continue using their old farming practices.
8. There is no invasion of privacy by meter readers or other inspectors.
9. The policy does not reduce short-term farm production outputs.

These desirable aspects can be used in the EBA model to predict the acceptability of conservation policy alternatives. Interviews with farmers or local experts are needed to determine their perceptions as to which policies possess which aspects, and to determine the relative importance of each aspect. For demonstrative purposes, Table 5.2 provides a listing of possible water conservation policies along with a first "guess" as to which aspects each policy possesses. In an application of the model, these "guesses" would be replaced by the results of the survey. Neither the list of policies nor the list of aspects is thought to be exhaustive.

Table 5.2 A preliminary listing of Conservation Policies showing which desirable aspects they might possess. This is to be determined through interviews with the irrigators.

Desirable Aspects: / Conservation Policies:		No additional uncertainty about water availability.	Fairness; all farmers treated equally.	Effective in halting groundwater mining.	Effective in stretching existing water supply.	Compliance is inexpensive.	Compliance is not inconvenient.	Permits old farming practices to continue.	No invasion of the privacy of farmers.	Does not reduce short-term farm output.
Groundwater Policies: Controlled Development										
1. Well Spacing						x		x	x	x
2. Moratorium on Drilling		x			x	x	x	x	x	x
3. Pumping Rotation		x	x			x		x		x
Planned Depletion (In 40 Years)										
1. Allocation	1-year	x			x	x		x		
2. Per Well	5-years				x	x	x	x		x
3. Allocation Per	1-year	x			x	x		x		
4. Irrigated Acre	5-years				x	x	x	x		x
5. Allocation Per	1-year	x	x		x	x		x		
6. Irrigable Acre	5-years		x		x	x	x	x		x
7. Allocation Per Crop					x					
8. User Charges			x		x		x	x		
9. Groundwater Shares Market			x		x			x		
Sustained Yield										
1. Allocation	1-year	x		x	x	x				
2. Per Well	5-years			x	x	x	x			
3. Allocation Per	1-year	x		x	x	x				
4. Irrigated Acre	5-years			x	x	x	x			
5. Allocation Per	1-year	x	x	x	x	x				
6. Irrigable Acre	5-years		x	x	x	x	x			
7. Allocation Per Crop				x	x					
8. User Charges			x	x	x		x			
9. Groundwater Shares Market			x	x	x					

Table 5.2 Continued.

Desirable Aspects: / Conservation Policies:	No additional uncertainty about water availability.	Fairness; all farmers treated equally.	Effective in halting groundwater mining.	Effective in stretching existing water supply.	Compliance is inexpensive.	Compliance is not inconvenient.	Permits old farming practices to continue.	No invasion of the privacy of farmers.	Does not reduce short-term farm output.
Surface Water Policies									
1. In-Farm Transfers	x	x		x	x	x	x	x	x
2. Water Rental Market		x		x			x	x	
3. Extra-Court Rights Transfers	x	x		x	x	x	x	x	x
4. Synchronized Deliveries	x	x		x	x	x	x	x	x
5. Water Importation	x	x		x		x	x	x	x
6. Weather Modification		x		x		x	x	x	x
Farming Practices - Mandatory									
1. Reuse Pits	x			x					x
2. Limited Tillage	x	x		x	x	x		x	x
3. Furrow Dikes	x	x		x	x	x		x	x
4. Bench Terracing	x	x		x				x	
5. Buried Pipe	x	x		x		x	x	x	x
6. Cut-Back Irrigation	x	x		x	x				x
7. Sprinkler Systems	x			x					
8. Drip Irrigation	x	x		x				x	x
9. Flow Meters	x	x		x	x	x	x		x
10. Improved Pump Efficiency	x	x			x	x	x	x	x
11. Irrigation Scheduling	x	x		x	x			x	x
12. Evaporation Control	x	x		x	x			x	x

CHAPTER 6

EXPERIMENTAL TESTS OF EBA

6.1 Purpose of the Experiments

The Elimination By Aspects (EBA) choice model was tested on recruited subjects in a classroom setting to better prepare for a field application of the model in the High Plains. Two separate classroom experiments were conducted to fulfill two different purposes. First, there was a need to replicate the experiment done by Tversky (1972a) to test the underlying hypotheses upon which the EBA model is constructed. These hypotheses, regularity, moderate stochastic transitivity, and multiplicative inequality, are not characteristic of other choice models. For instance, Luce's model assumes simple scalability, not regularity, and the strong form of stochastic transitivity. Second, there was a need to test the predictive accuracy of the EBA model to determine its value to decision makers as a means of identifying acceptable conservation policies. There was also a desire to compare EBA's predictive ability to that of an established choice model such as Luce's. Finally, the predictive experiment was needed in order to gain experience in using the EBA model and to learn which types of decision problems the EBA model is best at predicting, i.e., it was necessary to learn how to use this new tool.

The remainder of this chapter describes these two experiments including 1) hypotheses, 2) background, 3) data needs, 4) experimental designs, 5) procedures, 6) data analysis, and 7) the results. Suggestions are also made concerning field applications of the model.

6.2 Tversky's Experiment

6.2.1 Hypotheses

Choice probabilities of the EBA model exhibit three measurable properties, and it is hypothesized that human choice behavior exhibits these properties as well. The three hypotheses tested by Tversky's experiment are:

1) Choice behavior exhibits the property of regularity but violates simple scalability.
2) Choice behavior satisfies moderate stochastic transitivity (and therefore weak stochastic transitivity) but not strong stochastic transitivity.
3. Choice behavior satisfies the strong form of the multiplicative inequality property.

Recall that regularity is defined as follows. For all $x_g \varepsilon A \subseteq B$, $P(x_g;A) \geq P(x_g;B)$. In other words, the probability of choosing x_g cannot be increased by increasing the offered set.

A general formulation of the notion of independence from irrelevant alternatives (IIA) is the assumption of simple scalability. Simple scalability holds if and only if there exists a scale u defined on the alternatives of T and functions F_m in m arguments, $2 \leq m \leq t$ such that for any $A = \{x_1,x_2,..,x_g,..,x_m\} \subseteq T$, $P(x_g;A) = F_m[u(x_1),u(x_2),\ldots,u(x_g),..,u(x_m)]$ where each F_m is strictly increasing in the "g_{th}" argument and strictly decreasing the the remaining m-1 arguments provided $P(x_g;A) \neq 0, 1$ (Tversky, 1972a). A strong testable consequence of simple scalability is that for all $x_1,x_2 \varepsilon A$, $P(x_1;x_2) \geq 1/2$ iff $P(x_1;A) \geq P(x_2;A)$, provided $P(x_2;A) \neq 0$.

Thus, the ordering of x_1 and x_2 by choice probability is independent of the offered set and if x_1 is preferred to x_2 in one context, it is preferred to x_2 in any context. The notion of IIA is a stronger statement and implies the constant ratio rule (CRR) which states that

$$\frac{P(x_1;A)}{P(x_2;A)} = \frac{P(x_1;B)}{P(x_2;B)} \quad , x_1,x_2 \varepsilon A,B.$$

Therefore, according to IIA and CRR, if a decision maker is indifferent between x_1 and x_2 in one context, he should feel the same way in any context.

The three forms of stochastic transitivity can be defined as follows:

$$\begin{aligned} & P(x_1;x_2) \geq 1/2 \text{ and } P(x_2;x_3) \geq 1/2 \text{ imply} \\ \text{WEAK:}\quad & P(x_1;x_3) \geq 1/2 \\ \text{MODERATE:}\quad & P(x_1;x_3) \geq \min\,[P(x_1;x_2),\ P(x_2;x_3)] \\ \text{STRONG:}\quad & P(x_1;x_3) \geq \max\,[P(x_1;x_2),\ P(x_2;x_3)]. \end{aligned}$$

Multiplicative inequality is a property which relates binary and trinary choice probabilities as follows:

$$P(x_1;x_2,x_3) \geq P(x_1;x_2)\cdot P(x_1;x_3).$$

This asserts that the chance of choosing x_1 from $\{x_1,x_2,x_3\}$ is at least as large as the chance of choosing x_1 from both $\{x_1,x_2\}$ and $\{x_1,x_3\}$ in two independent choices.

6.2.2 Background

An experiment was performed by Tversky in 1971 using eight high school students in a Jerusalem (Israel) high school. He invented three tasks and used dot patterns, gambles, and score profiles as stimuli for the tasks, each of which had two attributes. Each task consisted of choosing one alternative from the offered set of alternatives. Of sixteen alternatives in each task three experimental ones were chosen such that two of them were very similar and the third was very different. The experimental triple was shown to the subjects 30 times (3 times per session for 10 sessions), and each experimental pair was shown 20 times with the subjects choosing one alternative each time. Tversky found that in two of the three tasks regularity held, but not simple scalability. He also determined that moderate stochastic transitivity generally held but not strong stochastic transitivity. Tversky did not examine multiplicative inequality although he probably had the data necessary to do so.

6.2.3 Data Needs

The three hypotheses stated above can be tested for one individual or for an entire population. In the classroom experiment the number of subjects was small enough (10) so that it was often possible to examine each hypothesis both on an individual basis and for the population of subjects (although not the population of the High Plains). To test the hypotheses for an individual, that individual must repeat his choice process enough times to enable statistically significant conclusions to be made concerning the validity of the hypotheses. Recall that two experimental alternatives, say y and z are similar and the third, x, is very different from y and z. Thus, to test the similarity hypothesis for example, enough choices must be made among the pairs {x,y} and {x,z} and the triple {x,y,z} to show that:

$$P(y;x) > P_z(y;x)$$

$$\text{and } P(z;x) > P_y(z;x)$$

$$\text{where } P_z(y;x) = \frac{P(y;x,z)}{P(y;x,z) + P(x;y,z)} \;.$$

The same repetition of choices is needed to test stochastic transitivity and the property of multiplicative inequality.

6.2.4 Experimental Design

Three tasks were used and the stimuli are shown in Figures 6.1, 6.2, and 6.3. Task 1 employed six 2-attribute alternatives including three experimental ones, two alike and one different as in Tversky's experiment, and three non-experimental ones. Score profiles were used to present the information on the slides. The four possible combinations of the (3) experimental alternatives, i.e., three pairs and one triplet, were presented on four experimental slides. Eight more non-experimental slides were also used which included non-experimental alternatives exclusively or in combination with experimental alternatives. The purpose of showing non-experimental slides was to increase the number of slides presented and thus prevent the subjects from memorizing the experimental slides.

Tasks II and III were identical to Task I except that different attributes were used, and Task II included only 3-attribute alternatives and Task III included only 4-attribute alternatives.

Ten MIT students from either farms or small towns on the High Plains were recruited and paid forty dollars to attend an initial seminar and then three 1-1/2 hour experimental sessions. In each session, subjects were shown many slides and told to choose one alternative from each slide. The alternatives represented different proposed water conservation policies and the subjects were instructed to make

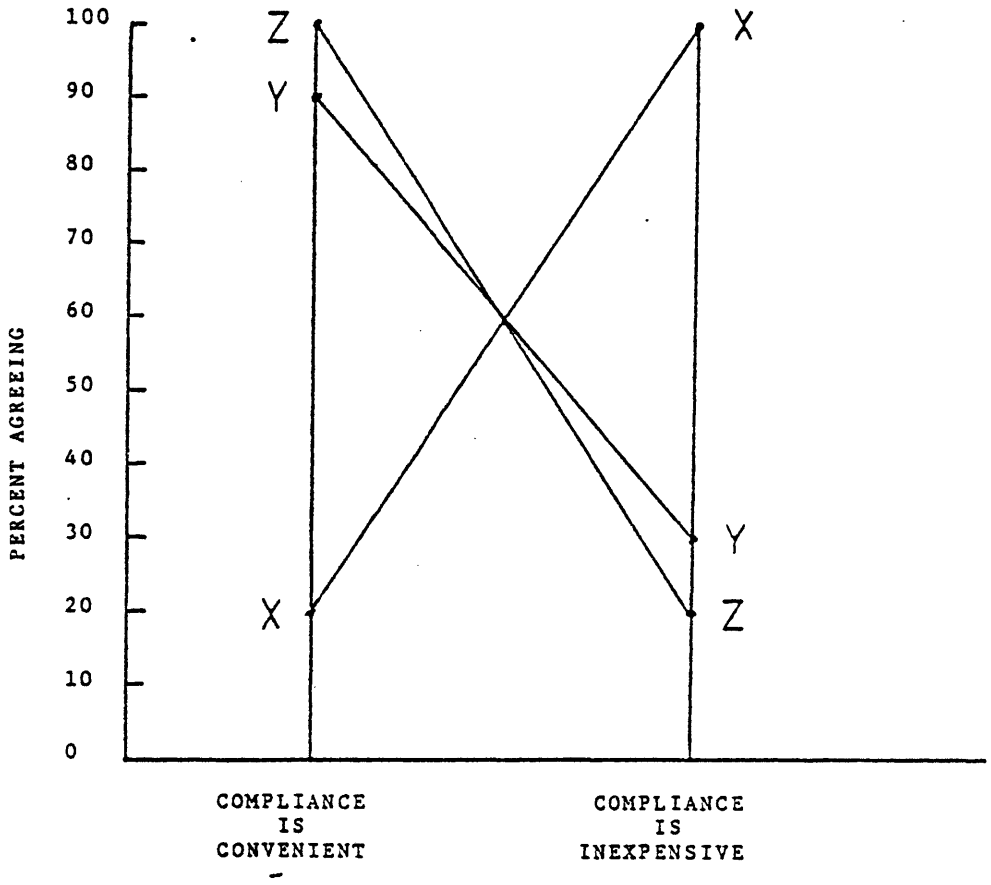


Figure 6.1 Slide employed in the replication of Tversky's experiment depicting the experimental alternatives used in Task 1.

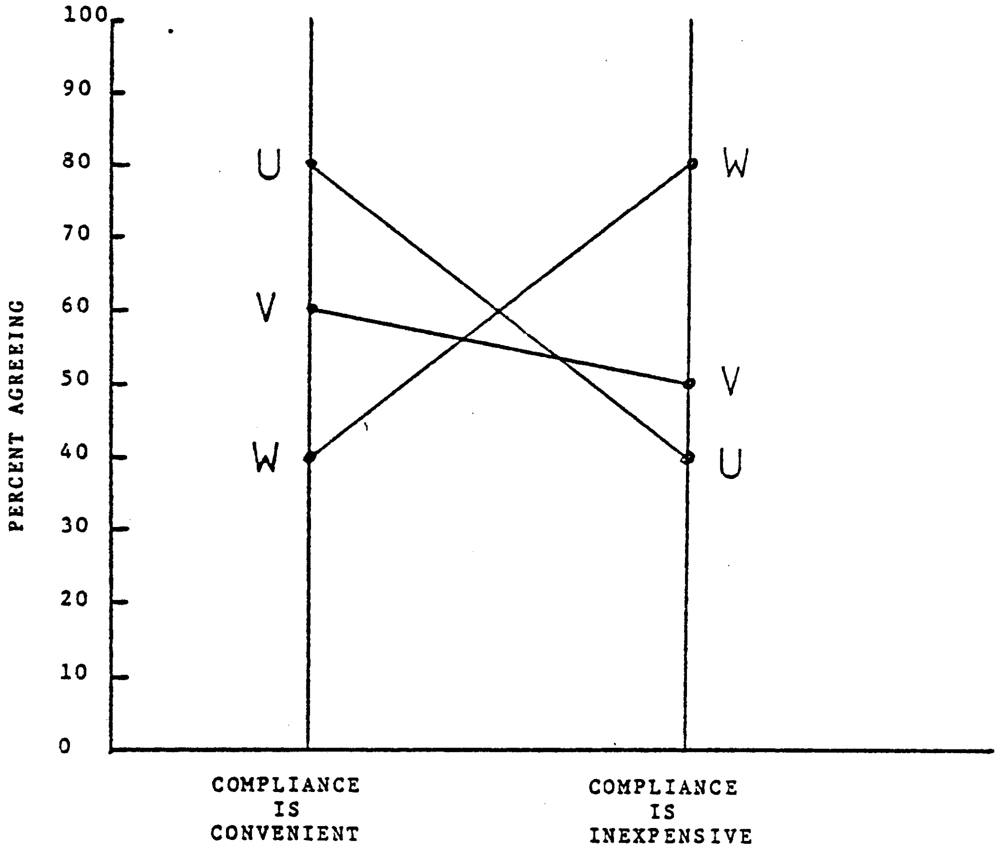


Figure 6.1 continued. Slide employed in the replication of Tversky's experiment depicting the non-experimental alternatives used in Task 1.

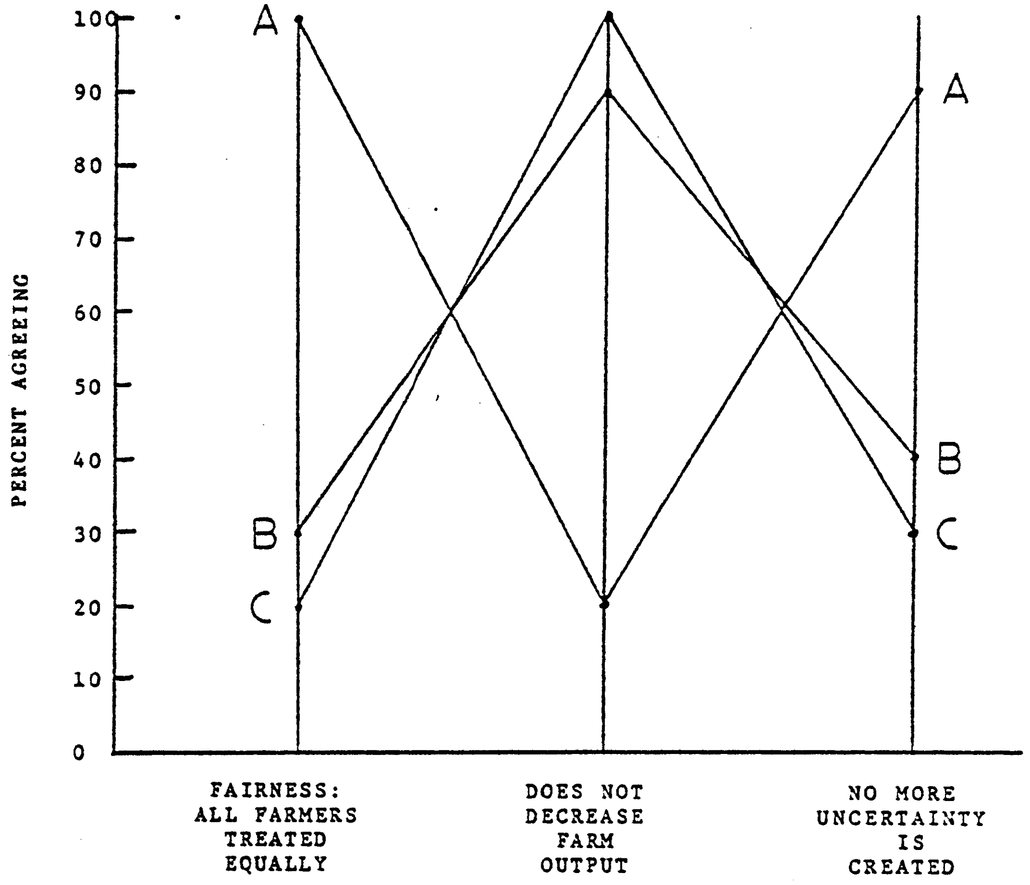


Figure 6.2 Slide employed in the replication of Tversky's experiment depicting the experimental alternatives used in Task 11.

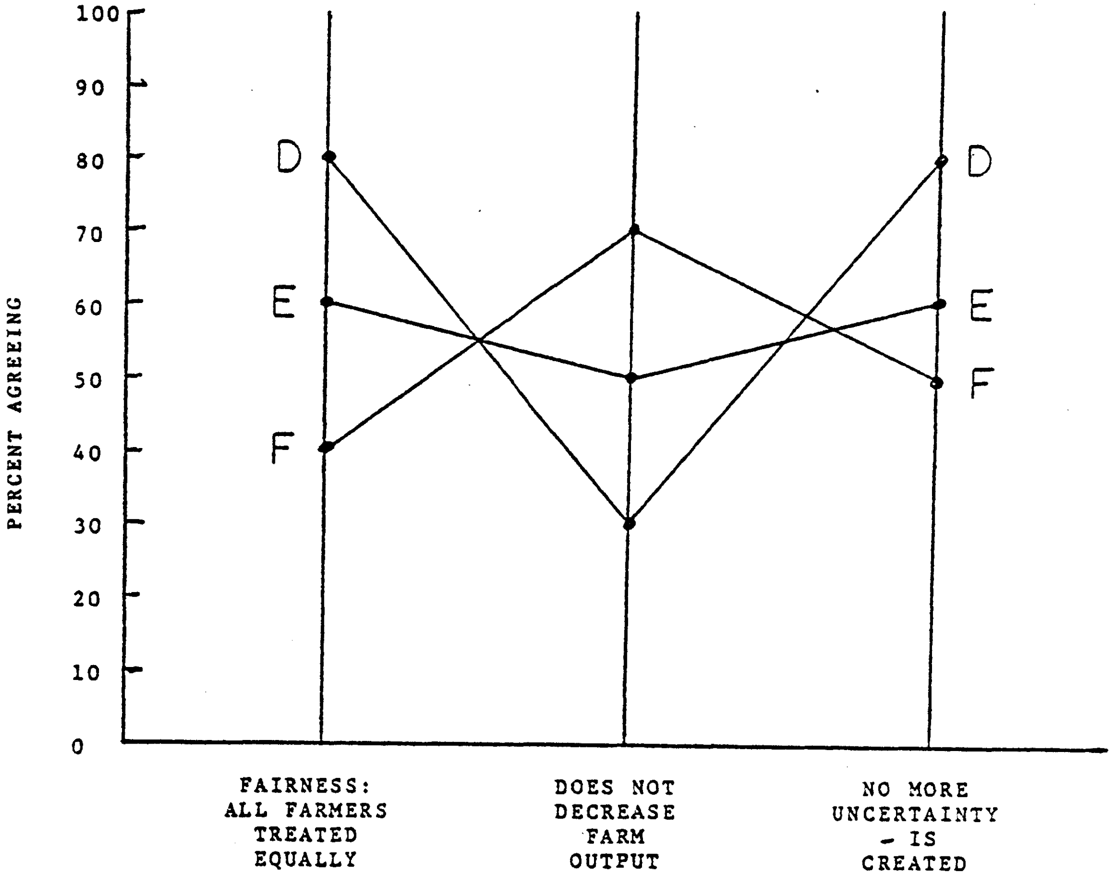


Figure 6.2 continued. Slide employed in the replication of Tversky's experiment depicting the non-experimental alternatives used in Task 11.

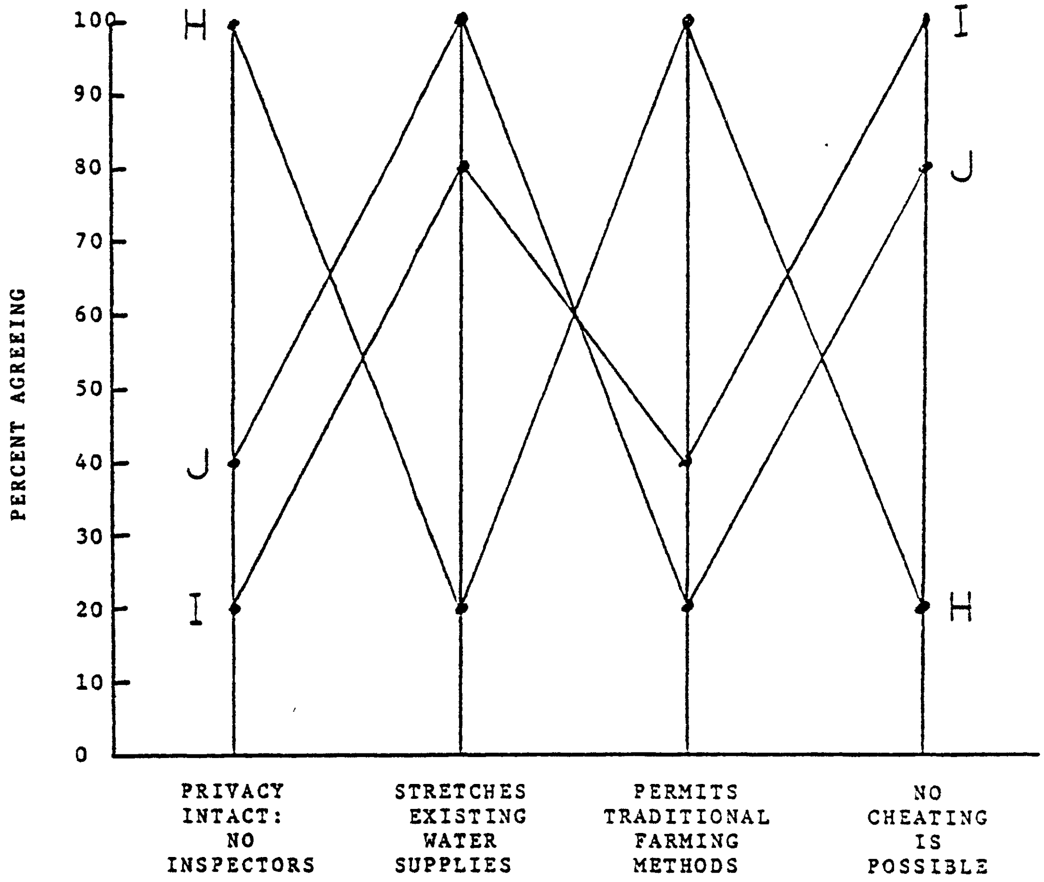


Figure 6.3 Slide employed in the replication of Tversky's experiment depicting the experimental alterntives used in Task III.

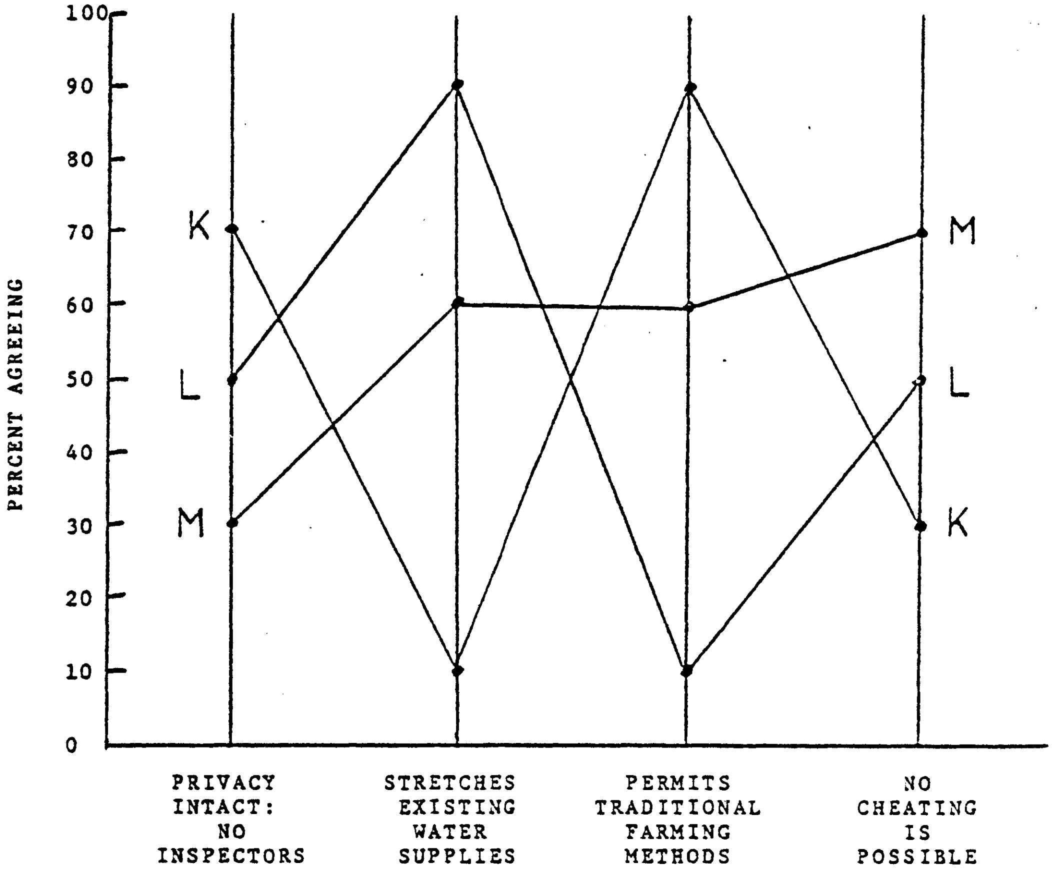


Figure 6.3 continued. Slide employed in the replication of Tversky's experiment depicting the non-experimental alternatives used in Task III.

their selections based solely on the alternatives' performance on the attributes shown. The subjects were told that the score of each alternative on each attribute represented the results of a survey conducted among farmers at a location where the policy was already in effect. For instance in Task I, considering the attribute "Compliance is Convenient," policy x has a score of 20, meaning that 20% of the farmers polled agreed that compliance with policy x is convenient.

The goals of the experimental design were:

1. To repeat each experimental slide as often as time permits. (Accomplish this by showing fewer non-experimental slides.)
2. To space the repetitions as far apart as possible. (Accomplish this by showing more experimental slides and mixing slides by all three tasks.)
3. To have subjects learn the tasks in order to make quick decisions. (Accomplish this by presenting Tasks I, II and III at separate sessions.)

Since these goals conflict, a compromise experimental design was chosen (see Table 6.1). This design provides for the following:

- 3 one and a half hour sessions
- stimuli from 2 tasks were used in each session
- a total of 20 repetitions of each experimental slide
- 160 total slides shown in each session
- 20 seconds per slide to decide
- every other slide is non-experimental
- experimental slides are repeated 10 times per session
- repetitions of experimental slides occur every 16 slides.

Table 6.1 Experimental design for presenting slides in the replication of Tversky's experiment.

TYPE OF SLIDE:	NUMBER OF SLIDES IN GROUP	SESSION 1		SESSION 2		SESSION 3	
		Number of times viewed each	Total number of slides	Number of times viewed each	Total number of slides	Number of times viewed each	Total number of slides
TASK I EXPERIMENTAL	4	10	40	10	40		
TASK I NON-EXPERIMENTAL	8	3	24	3	24	3	24
TASK II EXPERIMENTAL	4	10	40			10	40
TASK II NON-EXPERIMENTAL	8	3	24	3	24	3	24
TASK III EXPERIMENTAL	4			10	40	10	40
TASK III NON-EXPERIMENTAL	8	4	32	4	32	4	32
TOTAL NUMBER OF SLIDES VIEWED PER SESSION:			160		160		160

6.2.5 Classroom Procedure

All subjects were required to attend a seminar prior to the first session which provided background information about the groundwater problem on the High Plains and described various conservation policies and their consequences. At the beginnings of the first session, decision making with score profiles was explained as was the meaning of each of the attributes. Each slide was projected for about 20 seconds (longer at first) and then the subjects recorded their choices on an answer sheet.

6.2.6 Data Analysis

The alternatives used in the three tasks are as follows:

Task I Experimental alternatives Y and Z are similar and X is different. Alternatives U, V, and W are non-experimental.

Task II Experimental alternatives B and C are similar and A is different. Alternatives D, E, and F are non-experimental.

Task III Experimental alternatives I and J are similar, and H is different. Alternatives K, L, and M are non-experimental.

Subjects chose one alternative from each of the following experimental slides:

Task I {X,Y,Z}, {X,Z}, {X,Y}, {Y,Z}
Task II {A,B,C} {A,B} {A,C} {B,C}
Task III {H,I,J} {H,I} {H,J} {I,J}

This choice was repeated 20 times by each subject.

To compare the similarity hypothesis and the constant ratio rule calculate each subject's actual choice probabilities and see if the following statements of the similarity hypothesis are true, meaning that the constant ratio rule and simple scalability are violated:

Similarity Hypothesis implies $P(Y;X) > P_Z(Y;X)$ and $P(Z;X) > P_Y(Z;X)$.

Similarity Hypothesis implies $P(B;A) > P_C(B;A)$ and $P(C;A) > P_B(C;A)$.

Similarity Hypothesis implies $P(I;H) > P_J(I;H)$ and $P(J;H) > P_I(J;H)$.

Recall that

$$P_Z(Y;X) = \frac{P(Y;X,Z)}{P(Y;X,Z) + P(X;Y,Z)} .$$

Simple scalability implies that all the inequalities (>) above should be equalities (=).

Once this analysis has been made for each subject, the data can be aggregated to see if the similarity hypothesis holds for the population of subjects. This is done by averaging the individuals' choice probabilities to determine the group's choice probabilities.

To determine which, if any, forms of stochastic transitivity hold, calculate all the binary choice probabilities from the choices among experimental pairs of alternatives and record the frequency with which each form holds (see Section 6.2.1 for forms of stochastic transitivity). Similarly, to determine if the multiplicative inequality holds, calculate all trinary choice probabilities from among the experimental triplets and record the frequency with which the inequality holds (see Section 6.2.1 for a description of the Multiplicative Inequality).

6.2.7 Results

The subjects were exposed to each of the 12 experimental slides 20 times and chose one alternative at each viewing. The choice probability data reveals that the subjects were more consistent in their choices of alternatives in tasks which had fewer attributes. Out of 40 observations per task (i.e., 4 experimental slides per task times

10 subjects), Task I (2 attributes) had 28 cases where the subject picked the same alternative every time he/she viewed the slide. Task II (3 attributes) had 24 such cases and Task III (4 attributes) had only 15 such cases. This measure of consistency reflects the relative ease or difficulty of memorizing each of the tasks. The experiment was designed to allow the subjects to quickly learn each task but hopefully to forget their previous choice when the slides were repeated. It appears that presenting decision information in the score profile format is very effective. In this experiment, especially in Tasks I and II, the subjects both learn the task and often memorized their previous choices. As further results are presented, care will be taken to see if the decreased consistency in Task III affects any of the other results.

Table 6.2 presents the observed choice probabilities [$P(y;z)$] and the computed choice probabilities [$P_x(y;z)$]. The constant ratio rule (CRR) implies that $P(y;z) = P_x(y;z)$, the similarity hypothesis (SH) implies that $P(y;z) > P_x(y;z)$, and regularity implies that $P(y;z) \geq P(y;x,z)$. CRR and SH were tested as stated above but a stronger form of regularity, $P(y;z) \geq P_x(y;z)$ was tested. Notice that if $P(y;z) \geq P_x(y;z)$ then $P(y;z) \geq P(y;x,z)$. Recall that $P_x(y;z) \geq P(y;x,z)$ because

$$P_x(y;z) = \frac{P(y;x,z)}{P(y;x,z) + P(z;x,y)}$$

and the denominator is less than or equal to 1.00. Therefore, any time strong regularity holds, regularity also holds. Out of 53 observations, both strong regularity [$P(y;x) \geq P_z(y;x)$] and CRR [$P(y;x) = P_z(y;x)$] held in 25 cases, strong regularity held in an additional 13 cases as well, and neither held in 15 cases. Students' t-tests for the matched pairs were done to see if the differences between $P(y;x)$ and $P_z(y;x)$ were

Table 6.2 Observed and Computed Binary Choice probabilities. A large absolute t-value is the basis for rejecting the constant ratio rule (CRR) while only a large negative t-value rejects the Regularity Model. Also, a significantly large (positive) t-value is necessary to retain the similarity hypothesis.

Subject	Task I (2 Attributes)				Task II (3 Attributes)				Task III (4 Attributes)			
	P(Y;X)	P_Z(Y;X)	P(Z;X)	P_Y(Z;X)	P(B;A)	P_C(B;A)	P(C;A)	P_B(C;A)	P(I;H)	P_J(I;H)	P(J;H)	P_I(J;H)
1	1.00	1.00	0	UDF.	.818	1.00	.545	UDF.	1.00	UDF.	1.00	1.00
2	.045	0	0	0	.455	.500	.318	0	.955	0	.955	.955
3	0	.091	0	0	.818	.850	.818	.401	.909	1.00	.864	1.00
4	.045	0	.048	0	0	0	0	0	1.00	.955	1.00	0
5	0	0	0	0	0	0	0	0	.773	UDF.	.727	1.00
6	0	0	0	0	0	0	0	0	.909	1.00	.909	1.00
7	0	.045	0	0	1.00	1.00	1.00	UDF.	.636	1.00	.864	1.00
8	.318	.636	.190	0	.500	.267	.500	.389	.864	.929	.818	.890
9	0	0	0	0	.136	.100	.136	.100	1.00	1.00	1.00	1.00
10	1.00	1.00	1.00	UDF.	1.00	1.00	1.00	UDF.	1.00	1.00	1.00	1.00
Overall proportion	.241	.277	.124	0	.473	.472	.432	.127	.905	.861	.914	.885
t-tests	t = -1.08 ns Retain REG. Retain CRR		t = 1.257 ns Retain REG. Retain CRR		t = .031 ns Retain REG. Retain CRR		t=1.938 α=.05 Retain REG. Reject CRR		t = .355 ns Retain REG. Retain CRR		t = .262 ns Retain REG. Retain CRR	

REG. - STRONG REGULARITY, CRR - CONSTANT RATIO RULE, ns - not significant, UDF - UNDEFINED (division by zero) significant enough to reject either hypothesis. In all six sets of results shown in Table 6.2, the strong regularity hypothesis was retained. However, in one case, CRR was rejected at a significance level of .05. The only difference revealed between Tasks I, II and III with regard to these hypotheses, were that 9 of the 15 cases in which neither one held occurred in Task III with Tasks I and II having only 3 cases each. This can be attributed to the inconsistency of responses in Task III.

Table 6.3 presents the binary choice probabilities used to determine which forms of stochastic transitivity hold. Out of 30 observations, the weak form held in all cases, the moderate form held in 29 cases, and the strong form held in 19 cases. Since the strong form holds in cases where all three binary probabilities are equal (such as in Table 6.3, Subject #1, Task #1) and since this is the case when the choices are perfectly consistent, then it is not surprising to note that the strong form holds in 8 of 10 cases in Task I, in 7 of 10 cases in Task II but in only 4 of 10 cases in Task III. T-tests were performed to determine how appropriate each form was in describing the experimental choices. As shown in Table 6.3, the weak and moderate forms were retained in all three tasks, but the strong form was rejected at a .10 significance level in Task I and at a .025 level in Task III.

Table 6.4 presents the trinary choice probabilities and the products of the binary choice probabilities, data needed to evaluate the Multiplicative Inequality (MI). Overall, MI held in 71 of 90 (78.9%) observations, and specifically it held in 23 of 30 (76.7%) cases in Task I, 26 of 30 (86.7%) cases in Task II, and 22 of 30 (73.3%) cases in Task III. No significant trends of differences between the tasks (i.e., mono-

Table 6.4 Multiplicative Inequality (MI) data comparing trinary choice probabilities with binary products. Note a large negative t-value is needed to reject MI.

SUBJECT	TASK I				TASK II				TASK III			
	ALT. 1	Trinary P(1; 2,3)	Binary P(1;2) × P(1;3)	MI	ALT. 1	Trinary P(1; 2,3)	Binary P(1;2) × P(1;3)	MI	ALT. 1	Trinary P(1; 2,3)	Binary P(1;2) × P(1;3)	MI
1	X	0	0	*	A	0	.083		H	0	0	*
	Y	1.00	1.00	*	B	1.00	.818	*	I	0	0	*
	Z	0	0	*	C	0	0	*	J	1.00	1.00	*
2	X	1.00	.955	*	A	.500	.322	*	H	.045	.002	*
	Y	0	.045		B	.500	.455	*	I	0	0	*
	Z	0	0	*	C	0	0	*	J	.955	.955	*
3	X	.909	1.00		A	.136	.033	*	H	.045	0	*
	Y	.091	0	*	B	.773	.781		I	.864	.865	
	Z	0	0	*	C	.091	.037	*	J	.136	.041	*
4	X	1.00	.908	*	A	1.00	1.00	*	H	.045	0	*
	Y	0	.045		B	0	0	*	I	.955	1.00	
	Z	0	0	*	C	0	0	*	J	0	0	*
5	X	1.00	1.00	*	A	1.00	1.00	*	H	0	.062	
	Y	0	0	*	B	0	0	*	I	0	0	*
	Z	0	0	*	C	0	0	*	J	1.00	.727	*
6	X	1.00	1.00	*	A	1.00	1.00	*	H	0	.008	
	Y	0	0	*	B	0	0	*	I	.045	0	*
	Z	0	0	*	C	0	0	*	J	.955	.909	*
7	X	.955	1.00		A	0	0	*	H	0	.050	
	Y	.045	0	*	B	1.00	1.00	*	I	.682	.404	*
	Z	0	0	*	C	0	0	*	J	.318	.314	*
8	X	.364	.552		A	.500	.250	*	H	.045	.025	*
	Y	.636	.275	*	B	.182	.045	*	I	.591	.393	*
	Z	0	.026		C	.318	.454		J	.364	.445	
9	X	1.00	1.00	*	A	.818	.746	*	H	0	0	*
	Y	0	0	*	B	.091	.136		I	.955	.909	*
	Z	0	0	*	C	.091	0	*	J	.045	.091	
10	X	0	0	*	A	0	0	*	H	0	0	*
	Y	1.00	.955	*	B	1.00	1.00	*	I	.955	.952	*
	Z	0	.045		C	0	0	*	J	.045	.048	
t-test	t = .422 not significant Retain MI				t = 1.052 not significant Retain MI				t = 1.830 not significant Retain MI			

* Indicates that MI holds.

Table 6.3 Stochastic Transitivity data and the results of t-tests performed to test the applicability of the Strong, Moderate and Weak forms of Stochastic Transitivity.

Subject	TASK I							TASK II							TASK III						
	1	P(1;2)	2	P(2;3)	3	P(1;3)	Form	1	P(1;2)	2	P(2;3)	3	P(3;1)	Form	1	P(1;2)	2	P(2;3)	3	P(1;3)	Form
1	Y	1.00	X	1.00	Z	1.00	S	B	.818	A	.545	C	1.00	S	J	1.00	I	1.00	H	1.00	S
2	X	.955	Y	1.00	Z	1.00	S	A	.545	B	1.00	C	.591	M	J	1.00	I	.955	H	.955	M
3	X	1.00	Y	.773	Z	1.00	S	B	.955	C	.818	A	.818	M	I	.952	J	.864	H	.909	M
4	X	.953	Y	1.00	Z	.953	M	A	1.00	B	1.00	C	1.00	S	I	1.00	J	1.00	H	1.00	S
5	X	1.00	Y	.864	Z	1.00	S	A	1.00	B	1.00	C	1.00	S	J	1.00	I	.773	H	.727	W
6	X	1.00	Y	1.00	Z	1.00	S	A	1.00	B	1.00	C	1.00	S	J	1.00	I	.909	H	.909	M
7	X	1.00	Y	1.00	Z	1.00	S	B	1.00	C	1.00	A	1.00	S	I	.636	J	.864	H	.636	M
8	X	.682	Y	.864	Z	.810	M	C	.500	A	.500	B	.909	S	J	.545	I	.864	H	.818	M
9	X	1.00	Y	1.00	Z	1.00	S	A	.864	B	1.00	C	.864	M	I	.909	J	1.00	H	1.00	S
10	Y	.955	Z	1.00	X	1.00	S	B	1.00	C	1.00	A	1.00	S	I	.952	J	1.00	H	1.00	S

t-tests	Form	t	α	Rej/Ret	Form	t	α	Rej/Ret	Form	t	α	Rej/Ret
	STRONG	1.50	.10	Reject	STRONG	.14	ns	Retain	STRONG	2.32	.025	Reject
	MODERATE	-2.32	ns	Retain	MODERATE	-1.59	ns	Retain	MODERATE	-1.45	ns	Retain
	WEAK	-	ns	Retain	WEAK	-	ns	Retain	WEAK	-	ns	Retain

S - Strong, M - Moderate, W - Weak (Forms of Stochastic Transitivity), ns - Not Significant

{X,Y,Z}, {A,B,C}, and {H,I,J} are the sets of alternatives employed in Tasks I, II and III, respectively.

tonically increasing or decreasing from Task I to Task III) were found. T-tests revealed that MI should be retained for all three tasks. Furthermore, the strict form of MI,

$$P(x;y,z) > P(x;y) \cdot P(x;z)$$

was retained in Tasks II and III at a .05 significance level.

The results of Tversky's experiment can be summarized as follows. The score profiles present the decision information in a very efficient format but one which is more easily memorized than was desirable in this experiment. The regularity hypothesis (EBA model) held in all six cases while the constant ratio rule (Luce model) held in five of six cases. The similarity hypothesis was retained in only one of six cases. The data consistently displayed the moderate form of stochastic transitivity (EBA model) but displayed the strong form (Luce model) only about half the time. The Multiplicative Inequality (EBA and Luce models) was generally confirmed by the data. Therefore, the regularity property of the EBA model was reaffirmed by this experiment but not the stronger similarity hypothesis, Luce's constant ratio rule and strong stochastic transitivity were shown to be weak assumptions.

6.3 Predictive Experiment

6.3.1 Hypothesis

Two major hypotheses are tested by the predictive experiment.

1. That the EBA model is a good predictor of which conservation policies would be selected by a public referendum.
2. That the EBA model predicts these choices more accurately than Luce's model (with an additive utility function).

Luce's model represents the existing probabilistic choice models which have been used extensively in the past. In addition to testing the hypotheses, the predictive experiment provided invaluable experience and insights into predictive modelling which can only be gotten by an actual application of the model.

6.3.2 Background

Recall the recursive choice probability equation for the EBA model (see Section 4.1 for notation):

$$P(x_g;A) = \frac{\sum_{B_k \subset A} U(\bar{B}_k) \cdot P(x_g;B_k)}{\sum_{B_\ell \subset A} U(\bar{B}_\ell)}$$

where

$$U(\bar{B}_k) = \sum_{i=1}^{n} u(\alpha_i) \cdot K_{ik}$$

$$K_{ik} = V_{ik} \cdot \prod_{B_\ell \not\subset B_k} [V_{ik} - V_{i\ell}]$$

$$V_{ik} = \prod_{x_g \varepsilon B_k} V_g(\alpha_i) .$$

Similarly, the choice probability equation for Luce's model using an additive utility function is:

$$P(x_g;A) = \frac{U(x_g)}{\sum_{x_h \varepsilon A} U(x_h)}$$

where

$$U(x_g) = \sum_{i=1}^{n} u(\alpha_i) \cdot V_g(\alpha_i) .$$

Luce's model in this context is defined using the same notation and binary aspects used for the EBA model.

The EBA and Luce models differ in their assumptions and consequences. Several of these differences are examined in the Tversky's experiment, Section 6.2. The EBA model assumes that the decision maker employs the elimination by aspects strategy; successively thinking of new aspects and eliminating competing alternatives. Luce's model, on the other hand, assumes a holistic judgment of the relative worth of each of the alternatives and an elementary, not subdivided, decision. A significant difference in predictions arises from these two very different models. The EBA model predicts that a very good but dominated alternative has a zero probability of being chosen, while Luce's model assigns such an alternative a good chance of being selected. One can speculate that if the decision maker follows the EBA strategy, the EBA model will predict the decision correctly, and if the decision maker makes a holistic judgment, Luce's model will predict more accurately.

6.3.3 Data Needs

For the classroom experiment, it was assumed that the set of alternatives, $A = \{x_1,x_2,..,x_g,..,x_m\}$, and the set of aspects, $A' = \{\alpha_1, \alpha 2,..,\alpha_i,..,\alpha_n\}$, has already been determined. Three different categories of alternatives were presented: nine groundwater policies, three surface water policies and four farming practices. There were nine distinct aspects employed in the experiment.

The data needed to calibrate the EBA model for one subject is:

V_g - The possession function for each alternative (a list of which aspects each alternative possesses), and

$u(\alpha_i)$ - The relative importance of each aspect.

To calibrate the EBA model for the experimental group, the individual V_g and $u(\alpha_i)$ data must first be aggregated and then incorporated into the model. This same data is also needed to calibrate Luce's model, both for the individual and the group. In order to judge the predictive accuracy of the EBA and Luce's models it was necessary to have each individual rate each alternative and to vote on the alternatives in a referendum. For individual responses, it appears that the EBA model should be a better predictor of which alternative would receive the highest rating (i.e., which alternative would be chosen) while Luce's model should be a better predictor of rating distributions. For the group responses, the EBA model should provide a better prediction of the referendum outcome than Luce's model.

6.3.4 Experimental Design

The experiment involved 16 MIT students and faculty as subjects, six of whom were recruited and then paid for their participation because they had permanent residences on farms in the High Plains. The experiment covered a two week period during which the subjects first attended a background seminar describing the Ogallala problem and possible conservation alternatives. They then attended a test session where they completed answer sheets, and finally they attended a follow-up seminar which included a group discussion of the alternatives and a referendum to select alternatives. The alternatives used in the experiment are described below.

Groundwater Policies

1. Uniform well spacing of 3300 feet for all new wells.
2. New well permits cannot bring the depletion rate to more than 40%.

in 25 years (2% per year) within a 3-mile radius of the proposed site.

3. No new wells (moratorium).
4. Pumping rotation such that each well can be pumped only 3 days each week.
5. Specific allocation for each well such that a maximum depletion of 40% in 25 years (2% per year) occurs within a 3-mile radius of the well. A three year allocation period is used with full carryover, but limited borrow.
6. Uniform allocation per irrigable acre based on a 40 year average lifetime for the entire district. A five year allocation is used with limited carryover and no borrow.
7. Uniform allocation per irrigated acre based on attaining a sustained yield for the aquifer within the district. A one year allocation period is used with no carryover and no borrow.
8. User charges (dollars per acre-foot) set by the district board to reduce withdrawals so that supplies last 40 years. The money is then returned to the farmers as subsidies for water-saving farming practices and conservation-related investments.
9. A market for sustained-yield-shares, each of which entitles the bearer to pump one acre-foot each year. The shares are initially auctioned off by the district which uses the proceeds for subsidizing conservation practices.

Surface Water Policies

1. A surface water rental market where water rights owners can rent their water to any beneficial user.
2. Water is imported to the district and sold at cost to the farmer.
3. Weather modification (cloud seeding) financed by a tax on cropped acreage.

Farming Practices

1. Voluntary use of flow meters, reuse pits, sprinklers or center pivots, and irrigation scheduling.
2. Tax credit and subsidies for the use of flow meters, reuse pits, sprinklers or center pivots, and irrigation scheduling.
3. Mandatory use of flow meters, reuse pits, sprinklers or center pivots, and irrigation scheduling.
4. Both mandatory use of and tax credits and subsidies for use of flow meters, reuse pits, sprinklers or center pivots, and irrigation scheduling.

Although in an actual groundwater management district many combinations of alternatives can be selected from the three categories and from within categories, the experimental subjects were instructed to consider the three categories independently and to assume alternatives in the same category to be mutually exclusive.

Aspects were designed to be desirable features of conservation policies. They are as follows:

1. The policy does not create additional uncertainty about the future availability of water.
2. The policy is fair; all farmers are treated equally.

3. The policy is effective in halting the mining of groundwater.
4. The policy is effective in stretching the existing supply of water over a long period of time (30-50 years).
5. It is inexpensive for farmers to comply with this policy.
6. It is convenient for the farmers to comply with the policy.
7. The policy permits farmers to continue to use their traditional farming practices.
8. There is no invasion of privacy by meter readers or other inspectors.
9. The policy does not reduce short term farm outputs.

In many cases, the question of which alternatives possess which aspects required subjective judgments because of the imprecise definitions of the aspects. In these cases, the possession of aspects was a relative matter since the decision depended on the offered set of alternatives. For instance, if none of the alternatives was "truly" convenient but one was much more convenient than the others, then that alternative might be said to possess the aspect of convenience.

6.3.5 Classroom Procedure

The one and one half hour experimental session began with a brief review of the material presented in Section 5.2, Water Conservation Policy Options, including Figure 5.1, A Hierarchy of Policies, Programs, and Results of Efforts to Control the Groundwater Decline. Next, since the subjects were students, not farmers, it was necessary to heighten their awareness of the various differences in farmers' situations. This included differences between farmers with respect to the:

1. amount of land owned and irrigated,
2. number of wells owned,

3. access to surface water supplies,
4. ownership of center pivots, reuse pits, sprinklers, etc.,
5. depth to the groundwater (pumping costs),
6. thickness of the underlying aquifer,
7. debt level, and
8. age and education of the farmers.

The subjects were instructed to be aware of and sensitive to the needs and desires of farmers from these various different situations during the experiment instead of trying to represent any one specific farm situation. Thus the subjects probably reflected a less myopic point of view than most actual farmers.

Answer Sheet No. 1 (Appendix III) was used to assess the Possession Function, V_g, of each subject. The proctor first described an alternative and then read nine statements corresponding to the nine aspects. A pictoral diagram (Appendix III) accompanied each alternative for easier understanding. The subjects indicated on the answer sheets whether or not the alternative possessed each aspect. This was repeated for all alternatives.

Answer Sheet No. 2 (Appendix III) was used to assess the relative importance of each aspect, $u(\alpha_i)$, to each subject. This was done by the subjects first making paired comparisons among the aspects, then ranking the aspects, and finally rating them on a scale from 0 to 20. The paired comparisons and ranking were used as stimulus exercises for the ratings.

Answer sheets 1 and 2 provided the V_g and $u(\alpha_i)$ data needed to calibrate the EBA and Luce models. Answer Sheet No. 3 (Appendix III) instructed the subjects to rate the alternatives on a scale from 0 to

20. This information was needed to test the predictive accuracy of the two models.

The follow-up seminar began with a presentation of existing water conservation policies currently being used by the Groundwater Management Districts, Section 5.1 of this thesis. Next, a listing of the nine Groundwater, three Surface water, and four Farming Policy alternatives was distributed to those attending the seminar. Following a 45 minute discussion and debate over the alternatives each subject voted by raised hand for one alternative from each category.

6.3.6 Analysis of Data

The data consisted of a set of V_g (possession functions), $u(\alpha_i)$ (ratings of aspects), ratings of alternatives, and the referendum vote for each subject. Prior to the referendum, it was assumed that the alternative which received the highest rating was the subject's choice. After the $u(\alpha_i)$ had been normalized to lie between 0 and 1, the V_g and $u(\alpha_i)$ were used to calibrate and solve the choice probability equations for the EBA and Luce models (see Section 6.3.2 for equations). This yielded two sets of predictions of the probability that each subject would choose each alternative. Group predictions were made two different ways for both the EBA and Luce models. One way was to aggregate the individuals' responses first, and then to solve the choice models. The other way was to solve the choice models first for each individual, and then aggregate the results. In this experiment, both methods were used for both models for comparison, although in a large scale application the raw data would be aggregated first and then used in the models.

The procedure for aggregating individuals' ratings of aspects,

$u(\alpha_i)$, ratings of alternatives, EBA choice probabilities, and Luce choice probabilities was simply arithmetic averaging. The aggregation of individuals' possession functions, V_g, was done based on a "majority rule." That is, if more than half of the subjects indicated that a particular alternative, x_g, possessed a particular aspect, α_i, then the group value of $V_g(\alpha_i)$ was set at 1.0. Otherwise the group $V_g(\alpha_i)$ was equal to zero. Many different schemes for aggregating the V_g's could have been used. Since this study represents the first application of the EBA model there is no existing theory concerning the aggregation of EBA data. Such research is needed before the EBA model becomes fully operational. Because the experimental group was small, no attempt was made to subdivide it into more homogeneous subgroups as would be done in a large scale field application of the model.

6.3.7 Results

Table 6.5 presents the group results of the Predictive experiment. The results for each individual are contained in Appendix III. Data appearing in the rows marked "Highest Rating," indicate what fraction of the group rated each alternative the highest. Similarly, numbers in the "Referendum Vote" rows indicates what fraction of the group voted for each alternative. The "Ratings" data are the arithmetic averages of the ratings assigned by each individual. EBA and Luce model predictions in the top half of Table 6.5 are the group results determined by first averaging the individual responses and then running the models. In the bottom half of the table, the models were run for each individual first and then the model results were averaged. These results include several rows with "Expert's Possession Function." Since there was very little

Table 6.5 Observed and Predicted choice probabilities, group data from the Predictive Experiment

	TYPE OF RESULT	CONSERVATION POLICY ALTERNATIVES															
		GROUNDWATER									SURFACE WATER			FARMING PRACTICES			
		1	2	3	4	5	6	7	8	9	1	2	3	1	2	3	4
RAW DATA AVERAGED	Highest Rating	0	0	0	.125	.125	.313	.156	.188	.094	.677	.146	.177	.156	.688	.125	.031
	Referendum Vote	0	0	0	.188	0	.563	0	.125	.063	.813	.187	0	.250	.750	0	0
	EBA Predictions	0	0	.586	0	0	.284	.130	0	0	.319	.319	.362	0	1	0	0
	EBA & Expert Pos. Func.	.069	0	.069	0	0	.691	.135	0	.035	.260	.475	.264	.386	.386	.114	.114
	Ratings	.089	.103	.061	.118	.144	.191	.110	.121	.071	.460	.334	.206	.278	.358	.136	.228
	Luce Predictions	.117	.162	.184	.105	.074	.143	.122	.037	.055	.349	.349	.302	.246	.307	.223	.223
	Luce & Expert Pos. Fun.	.119	.095	.119	.077	.113	.169	.116	.115	.076	.317	.391	.291	.329	.329	.171	.171
MODEL RESULTS AVERAGED	Highest Rating	0	0	0	.125	.125	.313	.156	.188	.094	.677	.146	.177	.156	.688	.125	.031
	Referendum Vote	0	0	0	.188	0	.563	0	.125	.063	.813	.187	0	.250	.750	0	0
	EBA Predictions	.112	.098	.331	.126	.110	.068	.115	.013	.012	.281	.509	.209	.342	.522	.058	.078
	EBA & Expert Pos. Fun.	.067	0	.067	0	0	.689	.128	0	.050	.254	.476	.269	.386	.386	.114	.114
	Ratings	.089	.103	.061	.118	.144	.191	.110	.121	.071	.460	.334	.206	.278	.358	.136	.228
	Luce Predictions	.116	.133	.158	.119	.112	.129	.106	.066	.068	.327	.418	.254	.276	.346	.186	.192
	Luce & Expert Pos. Func.	.118	.094	.118	.077	.113	.169	.117	.116	.077	.313	.401	.286	.334	.334	.166	.166

agreement among subjects as to which alternatives possessed which aspects, the analysis was repeated using one common possession function defined by the author. Therefore, the model predictions using each subject's possession function can be compared to the predictions made using the expert's.

As expected, the referendum voting, which followed a debate over the alternatives, was more polarized in all three categories (Groundwater, Surface water, and Farming Practices) than the highest ratings previously assigned privately by each individual (Meyers and Lamm, 1975).

To allow the reader to comprehend visually how the predicted choice probabilities compare to the observed choice frequences, Appendix III contains graphic displays of the data plotted using the numbers in Table 6.5. Perfectly accurate predictions would lie on the diagonal shown in each figure.

Table 6.6 presents the results of Chi-Squared tests done to compare the observed choice frequencies and the predicted choice probabilities. Note that the Chi-Squared test determines if the differences between the observed and predicted distributions are significant. Therefore, the less significant the differences, the more accurate the model.

Table 6.7 presents the results of linear regression tests done to determine how well the model predictions of choice probabilities correlate with the observed choice frequencies. The closer the correlation coefficient is to +1.00, the more accurate the prediction. Considering all policies together, according to the Chi-Squared analysis, none of the models consistently performed well predicting either the highest ratings or the referendum voting (predictions of ratings will be

Table 6.6 Chi-Squared analysis testing the significance of the differences between the observed choice frequencies and the predicted choice probabilities. I.e., a highly significant difference indicates an inaccurate prediction, no significance indicates an accurate prediction.

GROUP RESULTS	CHI-SQUARED TESTS		GROUNDWATER POLICIES		SURFACE WATER POLICIES		FARMING POLICIES		ALL POLICIES	
	OBSERVED CHOICES	PREDICTED CHOICES	χ^2	1/ SIG. α	χ^2	SIG. α	χ^2	SIG. α	χ^2	SIG. α
RAW DATA AVERAGED	Highest Ratings	EBA Predictions	9.50	.01	9.44	.01	2.24	.20	20.51	.01
	Highest Ratings	EBA (w/Expert)2/	7.16	.20	14.81	.001	6.96	.10	28.03	.001
	Referendum Votes	EBA Predictions	15.84	.001	18.91	.001	1.00	ns	35.75	.001
	Referendum Votes	EBA (w/Expert)	5.11	ns	25.83	.001	9.91	.02	40.85	.001
	Ratings	Luce Predictions	6.25	ns	1.06	ns	.75	ns	8.06	ns
	Ratings	Luce (w/Expert)	1.13	ns	1.56	ns	.58	ns	3.27	ns
	Referendum Votes	Luce Predictions	34.69	.001	15.91	.001	17.36	.001	67.97	.001
	Referendum Votes	Luce (w/Expert)	26.30	.001	18.77	.001	14.65	.01	59.72	.001
MODEL RESULTS AVERAGED	Highest Ratings	EBA Predictions	69.70	.001	13.15	.01	4.15	ns	87.00	.001
	Highest Ratings	EBA (w/Expert)	6.14	.20	15.43	.001	6.96	.10	28.53	.001
	Referendum Votes	EBA Predictions	89.30	.001	22.91	.001	4.16	ns	116.3	.001
	Referendum Votes	EBA (w/Expert)	4.61	ns	26.79	.001	9.91	.02	41.3	.001
	Ratings	Luce Predictions	2.52	ns	1.28	ns	.33	ns	4.13	ns
	Ratings	Luce (w/Expert)	1.12	ns	1.64	ns	.64	ns	3.40	ns
	Referendum Votes	Luce Predictions	34.85	.001	17.66	.001	13.63	.01	66.14	.001
	Referendum Votes	Luce (w/Expert)	26.27	.001	19.18	.001	13.94	.01	59.39	.001

1/Level of Significance of the differences between the observed and the predicted choices, 2/ Using the expert's possession function.

ns - not significant, greater than .20

Table 6.7 Linear regression analysis comparing the observed and predicted choice probabilities to examine the accuracy of the EBA and Luce models.

GROUP RESULTS	CORRELATION COEFFICIENTS		Groundwater Policies	Surface Water Policies	Farming Policies	All Policies
	OBSERVED CHOICES	PREDICTED CHOICES				
RAW DATA AVERAGED	Highest Ratings	EBA Predictions	.77	-.45	.98	.80
	Highest Ratings	EBA (Expert Possession Function)	.70	-.56	.73	.49
	Referendum Votes	EBA Predictions	.18	-.68	.94	.57
	Referendum Votes	EBA (Expert Possession Function)	.87	-.31	.82	.62
	Ratings	Luce Predictions	-.09	.87	.88	.82
	Ratings	Luce (Expert Possession Function)	.63	.25	.84	.88
	Referendum Votes	Luce Predictions	.06	.68	.99	.47
	Referendum Votes	Luce (Expert Possession Function)	.60	-.05	.82	.54
MODEL RESULTS AVERAGED	Highest Ratings	EBA Predictions	-.48	-.34	.87	.46
	Highest Ratings	EBA (Expert Possession Function)	.70	-.59	.67	.48
	Referendum Votes	EBA Predictions	-.28	-.07	.96	.47
	Referendum Votes	EBA (Expert Possession Function)	.88	-.35	.82	.61
	Ratings	Luce Predictions	.02	.45	.93	.87
	Ratings	Luce (Expert Possession Function)	.63	.23	.84	.87
	Referendum Votes	Luce Predictions	.06	.16	.97	.52
	Referendum Votes	Luce (Expert Possession Function)	.60	-.08	.82	.54

discussed later). All models could be rejected at a .01 or a .001 level of significance and their correlation coefficients averaged .55. However, some models did perform better than others. In 4 of 6 cases, according to the Chi-Squared tests, and in 5 of 6 cases based on the regression tests, the models which used the expert's possession function outperformed the models using the individual possession functions. Furthermore, the results imply that the accuracy of the EBA model predictions is more sensitive to changes in the possession function than changes in the relative importance of aspects. This would be expected from the EBA strategy and can be deduced from the results. Observe that in Tables 6.6 and 6.7, there is very little difference between the descriptive statistics in the top and bottom halves of the tables for models which used the expert's possession function. There is a large difference for the other models. According to the EBA model, differences between individuals' possession functions lead to much greater disagreement about the choice probabilities than differences between their weights for each aspect.

The comparison between the EBA and the Luce models is made on the basis of their ability to predict the referendum voting. The referendum was chosen since it reflects the peoples' attitudes after they have been polarized through discussions. This is usually the case in public participation in decision making. Table 6.8 presents a comparison of the accuracy of the EBA and Luce models in predicting the results of the referendum and also permits an easy comparison between the models with and without the expert's possession function. Considering the separate predictions in the three policy categories, according to the Chi-Squared tests, the EBA models were superior in 7 cases and Luce

Table 6.8 A comparison of the accuracy of the EBA and Luce models in predicing the results of the referendum

GROUP RESULTS	PREDICTIVE MODELS	Groundwater Policies		Surface Water Policies		Farming Policies		All Policies	
		X^2	R^2	X^2	R^2	X^2	R^2	X^2	R^2
RAW DATA AVERAGED	EBA Predictions	15.84	.18	18.91	-.68	1.00	.94	35.75	.57
	Luce Predictions	34.69	.06	15.91	.68	17.36	.99	67.97	.47
	EBA (Expert Possession Func.)	5.11	.87	25.83	-.31	9.91	.82	40.85	.62
	Luce (Expert Possession Func.)	26.30	.60	18.77	-.05	14.75	.82	59.72	.54
MODEL RESULTS AVERAGED	EBA Predictions	89.30	-.28	22.91	-.07	4.16	.96	116.30	.47
	Luce Predictions	34.85	.06	17.66	.16	13.63	.97	66.14	.52
	EBA (Expert Possession Func.)	4.61	.88	26.79	-.35	9.91	.82	41.30	.61
	Luce (Expert Possession Func.)	26.27	.60	19.18	-.08	13.94	.82	59.39	.54

X^2 - Chi-Squared statistic, R^2 - Correlation Coefficient models were superior in 5 cases. Similarly, in 3 cases the EBA model predictions had higher correlation coefficients, in 7 cases the Luce model did better and the models were equal in 2 cases.

One purpose of this experiment was to run the EBA and Luce models in different ways in order to learn how to apply them in a future field application. The selection of a preferred method for applying the models will be based on the ease and simplicity of implementing the models on one hand and on the accuracy of the predictions on the other. Therefore, the criteria of simplicity and accuracy shall be the basis of comparing the following model forms:

1. Averaging Raw Data versus Averaging Model Results,
2. Models with individuals' possession functions versus models using the expert's possession function,
3. EBA models versus Luce models (additive utility function).

An examination of Table 6.8 and experience gained in the experiment seems to suggest the following trends:

		SIMPLER	MORE ACCURATE
1.	Raw Data Averaged	MUCH	SAME
	Model Results Averaged		SAME
2.	Individual Possession Functions		
	Expert's Possession Function	MUCH	SLIGHTLY*
3.	EBA Models		SLIGHTLY*
	Luce Models	SLIGHTLY	

*Models using the expert's possession function were much more accurate than models with individuals' possession functions when the number of alternatives was large.

A preliminary conclusion from these results is that a field application of either model could be done by 1) averaging the raw data and 2) using an expert's possession functions. Comparing the EBA and Luce models under those conditions reveals that the EBA model was more accurate (see rows 3 and 4 in Table 6.8 for comparison). The EBA model did particularly well when the number of alternatives was large, i.e., it performed well in predicting the groundwater policies which had 9 alternatives. This is evidenced by the fact that the EBA model had a Chi-Squared of 5.11, good enough to retain the model. In this case, Luce's model was rejected at a .001 significance level with a Chi-Squared of 26.3. Again, with respect to groundwater policies, the EBA model had a correlation coefficient of .87 compared to .60 for Luce's model. With regard to surface water policies, (3-alternatives), neither model did well. Finally, considering farming practices (4-alternatives) the EBA model did somewhat better with a Chi-Squared of 9.91 compared to 14.75 for Luce's model, although both had correlation coefficients of .82.

As mentioned earlier, Luce models have been used extensively, mainly in transportation demand studies. There seem to be three reasons favoring Luce models. First, Luce models are intuitively appealing. Second, they are computationally simple. Finally, they are good at predicting ratings. Previous to this research and partially confirmed by this research, no models are good at predicting choice probabilities consistently and in a wide range of applications (Slovic, et al., 1977). The EBA and Luce models in this experiment were rejected more often than they were retained. Therefore, it may have been desirable to use the Luce model since at least it was good at predicting ratings, a kind of surrogate for choice probabilities, especially for holistic decisions.

Recall that rating schemes determine the relative worth of the alternatives but not the probability that an alternative will be chosen. Lines 5, 6, 13 and 14 of Tables 6.6 and 6.7 show that for predicting ratings, Luce's model was never rejected and often had correlation coefficients above .80. This can also be seen in plots of the data, A3.5, 6, 13 and 14 in Appendix III. Both ratings and Luce predictions (using an additive utility function) tend to be much closer to a uniform distribution across the alternatives than actual choice probabilities as given by the referendum. Many current users of Luce models use the Logit model (see Section 3.2.1) which does not display this nearly uniform distribution and more closely approximates actual choice probabilities. The exponentiated utility functions of the Logit model magnify the slight differences between the alternatives. Choice probability predictions from a Logit model usually have a greater variance than predictions from an additive Luce model, although both models rely on the same basic assumptions, such as simple scalability, independence from irrelevant alternatives, and strong stochastic transitivity. An obvious next step for future research is to compare the EBA model to a Logit model.

6.4 Suggestions For a Field Application

As was anticipated, by conducting the predictive experiment much was learned about how to use the EBA (and Luce's) model.

6.4.1 The Aggregation Problem

This is a general heading describing a number of "first-run" difficulties which occurred in the predictive experiment. First, there was little agreement between subjects concerning either the possession of aspects by alternatives or the relative importance of the aspects. Therefore, the group's possession function as determined by the "majority rule" was arbitrary. For a field application, it is thus recommended that the possession function be determined a priori through discussions with local water experts. The EBA and Luce models solved in this experiment performed better when the expert's possession function was used. Since determining the possession of aspects for each individual was by far the most time consuming part of this experiment, eliminating it would allow more time for determining the relative importance of the aspects.

Another difficulty encountered was the failure of the set of aspects, A', to capture enough information about the alternatives to make good predictions. If any important quality or characteristic which distinguishes one alternative from another is not included in the set of aspects, then predictive models perform less accurately. It is suspected that an aspect encompassing "the probability of success of an alternative" was missing from the classroom experiments thus compromising the models' predictive accuracy. Furthermore, the alternatives need to be characterized by aspects which are more concrete, less conceptual, because decision problems with distinct, clearly defined aspects are much more likely to be solved through a sequential elimination procedure (i.e., EBA) than problems with conceptual aspects. Problems with vague or very subjectively defined conceptual aspects are more likely to be decided upon via a holistic judgment (as in Luce's model). Therefore, it is recommended that the set of aspects employed in the model be carefully defined through consultations with local water experts to establish a complete set of clearly defined and universally recognized aspects.

A final difficulty common to all direct assessment procedures is the difference between what an individual thinks he would do in a certain situation and what he actually does in that situation; i.e., the difference between uncommitted and committed behavior. For example, it would not be uncommon for an individual to proudly state that honesty is much more important than monetary gain and then quietly proceed to cheat someone. To lesser extremes it is often the case because people think that their decisions are governed by one value system when in fact their actual decisions reflect a very different set of values. This subconscious misunderstanding by the decision maker of his own value system can be avoided by avoiding direct assessments; i.e., where the individual is required to state directly which aspects are more important than others. Instead, it is recommended that "indirect assessment" methods be used to weight the aspects. This consists of having the subjects rate alternatives whose possession functions, V_g, are know a priori by the analyst and the subjects. If, for example, the subject consistently rates the more convenient alternatives higher than one which conserves the existing water supply, then convenience is more important than conservation and the weight for each aspect, $u(\alpha_i)$ can be determined.

6.4.2 Data Needs and Interviews

From local water experts (e.g., GWMD managers) are needed 1) A, the set of alternatives, 2) A', the set of aspects, and 3) V_g, the possession function for each alternative. From the farmers is needed $u(\alpha_i)$, the relative importance of each alternative. This information is used to calibrate the EBA and Luce's models.

Furthermore, choices from among at least two groups of alternatives are needed from the farmers. One set of choices among alternatives is needed for the indirect assessment to determine $u(\alpha_i)$ for each aspect. The second set of choices is needed to verify the predictive accuracy of the models.

Interviews with farmers are expected to begin with a few background questions to obtain socio-economic and geographic information about the farmers such as "How many acres do you farm? How do you obtain your water supply and how many wells do you have? How deep is the water table? How long do you think your groundwater supply is going to last?" Following these, the farmers would be asked to make a number of choices of conservation policies from among various offered sets of alternatives. It is not recommended that the farmers be asked to directly rate the relative important of each aspect. Although this method is simpler for both the farmer and the analyst, it is likely to be less accurate than indirect assessment methods. Sophisticated attribute choice models which are calibrated in terms of stated intentions, as opposed to observed behavior, tend to be weak predictors of actual public responses to new policies (Gensch).

6.4.3 Sampling Considerations

Two crucial considerations which need to be addressed before any interviews are conducted deal with the number of samples to be taken and what to sample; i.e., stratification design.

Partitioning the population into nearly homogenous groups has the advantage of increasing the predictive accuracy of the model. If a few preliminary samples can be taken before the main survey, this information can be used to stratify the population (if necessary) and to determine how many samples should be taken from each strata. If F_b is the fraction of the population in the bth strata and if N is the total number of samples which can be taken, then N_b, the number of samples to be taken from strata b is

$$N_b = \frac{F_b \sigma_b}{\sum_{b'=1}^{B} F_{b'} \sigma_{b'}} N$$

where σ_b is the standard deviation of the bth strata. This result is very intuitive: if one group has a large variance it should be sampled more often than an equal size group of a lower variance. This strategy minimizes the variances of the mean of the prediction (Lerman, 1979). The data requirements of the EBA model dictate a strategy of long interviews (15-30 minutes) with few individuals (20-40) rather than quick interviews (2-5 minutes) with many individuals (100-200). Therefore, since the total number of samples, N, in a field application will be relatively small, the number of possible subgroups will be limited to 2 or 3.

6.5 Summary

A very brief summary of the results is appropriate.

6.5.1 Tversky's Experiment

1. Score profiles present decision information in a very efficient decision format but one which is more easily memorized than is desired for this experiment. Real

world decision information is less neatly packaged.

2. The Regularity Hypothesis (EBA model) held in all six cases tested while the constant ratio rule (Luce model) held in five of six cases. The Similarity hypothesis (EBA model) was retained in only one of the six cases.
3. The data consistantly displayed the moderate form of stochastic transitivity (EBA model) but displayed the strong form (Luce model) only about half of the time.
4. The multiplicative inequality hypothesis (EBA and Luce models) is generally confirmed by the data.
5. Therefore, the regularity property of the EBA model was reaffirmed by this experiment but not the stronger similarity hypothesis. The constant ratio rule and strong stochastic transitivity properties of Luce's model were shown to be weak assumptions.

6.5.2 Predictive Experiment

1. There was very little agreement between subjects as to which alternatives possessed which aspects.
2. Group discussions polarized the individuals' opinions toward the dominate viewpoints.
3. Predictive models using the expert's possession function generally did better than models using the individuals' possession functions.
4. The EBA model is more sensitive to changes in the possession function than to changes in the weights of the aspects.

5. The EBA model was more accurate when a larger number of alternatives were available.
6. It is simpler to aggregate the raw data first and then run the EBA model than to run the model for each subject first and then aggregate the model results. Also, there was no advantage in accuracy for either method.
7. It is simpler to assess and use the expert's possession function than to assess and use the possession function of each subject.
8. Luce's model is a good predictor of ratings. It is much better than the EBA model in this regard.
9. The EBA model is a better predictor of choice probabilities than Luce's model (with an additive utility function), especially when a large number of alternatives is involved.

CHAPTER 7

FINDINGS AND CONCLUSIONS

This chapter summarizes the major findings and observations which have been made throughout this study. The first section presents a discussion of observations made concerning 1) the nature of policy acceptance, 2) developing a method to predict policy acceptance, and 3) tests of predictive models. The second section presents the results of the laboratory experiments. The third section describes the contributions made by this research. The fourth and final section makes recommendations concerning a field application of the EBA model and future research needs of predictive choice modelling.

7.1 Discussion

Much was learned about the acceptance of water conservation policies in the High Plains and predictive modelling which can provide valuable insight for those interested in the problem. These observations are discussed below.

7.1.1 Concerning the Nature of Policy Acceptance

A. The High Plains seems to consist of two distinct regions with the Platte River and the North Platte River forming the boundary. Different water conservation policies are relevant in each region (See section 1.2.2).

B. As the Ogallala problem and the various legal and institutional constraints were better understood, it appeared that High Plains irrigators and managers have fewer options for obtaining and transferring water than was originally supposed.

C. It was also discovered that the irrigators, as individuals acted economically rationally to use up the groundwater resources. Similarly, the state legislatures were too slow to react to the problem and missed their chance to curb overdevelopment. Importation plans, even within the same state appear to be politically unpopular. It seems that strict water conservation policies will be an important component of any solution, with or without importation.

D. Because of the traditional resentment by farmers of any state or federal policies, it appears that the major role in developing and implementing new conservation policies will be played by the local groundwater management districts (GWMD's) (See Section 1.2.3).

7.1.2 Concerning Developing a Method to Predict Policy Acceptance

A. A literature search was conducted and revealed that no previous attempts have been made to model and predict policy acceptance; public opinion polls were the closest thing (See Section 1.3).

B. Slovic, Fischhoff, and Lichtenstein (1977) in their review of behavioral decision theory note that: recent predictive research has moved away from regression and other "black box" models and has moved toward 1) using disaggregate (individual) data, 2) accounting for the randomness of utility functions, and 3) developing conceptual models of human decision making behavior (See Section 3.2.2).

C. Choice models (including the EBA model) seem more appropriate than aggregate black box models because of 1) the highly individual and subjective nature of policy acceptance, 2) the lack of previous data required for aggregate models, and 3) the desire to incorporate psychological decision theory into the model (See Section 3.1).

D. For some problems, Tversky's EBA model has theoretical advantages over many more common choice models (including Luce's model) (See Section 4.2).

E. Policy acceptance by its very nature usually lacks concrete aspects and thus the EBA model will probably never be as good of a predictor of policy acceptance as it would be at predicting the choice probabilities among tangible objects. It should accurately predict automobile sales, for instance.

7.1.3 Concerning Tests of Predictive Models

A. The choices which were predicted on the basis of the subjects' stated (uncommitted) preferences did not seem to agree well with their actual choices (committed behavior) among conservation policy alternatives (See Section 6.3.7).

B. The predictive experiment results exhibited considerable disagreement between individuals concerning the possession functions (See Section 6.3.7). When "fuzzy" aspects are involved, it is necessary for the subjects to realize *a priori* that possession of aspects is a relative matter which depends on the offered set of alternatives.

7.2 Major Findings

The following statements were shown to be true in the experiments performed during this research:

A. Tversky's experiment showed that 1) the regularity hypothesis (EBA model) held slightly more often than the constant ratio rule (Luce's model) which held much more often than the similarity hypothesis (EBA model), 2) the moderate form of stochastic transitivity (EBA model) held consistently with the strong form (Luce's model) holding about half of the time, and 3) the multiplicative inequality (EBA and Luce models) was confirmed. The constant ratio rule and strong stochastic transitivity assumptions of Luce's model were shown to be weak.

B. The predictive experiment demonstrated that the expert's possession function should be used instead of individual possession functions and that the raw data should be aggregated first and then the model run, not vice versa.

C. The predictive experiment showed that the EBA model is a good predictor of choice probabilities when a large number of alternatives is available. It is a poor predictor when there are few alternatives or when individuals' possession functions are used.

D. Luce's model (additive utility function) is a good predictor of ratings but a poor predictor of choice probabilities.

7.3 Contributions of the Research

This research supports the view that the groundwater depletion problem in the Ogallala aquifer has now become a problem of conservation policy acceptance. Supply-side alternatives are now being thought of in conjunction with or replaced by controls on demand.

This research presented the first attempt known to the author to frame the managers, the farmers, their decisions, and the various physical and decision components into an Irrigation Management System. Much more work needs to be done, however, in further specifying this system.

This study presented the first attempt ever to model and predict policy acceptance of any kind. This seems very ironic in light of how much time and effort is devoted to formulating and implementing new policies. Considering and predicting acceptance _a priori_ has long been neglected.

This research provides the first application of Tversky's EBA model to a real problem and the first comparison of EBA to Luce's model in an actual experiment. It also presented the first replication of Tversky's experimental test of the EBA model's assumptions.

Finally, the study presented many valuable recommendations for future applications of the EBA model, future improvements in choice and policy acceptance modelling.

7.4 Recommendation for Future Research

It seems that the phenomenon of switching from supply alternatives to demand alternatives (as is the case in the High Plains) because of political and economic resistance to supply alternatives is occurring more and more in many public services which provide water, power, waste disposal, etc. Since capacity expansion is opposed, controls on demands of all sorts of public goods will be necessary and thus predicting policy acceptance will become increasingly important.

The EBA model should be used on problems which lend themselves to the EBA strategy and not holistic judgments. Since most policy alternatives are not concrete enough for the EBA strategy, research should be done to either 1) devise a method for describing policy alternatives in more concrete terms in order to use the EBA model, or 2) to pursue other models. The EBA model should be tested under conditions which seem optimal for the EBA strategy (such as an automobile sales experiment) to confirm that it does indeed perform well under those conditions. Also, the EBA model should be compared to more sophisticated choice models, notably the Logit model, to confirm or refute the superiority of the EBA model for specific decision problems. Finally, a word on the future of choice modelling. The EBA strategy is just one of many possible heuristics which might be used in making a choice (see Table 3.1). These heuristics require that the alternatives and aspects (or attributes) of the decision problem be clearly defined and known to the decision maker. The key to future improvement in choice modelling and policy acceptance modelling lies in developing a processing model which would predict when and why decision makers use each heuristic and when they make holistic decisions.

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APPENDIX I

ENDERS RESERVOIR: AN EXAMPLE OF GROUNDWATER DEPLETION

This appendix provides a specific example depicting the nature of the policy acceptance problem. It describes the groundwater and surface water situations in Southwest Nebraska and presents the findings of a U.S. Water and Power Resources Service (WPRS) study of supply-side alternatives. The study concludes that no supply-side alternatives are feasible and recommends water conservation. This case study is offered as evidence for the earlier stated contention that demand controls (i.e., conservation policies) are an important part of alternative solutions to the Ogallala problem.

Because the Ogallala is so extensive and varies considerably in both its thickness and depth, some parts of the High Plains will begin to suffer from the effects of groundwater mining long before others. Such is the case with the Frenchman Valley and Hitchcock and Red Willow (H & RW) Irrigation Districts in the southwest corner of Nebraska. A visit was made to this area to learn about the problem from local officials involved in water resources management.

AI.1 Physical Description. Enders Dam and Reservoir were built by the U.S. Water and Power Resources Service (WPRS, formerly the Bureau of Reclamation) on the Frenchman River in 1951 to provide surface water storage for the Frenchman Valley and H & RW irrigation districts (see Figure AI.1). Enders Reservoir provides water for the Culbertson Canal (built in 1890) and the Culbertson Extension Canal (built in 1961)

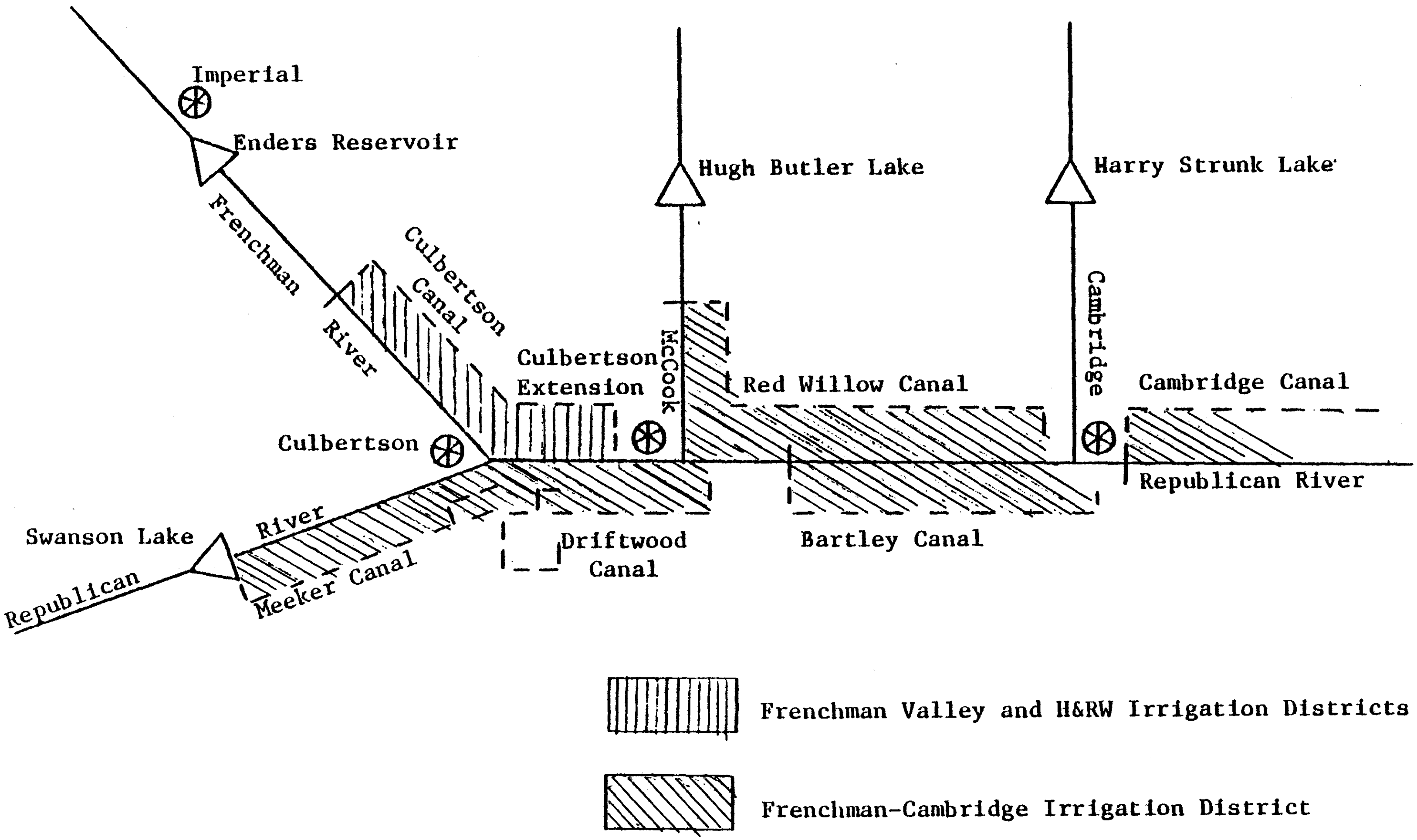


Figure A1.1. Schematic diagram depicting the canals, rivers, reservoirs, and irrigation districts in the vicinity of McCook, Nebraska.

which together provide cheap, gravity flow irrigation water for 21,000 acres of farm land which lies between the canals and the Frenchman and Republican Rivers.

The Ogallala aquifer is very thin or nonexistent in this area and in other bottomlands of the High Plains because the rivers are incised deeply into the formation. Thus, although groundwater is close to the surface, wells have low yields.

A1.2 <u>The Water Supply Problem and Its Causes</u>. For a while after Enders Dam was built, i.e., from 1956 until about 1974, the system worked very well. The farmers in these two districts could usually expect to receive about 15 to 18 inches of water per year from the canals. Since this area of Nebraska receives about 20 inches of rain per year, the farmers need at least 12 inches and desire about 15 inches of canal water to grow crops like irrigated corn.

In the mid-1960's, very extensive groundwater development began in Chase, Dundy and Perkins Counties, upstream of Enders on the Frenchman River. Figure A1.2 shows the increase in the number of wells in Chase and Dundy Counties from less than 200 when Enders Dam was built to about 2000 wells today. Figure A1.3 shows the corresponding decrease in the inflow to Enders and, consequently, the deliveries to the canals. Finally, Figure A1.4 shows the decline in the deliveries of water to the farms. The great grandchildren of the farmers who built the Culberton Canal in 1890 receive only 6" of irrigation water in 1980. Nebraska water law is so rigid that it does not even permit these farmers to apply twice as much water (i.e., 12") on half of their land in order to save half the

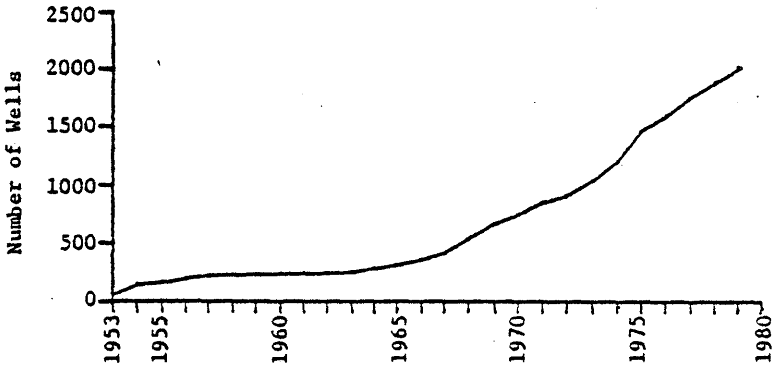


Figure A1.2. Cummulative number of wells in Chase and Dundy Counties.

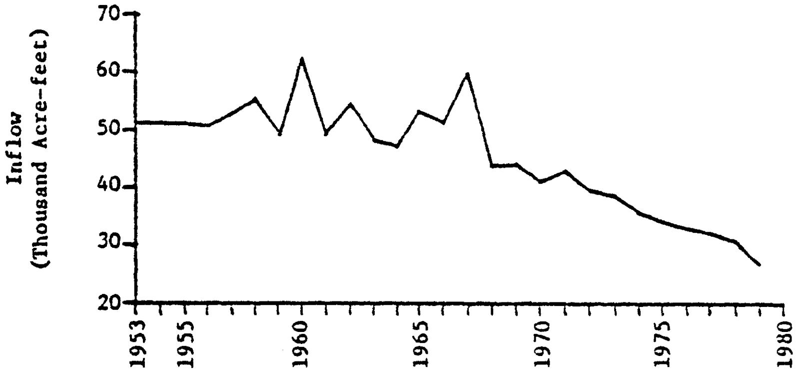


Figure A1.3. Inflow to Enders Reservoir.

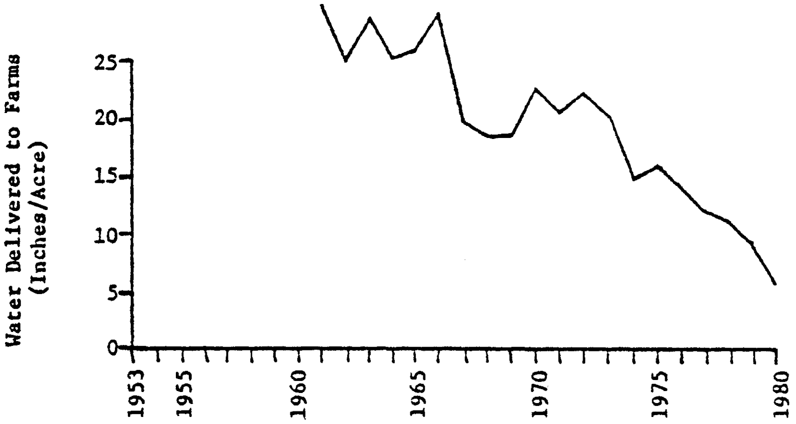


Figure A1.4. Water delivered to farms in the Frenchman Valley and Hitchcock and Red Willow Irrigation Districts.

farm. Recall that in Nebraska the water rights are legally fixed to the land. Furthermore, Nebraska water law does not recognize any connection between surface water and groundwater. This has lead to the ironic and tragic situation whereby center-pivot farmers with wells in Chase and Dundy Counties, who have been there less than 10 years, are ruining surface water irrigators downstream whose farms have been there nearly 100 years.

A1.3 Alternatives Investigated. WPRS has investigated this dilemma and has evaluated many proposed solutions including (WPRS, 1977):

1. Improvement of Farm Efficiency:
    - Irrigation management and scheduling
    - Reuse pits
2. Structural Alternatives:
    - Installing wells near canals to capture seepage
    - Canal lining
    - Installing pipes in the laterals
    - Building a dam on Stinking Water Creek
    - Building a pumped storage facility in Fish Canyon

A1.4 Conclusions. The conclusions reached by the investigation were bleak (WPRS, 1978):

1. Groundwater development above Enders caused the reduced inflow. This was a direct result of Nebraska's failure to recognize the connection between surface and groundwater.
2. The perennial flow of the Frenchman River and Stinking

Water Creek will be zero by 1991.

3. Groundwater resources are insufficient to meet the needs of the Frenchman Valley and H & RW districts.
4. None of the structural alternatives can be justified as a long term solution.
5. No solution has been identified.
6. Irrigators should try to conserve to make the water last a little longer.

The reason that no solution was possible is because the cause of the problem is in one area, (Chase and Dundy Counties) and the effects are being felt more than a hundred miles away in Hitchcock and Red Willow Counties. Clearly a regional solution is mandated, but this cannot happen under current Nebraska law.

APPENDIX II

WATER IMPORTATION PLANS

This appendix describes several of the famous water importation schemes proposed to divert water to the High Plains from as far away as Alaska. It also includes the relatively small scale importation plans which are now being considered as part of the Six-State High Plains Ogallala Aquifer Study.

Historically, most power and water utilities pursued supply-side alternatives, adding capacity as necessary to stay ahead of the demand. Power or water shortages were avoided as well as demand-oriented management strategies. Therefore, it is not surprising that the first solutions offered for the Ogallala problem were water importation schemes big enough to allow the demands to continue to grow.

To many, it now seems that water conservation programs, including restrictions on groundwater use, are much more likely to occur than large-scale water importation projects because of high costs and political opposition. However, the importation schemes are truly fascinating from an engineering point of view and are therefore summarized below.

A. NAWAPA Plan. In 1964 the Ralph M. Parsons Company proposed the North American Water and Power Alliance (NAWAPA) whereby 158 million acre-feet per year would be diverted from the Yukon, Susitna and Tanana Rivers (in Alaska and the Yukon Territory) and sent by canal to water short areas in the High Plains, California, Canada, and Mexico (see Figure A2.1). The cost in 1977 dollars was estimated at $200 billion (Dolan, no date).

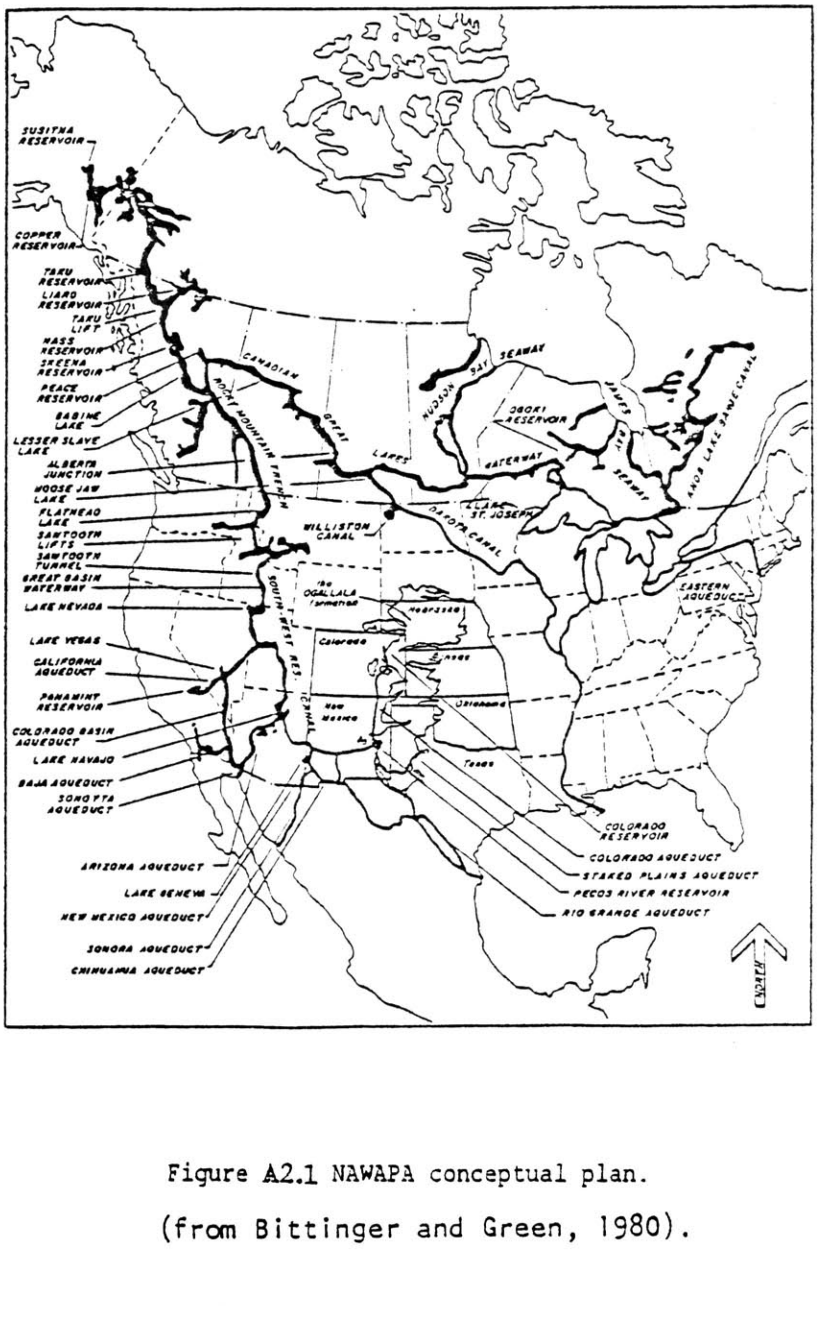


Figure A2.1 NAWAPA conceptual plan.

(from Bittinger and Green, 1980).

B. Beck Plan. In 1967 R. W. Beck and Associates proposed "A New Water Resource Plan for the Great Plains" whereby 9-15 million acre-feet per year would be diverted from Missouri and Niobrara Rivers (in Nebraska and South Dakota) and sent by canal through western Nebraska and eastern Colorado into the Oklahoma and Texas Panhandles as shown in Figure A2.2 (Bathen et al., 1967).

C. Smith Plan. In 1968 Lewis G. Smith, a retired Bureau of Reclamation engineer, proposed a "National Water Plan" whereby 40 million acre-feet per year would be diverted from the Liard and Mackenzie Rivers (northwest Canada) and sent by canal to many water-short areas including California, the High Plains and Mexico as shown in Figure A2.3 (Smith, 1969). The cost in 1980 dollars is estimated at 200 billion dollars.

D. Rocky Mountain Plan. In 1977 a paper was presented to the American Society of Civil Engineers whereby 12-25 million acre-feet per year would be diverted from the Peace River (northern Canada) and sent by canal to water short areas including the High Plains (Dunn et al., 1977). The cost in 1977 dollars was estimated at 30-54 billion dollars.

E. High Plains Study Preliminary Routes. Presently (1980) the U.S. Army Corps of Engineers is-examining as part of the High Plains Study several smaller-scale importation plans which have more political viability than the previous projects in A-D. Several of the importation routes that they are examining are shown in Figure A2.4 (Wilson, 1980).

The large scale importation plans A-D might have solved all or part of the Ogallala problem. However, high costs and stiff political opposition prevented their implementation. Because of many such stalled

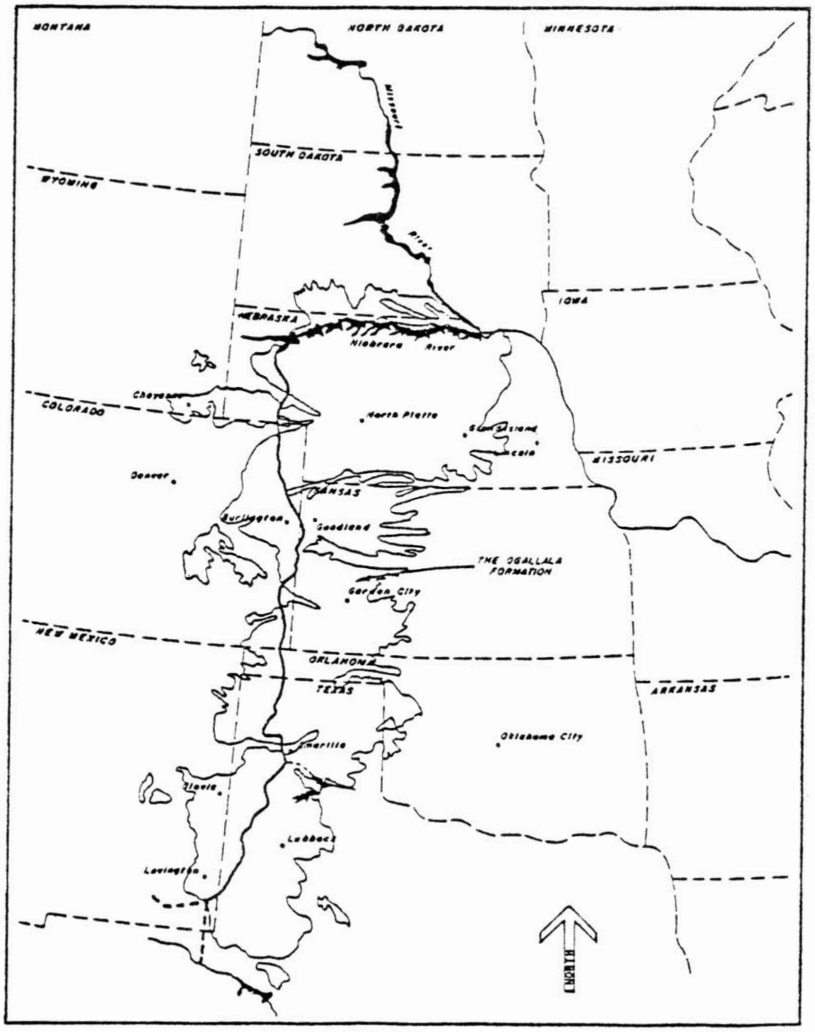


Figure A2.2 R. W. Beck plan.

(from Bittinger and Green, 1980).

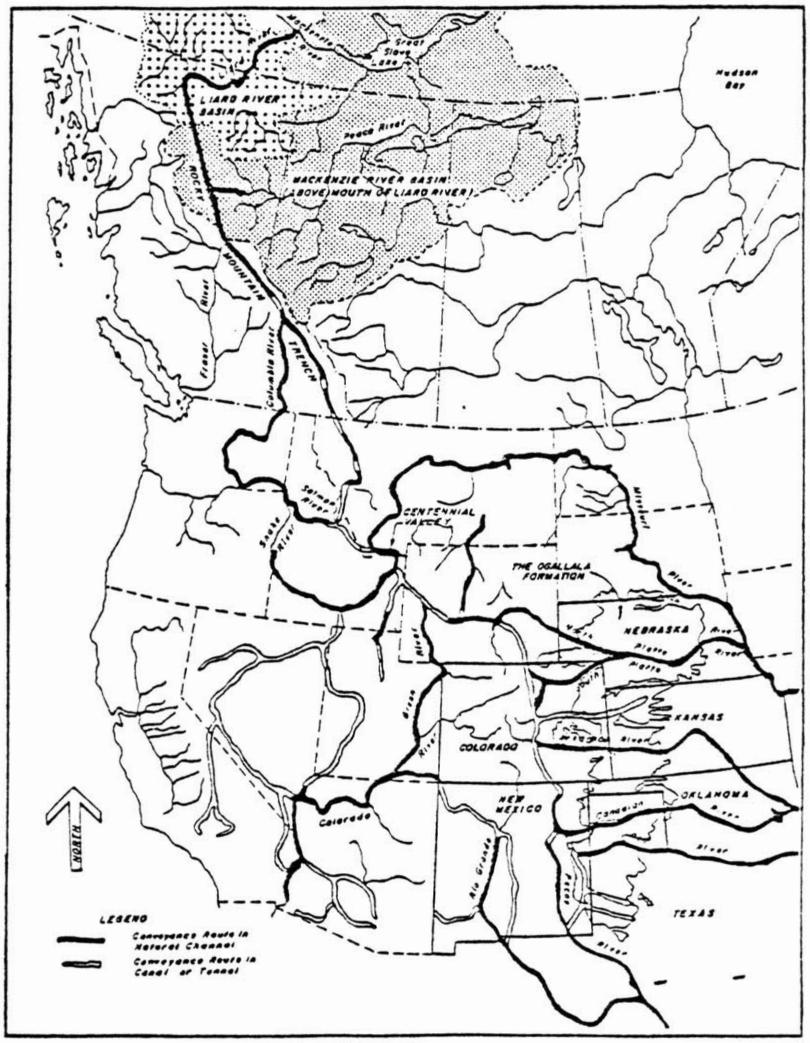


Figure A2.3 Lewis G. Smith's water import plan.

(from Bittinger and Green, 1980).

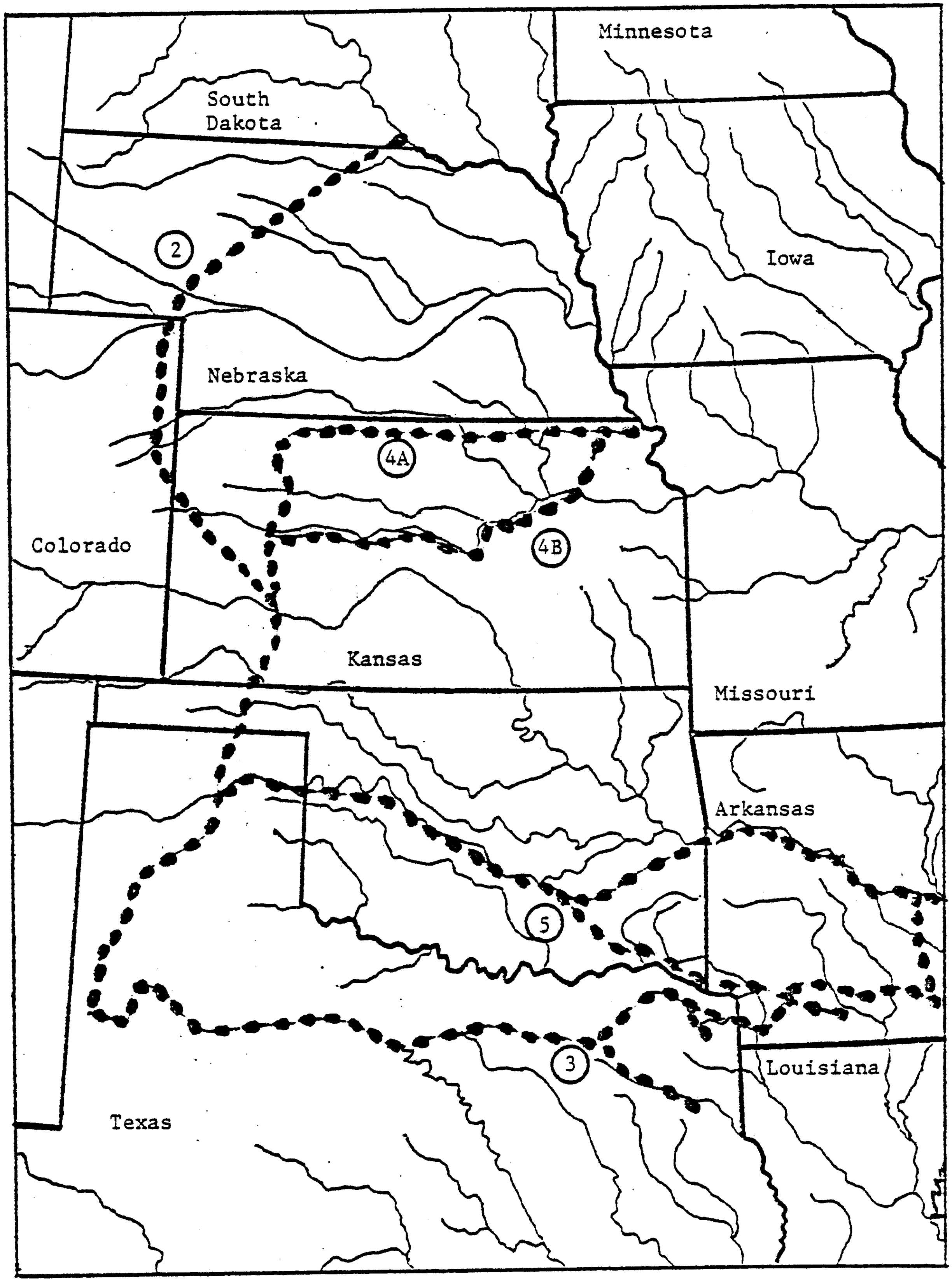


Figure A2.4 High Plains Study Preliminary Routes for Water Importation. Alternatives 2, 3, 4A, 4B, and 5 are shown. (Wilson, 1980).

projects, engineers are seeking a more balanced approach which attacks the problem from both sides: relatively small capacity expansion is coupled with controls on demands. Plan E, High Plains Preliminary Routes, is a candidate for such a balanced solution. Since Federal funds would be needed in order to build even this small-scale importation system, Federal guidelines would be likely to follow concerning the use and conservation of water. Because the cost of providing this water would be so high, very strict conservation of the imported water, and probably the existing groundwater as well, would be required of the users. A thorough discussion of water conservation measures appears in Chapter Five.

APPENDIX III

PREDICTIVE EXPERIMENT: ANSWER SHEETS AND RESULTS

Appendix III contains the following:

1. The answer sheets and illustrations used in the predictive experiment.
2. Tables of Results for each subject (Table A3.1).
3. Plots of the results comparing the group's actual choice probabilities with the models' choice probability predictions (Figures A3.1 to A3.16).
4. Graphs displaying the frequency of the subjects' actual choices, F_i, given the predicted choice probability, P_i (Figures A3.17 to A3.22).

Note that $F_i = \frac{n_i}{N_i}$

where P_i = predicted choice probability (discretized),

$P_i = 0, .1, .2, \ldots, 1.0,$

F_i = frequency of actual choices given P_i,

N_i = number of predicted choice probabilities in interval i, $[P_i - P_{i-1}]$, $i = 1, 2, \ldots, 10,$

n_i = number of actual choices whose predicted choice probability is in interval i,

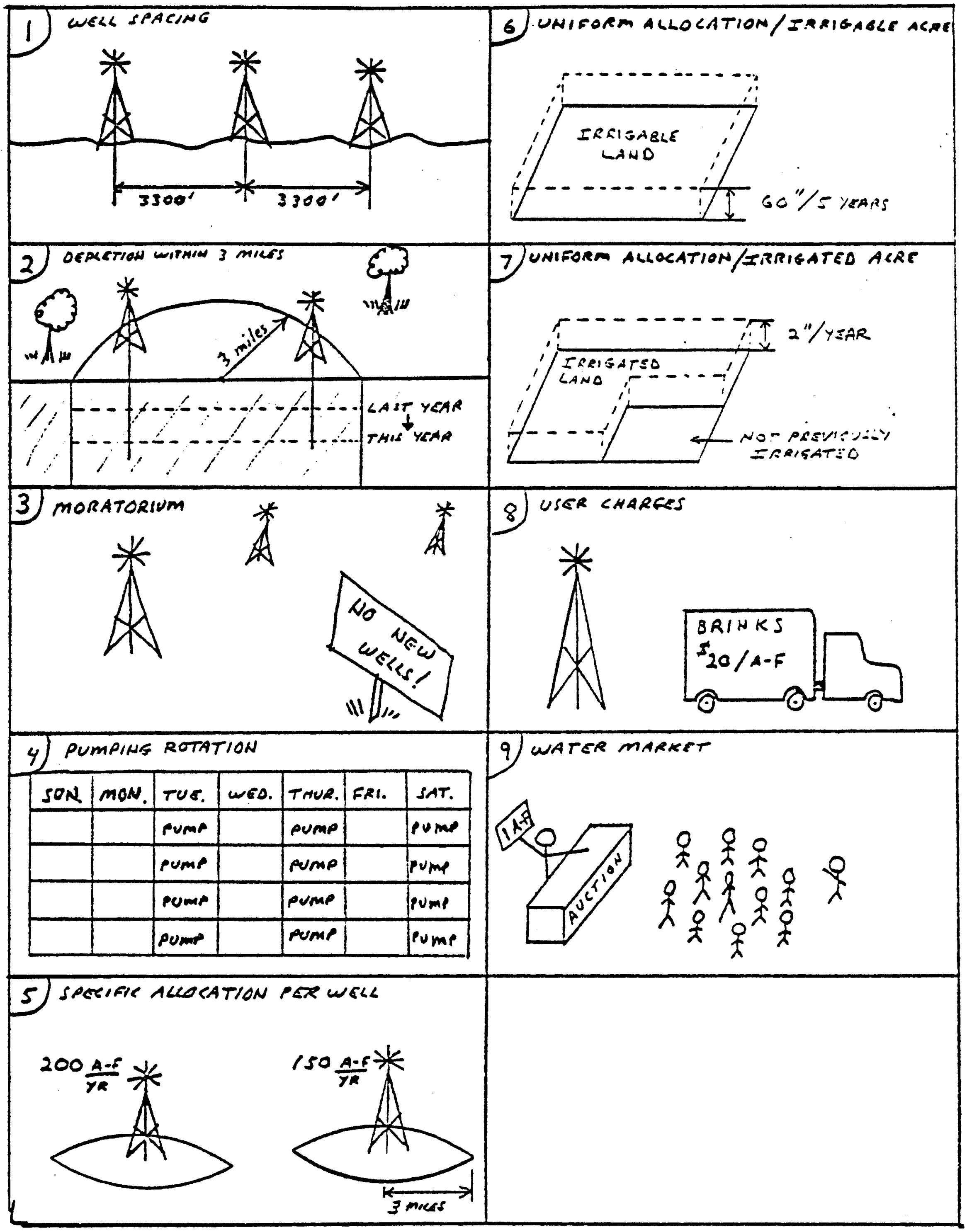
and note

$N = \sum_{i=1}^{10} N_i$ = number of alternatives times the number of subjects, = (9+3+4) x 16 = 256.

Name:____________________ Date:____________

ANSWER SHEET NO. 1	
Groundwater Policies	Circle the number if you agree with the statement.
1. Uniform well spacing of 3300 feet.	1 2 3 4 5 6 7 8 9
2. New well permits cannot bring the depletion rate to more than 2% per year within a 3-mile radius of the proposed site.	1 2 3 4 5 6 7 8 9
3. Moratorium on new wells.	1 2 3 4 5 6 7 8 9
4. Pumping rotation such that each well can be pumped at most 3 days per week.	1 2 3 4 5 6 7 8 9
5. Specific allocation per well based on a 2% per year maximum depletion within a 3-mile radius of the well. Three year allocation period, full carryover, limited borrow.	1 2 3 4 5 6 7 8 9
6. Uniform allocation per irrigable acre based on a 40 year lifetime for the whole district. Five year allocation period with limited carryover, no borrow.	1 2 3 4 5 6 7 8 9
7. Uniform allocation per irrigated acre designed to attain a sustained yield for the aquifer in the district. One year allocation period with no carryover and no borrow.	1 2 3 4 5 6 7 8 9
8. User charges set by the district board to reduce withdrawals in order to make supplies last 40 years. User charge is in the form of $ per acre-foot per year.	1 2 3 4 5 6 7 8 9
9. Market for sustained yield shares. One share equals one acre-foot per year.	1 2 3 4 5 6 7 8 9

GROUNDWATER POLICIES

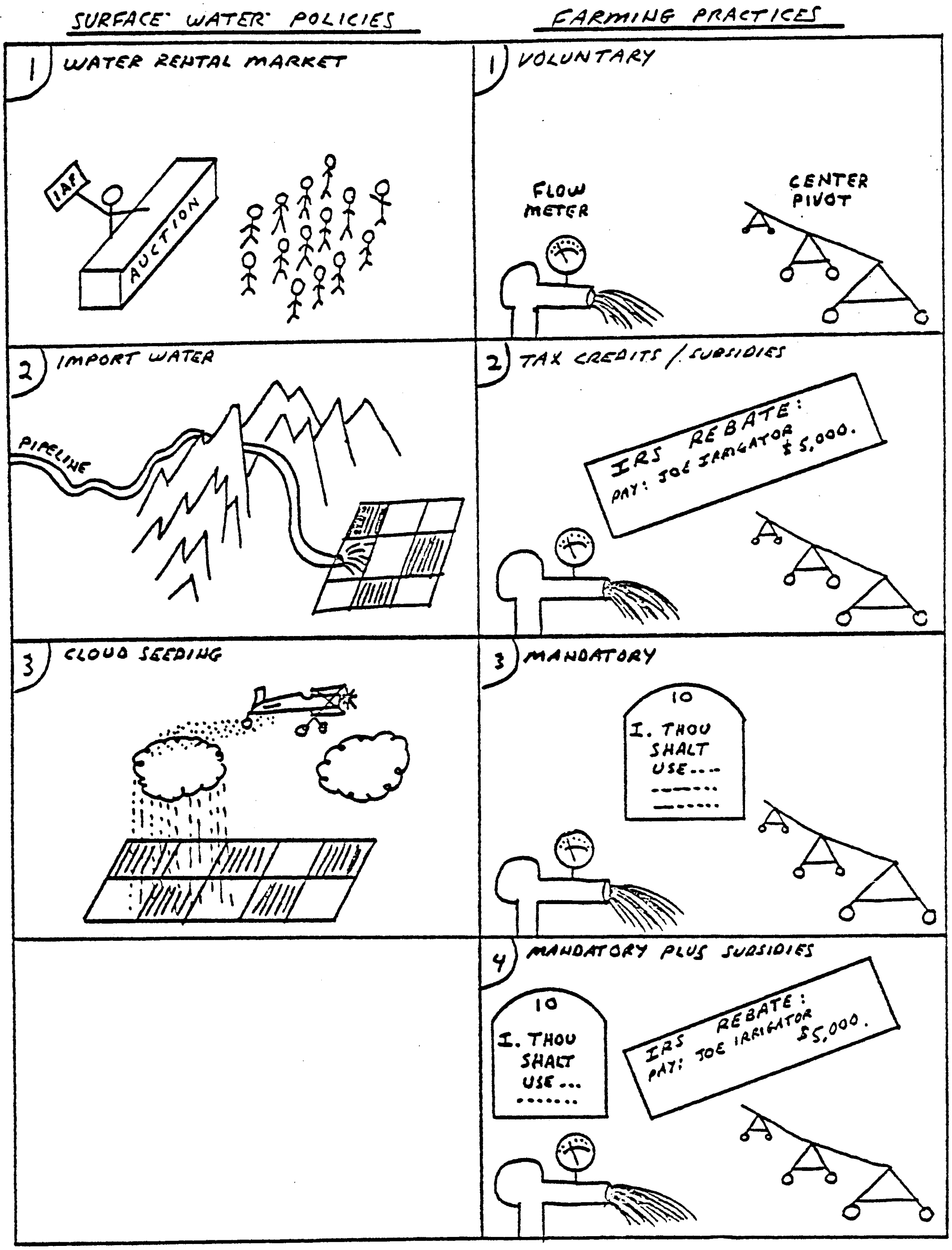


SUN	MON.	TUE.	WED.	THUR.	FRI.	SAT.
		PUMP		PUMP		PUMP
		PUMP		PUMP		PUMP
		PUMP		PUMP		PUMP
		PUMP		PUMP		PUMP

Name:______________________________ Date:____________

ANSWER SHEET NO. 1 continued	
Surface Water Policies	Circle the number if you agree with the statement.
1. Surface water rental market where water rights owners can rent their water to any legitimate user.	1 2 3 4 5 6 7 8 9
2. Water imported from other watersheds and sold at cost to farmers.	1 2 3 4 5 6 7 8 9
3. Weather modification (cloud seeding) financed by a tax on cropped acreage.	1 2 3 4 5 6 7 8 9

Farming Practices	Circle the number if you agree with the statement.
1. Voluntary use of flow meters, reuse pits, sprinklers or center pivots, and irrigation scheduling.	1 2 3 4 5 6 7 8 9
2. Tax credit and subsidies for flow meters, reuse pits, sprinklers or center pivots, and irrigation scheduling.	1 2 3 4 5 6 7 8 9
3. Mandatory use of flow meters, reuse pits, sprinklers or center pivots, and irrigation scheduling.	1 2 3 4 5 6 7 8 9
4. Mandatory use of and tax credits and subsidies for flow meters, reuse pits, center pivots or sprinklers, and irrigat. scheduling.	1 2 3 4 5 6 7 8 9


SURFACE WATER POLICIES
1) WATER RENTAL MARKET
1AF
AUCTION
2) IMPORT WATER
PIPELINE
3) CLOUD SEEDING
FARMING PRACTICES
1) VOLUNTARY
FLOW METER
CENTER PIVOT
2) TAX CREDITS / SUBSIDIES
IRS REBATE:
PAY: JOE IRRIGATOR $5,000.
3) MANDATORY
10
I. THOU SHALT USE....
4) MANDATORY PLUS SUBSIDIES
10
I. THOU SHALT USE...
IRS REBATE:
PAY: JOE IRRIGATOR $5,000.

Name:________________________ Date:___________

ANSWER SHEET NO. 2

Aspects:
1. NO UNCERTAINTY - The policy does not create additional uncertainty about water availability.
2. FAIRNESS - All farmers are treated equally.
3. HALTS MINING - The policy is effective in halting the mining of groundwater.
4. PROLONGS SUPPLY - The policy is effective in stretching the existing supply over a long time.
5. INEXPENSIVE - It is inexpensive for farmers to comply with the policy.
6. CONVENIENT - It is convenient for the farmers to comply with the policy.
7. TRADITIONAL - The policy permits farmers to continue to use their traditional farming practices.
8. PRIVACY - There is no invasion of privacy by meter readers or other inspectors.
9. OUTPUTS - The policy does not reduce short term farm outputs.

Paired Comparisons: In each of the following pairs of aspects, circle the one which is more important to you.

NO UNCERTAINTY---FAIRNESS
FAIRNESS----------HALTS MINING
HALTS MINING------PROLONGS SUPPLY
PROLONGS SUPPLY--INEXPENSIVE
INEXPENSIVE------CONVENIENT
CONVENIENT--------TRADITIONAL
TRADITIONAL-------PRIVACY
PRIVACY-----------OUTPUTS
OUTPUTS-----------NO UNCERTAINTY

OUTPUTS---------FAIRNESS
PRIVACY---------HALTS MINING
TRADITIONAL-----PROLONGS SUPPLY
CONVENIENT------NO UNCERTAINTY
INEXPENSIVE-----OUTPUTS
PROLONGS SUPPLY-PRIVACY
HALTS MINING---CONVENIENT
FAIRNESS--------TRADITIONAL
NO UNCERTAINTY-INEXPENSIVE

Name:__________________________ Date:_____________

ANSWER SHEET NO.2 continued

Ranking: Please rank the aspects in order of importance.

Most important 1.________________________

2.________________________

3.________________________

4.________________________

5.________________________

6.________________________

7.________________________

8.________________________

Least important 9.________________________

Rating: Please rate the aspects by circling the appropriate number.

↑ more important

less important ↓

20	20	20	20	20	20	20	20	20
19	19	19	19	19	19	19	19	19
18	18	18	18	18	18	18	18	18
17	17	17	17	17	17	17	17	17
16	16	16	16	16	16	16	16	16
15	15	15	15	15	15	15	15	15
14	14	14	14	14	14	14	14	14
13	13	13	13	13	13	13	13	13
12	12	12	12	12	12	12	12	12
11	11	11	11	11	11	11	11	11
10	10	10	10	10	10	10	10	10
9	9	9	9	9	9	9	9	9
8	8	8	8	8	8	8	8	8
7	7	7	7	7	7	7	7	7
6	6	6	6	6	6	6	6	6
5	5	5	5	5	5	5	5	5
4	4	4	4	4	4	4	4	4
3	3	3	3	3	3	3	3	3
2	2	2	2	2	2	2	2	2
1	1	1	1	1	1	1	1	1
0	0	0	0	0	0	0	0	0
NO UNCERTAINTY	FAIRNESS	HALTS MINING	PROLONGS SUPPLY	INEXPENSIVE	CONVENIENT	TRADITIONAL	PRIVACY	OUTPUTS

Name: ____________

Date: ____________

ANSWER SHEET NO. 3

Rating Policies: Please rate the alternatives by circling the appropriate numbers.

Groundwater Policies	more likely to be selected by you ⟶ ⟵ less likely to be selected by you
1. Uniform well spacing of 3300 feet.	0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
2. New well permits cannot bring the depletion rate to more than 2%/year within a 3-mile radius of the proposed site.	0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
3. Moratorium on new wells.	0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
4. Pumping rotation such that each well can be pumped at most 3 days per week.	0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
5. Specific allocation per well based on a 2%/year maximum depletion within a 3-mile radius of the well. 3-yr. period	0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
6. Uniform allocation per irrigable acre based on a 40 year average lifetime. 5-yr. period.	0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
7. Uniform allocation per irrigated acre to achieve sustained yield on average. 1-yr. period	0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
8. User charges set by district to make water supplies last for 40 years. Charge is $ per acre foot per year.	0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
9. Market for sustained yield shares. One share equals one acre-foot per year.	0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

Name: ____________________ Date: ____________

ANSWER SHEET NO. 3 continued

Rating Policies: Please rate the alternatives by circling the appropriate numbers.

Surface Water Policies	more likely to be selected by you ⟶ ⟵ less likely to be selected by you
1. Surface water rental market where water rights owners can rent their water to any legitimate user.	0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
2. Water imported from other watersheds is sold at cost to the farmers.	0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
3. Weather modification (cloud seeding) financed by a tax on cropped acreage.	0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

Farming Practices	
1. Voluntary use of flow meters, reuse pits, sprinklers/center pivots, and irrigation scheduling.	0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
2. Tax credits and subsidies for flow meters, reuse pits, sprinklers/center pivots, and irrigation scheduling.	0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
3. Mandatory use of flow meters, reuse pits, sprinklers/center pivots, and irrigation scheduling.	0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
4. Subsidized, but mandatory use of flow meters, reuse pits, sprinklers/center pivots, and irrigation scheduling.	0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

Table A3.1 Observed and predicted choice probabilities; data from the Predictive Experiment.

SUBJECT	TYPE OF RESULT	CONSERVATION POLICY ALTERNATIVES															
		GROUNDWATER									SURFACE WATER			FARMING PRACTICES			
		1	2	3	4	5	6	7	8	9	1	2	3	1	2	3	4
1	Highest Rating				X						X				X		
	Referendum Vote				X	•					X				X		
	EBA Predictions	0	0	.049	.951	0	0	0	0	0	.423	.090	.487	.043	.479	0	.479
	EBA & Expert Pos. Func.	.027	0	.027	0	0	.946	0	0	0	.336	.454	.210	.361	.361	.139	.139
	Ratings	0	.074	.191	.294	.118	.250	0	.074	0	.741	.148	.111	.333	.436	.077	.154
	Luce Predictions	.150	.148	.157	.197	.092	.099	.056	.069	.032	.378	.235	.387	.187	.283	.247	.283
	Luce & Expert Pos. Func	.135	.099	.135	.085	.124	.166	.108	.115	.032	.306	.376	.318	.296	.296	.204	.204
2	Highest Rating						X				X			X			
	Referendum Vote						X				X			X			
	EBA Predictions	.216	.113	0	0	.557	0	.114	0	0	.500	.500	0	.500	.500	0	0
	EBA & Expert Pos. Func.	.065	0	.065	0	0	.745	.097	0	.027	.385	.359	.259	.398	.398	.102	.102
	Ratings	.171	.132	0	.118	.105	.237	.184	039	.013	.463	.415	.122	.304	.339	.125	.232
	Luce Predictions	.140	.129	.106	.142	.154	.138	.112	112	.048	.395	.395	.210	.272	.272	.228	.228
	Luce & Expert Pos. Func	.122	.082	.122	.094	.098	.178	.125	102	.076	.367	.367	.266	.329	.329	.171	.171

Table A3.1 continued

SUBJECT	TYPE OF RESULT	CONSERVATION POLICY ALTERNATIVES															
		GROUNDWATER									SURFACE WATER			FARMING PRACTICES			
		1	2	3	4	5	6	7	8	9	1	2	3	1	2	3	4
3	Highest Rating						X				X				X		
	Referendum Vote						X				X			X			
	EBA Predictions	.739	0	0	0	0	0	.261	0	0	0	.912	.088	.439	.395	.166	0
	EBA & Expert Pos. Func.	.029	0	.029	0	0	.646	.219	0	.076	.239	.478	.283	.375	.375	.125	.125
	Ratings	.129	.158	.050	.109	.168	.178	.129	.069	.010	.533	.467	0	.358	.377	.094	.170
	Luce Predictions	.163	.142	.125	.127	.079	.136	.122	.050	.056	.241	.533	.225	.296	.288	.210	.206
	Luce & Expert Pos. Func	.103	.080	.103	.071	.111	.177	.137	.114	.105	.321	.407	.272	.338	.338	.162	.162
4	Highest Rating							X					X			X/2	X/2
	Referendum Vote				X						X				X		
	EBA Predictions	0	.589	.084	0	0	.033	.251	0	.044	0	.362	.638	.467	0	.267	.267
	EBA & Expert Pos. Func.	.047	0	.047	0	0	.609	.237	0	.059	.333	.421	.245	.361	.361	.139	.139
	Ratings	.081	.137	.113	.081	.121	.129	.145	.113	.081	.313	.250	.438	.145	.236	.309	.309
	Luce Predictions	.086	.167	.118	.103	.105	.134	.140	.048	.099	.162	.360	.477	.244	.220	.268	.268
	Luce & Expert Pos. Func.	.115	.087	.115	.084	.111	.165	.123	.110	.090	.349	.374	.277	.306	.306	.194	.194

Table A3.1 Continued

SUBJECT	TYPE OF RESULT	CONSERVATION POLICY ALTERNATIVES															
		GROUNDWATER									SURFACE WATER			FARMING PRACTICES			
		1	2	3	4	5	6	7	8	9	1	2	3	1	2	3	4
5	Highest Rating					X/2	X/2				X/3	X/3	X/3		X		
	Referendum Vote						X					X			X		
	EBA Predictions	.207	.207	.207	0	.190	.190	0	0	0	.500	.500	0	0	1	0	0
	EBA & Expert Pos. Func.	.104	0	.104	0	0	.591	.158	0	.043	.361	.379	.259	.372	.372	.128	.128
	Ratings	.192	.096	.164	0	.247	.247	.041	.014	0	.333	.334	.333	.238	.317	.159	.286
	Luce Predictions	.161	.161	.161	.138	.125	.125	.092	0	.037	.458	.458	.083	.233	.309	.195	.263
	Luce & Expert Pos. Func.	.122	.088	.122	.091	.102	.168	.124	.098	.086	.363	.368	.269	.314	.314	.186	.186
6	Highest Rating				X							X			X		
	Referendum Vote						X				X				X		
	EBA Predictions	0	0	.744	.213	0	0	.043	0	0	0	.500	.500	.500	.500	0	0
	EBA & Expert Pos. Func.	.120	0	.120	0	0	.761	0	0	0	.256	.494	.251	.376	.376	.124	.124
	Ratings	.100	.100	.043	.229	.157	.186	.114	.043	.029	.304	.478	.217	.296	.315	.148	.241
	Luce Predictions	.062	.167	.216	.149	.104	.111	.104	.045	.045	.244	.378	.378	.379	.379	.121	.121
	Luce & Expert Pos. Func.	.130	.104	.130	.072	.121	.167	.104	.118	.054	.307	.391	.302	.324	.324	.176	.176

Table A3.1 Continued

SUBJECT	TYPE OF RESULT	CONSERVATION POLICY ALTERNATIVES															
		GROUNDWATER									SURFACE WATER			FARMING PRACTICES			
		1	2	3	4	5	6	7	8	9	1	2	3	1	2	3	4
7	Highest Rating							X			X			X			
	Referendum Vote						X				X				X		
	EBA Predictions	0	0	.846	0	0	0	0	0	.154	0	1	0	0	1	0	0
	EBA & Expert Pos. Func.	.074	0	.074	0	0	.603	.178	0	.070	.215	.557	.228	.390	.390	.110	.110
	Ratings	.074	.093	.078	.130	.111	.167	.185	.148	.065	.450	.350	.200	.357	.286	.143	.214
	Luce Predictions	.083	.076	.200	.115	.101	.165	.113	.071	.075	0	1	0	0	1	0	0
	Luce & Expert Pos. Func.	.115	.097	.115	.072	.111	.164	.115	.124	.088	.215	.557	.228	.390	.390	.110	.110
8	Highest Rating									X	X				X		
	Referendum Vote						X				X				X		
	EBA Predictions	0	0	.190	.100	0	.391	.318	0	0	.253	.670	.077	.605	.395	0	0
	EBA & Expert Pos. Func.	.041	0	.041	0	0	.544	.268	0	.106	.342	.491	.167	.386	.386	.114	.114
	Ratings	.051	.101	.020	.081	.121	.141	.152	.162	.172	.536	.357	.107	.026	.368	.263	.342
	Luce Predictions	.070	.077	.138	.121	.113	.162	.147	.070	.102	.344	.374	.282	.342	.305	.177	.177
	Luce & Expert Pos. Func.	.106	.070	.106	.070	.092	.176	.147	.118	.114	.355	.417	.228	.330	.330	.170	.170

Table A3.1 Continued

SUBJECT	TYPE OF RESULT	CONSERVATION POLICY ALTERNATIVES															
		GROUNDWATER									SURFACE WATER			FARMING PRACTICES			
		1	2	3	4	5	6	7	8	9	1	2	3	1	2	3	4
9	Highest Rating					X					X					X	
	Referendum Vote						X				X				X		
	EBA Predictions	.195	0	.451	0	.255	0	0	.099	0	.563	.168	.269	.250	.250	.250	.250
	EBA & Expert Pos. Func.	.125	0	.125	0	0	.493	.046	0	.231	.087	.616	.297	.391	.391	.109	.109
	Ratings	.099	.143	.044	.055	.187	.143	.044	.165	.121	.425	.200	.375	.250	.200	.283	.267
	Luce Predictions	.109	.121	.158	.071	.139	.105	.111	.105	.081	.375	.295	.330	.250	.250	.250	.250
	Luce & Expert Pos. Func.	.121	.114	.121	.063	.124	.163	.097	.126	.070	.279	.408	.313	.348	.348	.152	.152
10	Highest Rating						X						X		X		
	Referendum Vote						X					X			X		
	EBA Predictions	0	0	.423	.191	0	.271	0	.115	0	0	.834	.166	.500	.500	0	0
	EBA & Expert Pos. Func.	.012	0	.012	0	0	0	.108	0	.036	.302	.445	.253	.368	.368	.132	.132
	Ratings	.053	.067	.040	.080	.173	.253	.107	.213	.013	.071	.321	.607	.128	.513	.026	.333
	Luce Predictions	.112	.153	.161	.140	.078	.153	.053	.098	.053	.286	.400	.313	.277	.277	.223	.223
	Luce & Expert Pos. Func.	.109	.080	.109	.080	.115	.182	.119	.119	.086	.344	.394	.262	.321	.321	.179	.179

Table A3.1 Continued

SUBJECT	TYPE OF RESULT	CONSERVATION POLICY ALTERNATIVES															
		GROUNDWATER									SURFACE WATER			FARMING PRACTICES			
		1	2	3	4	5	6	7	8	9	1	2	3	1	2	3	4
11	Highest Rating						X					X/2	X/2		X		
	Referendum Vote				X						X			X			
	EBA Predictions	0	0	.196	.557	0	.209	.038	0	0	0	.378	.622	.500	.500	0	0
	EBA & Expert Pos. Func.	0	0	0	0	0	.793	.169	0	.038	.348	.364	.289	.425	.425	.075	.075
	Ratings	.045	.045	.194	.283	.060	.299	.075	0	0	.273	.364	.364	.297	.313	.156	.234
	Luce Predictions	.077	.077	.175	.253	.067	.182	.067	.034	.067	.294	.320	.386	.312	.312	.188	.188
	Luce & Expert Pos. Func.	.124	.091	.124	.091	.107	.171	.119	.109	.064	.335	.362	.302	.332	.332	.168	.168
12	Highest Rating								X		X/2	X/2			X		
	Referendum Vote								X			X		X			
	EBA Predictions	0	.500	.500	0	0	0	0	0	0	.365	.365	.270	.419	.581	0	0
	EBA & Expert Pos. Func.	.146	0	.146	0	0	.707	0	0	.001	.230	.447	.293	.418	.418	.082	.082
	Ratings	0	.052	0	.143	.208	.234	.013	.260	.091	.500	.500	0	.308	.385	0	.308
	Luce Predictions	.120	.153	.153	.117	.117	.117	.117	.036	.070	.364	.364	.271	.329	.343	.164	.164
	Luce & Expert Pos. Func.	.131	.108	.131	.073	.108	.166	.110	.112	.060	.300	.391	.310	.359	.359	.141	.141

Table A3.1 Continued

SUBJECT	TYPE OF RESULT	CONSERVATION POLICY ALTERNATIVES															
		GROUNDWATER									SURFACE WATER			FARMING PRACTICES			
		1	2	3	4	5	6	7	8	9	1	2	3	1	2	3	4
13	Highest Rating								X		X			X/2	X/2		
	Referendum Vote								X		X				X		
	EBA Predictions	0	0	.449	0	.531	0	.020	0	0	0	1	0	0	1	0	0
	EBA & Expert Pos. Func.	.065	0	.065	0	0	.843	.015	0	.011	.139	.646	.216	.375	.375	.125	.125
	Ratings	.162	.176	0	.068	.108	.135	.108	.216	.027	.857	.095	.048	.409	.409	.045	.136
	Luce Predictions	.116	.150	.162	.062	.169	.099	.089	.104	.048	.361	.439	.200	.367	.371	.131	.131
	Luce & Expert Pos. Func.	.108	.097	.108	.052	.126	.182	.094	.144	.090	.311	.427	.262	.347	.347	.153	.153
14	Highest Rating						X/2			X/2	X			X/2		X/2	
	Referendum Vote						X				X			X			
	EBA Predictions	.271	0	.281	0	.448	0	0	0	0	.499	.501	0	.250	.250	.250	.250
	EBA & Expert Pos. Func.	.061	0	.061	0	0	.685	.143	0	.051	.142	.504	.354	.435	.435	.065	.065
	Ratings	.057	.115	.057	.080	.115	.172	.115	.115	.172	.666	.333	0	.288	.192	.288	.231
	Luce Predictions	.166	.078	.150	.055	.174	.152	.072	.056	.097	.499	.501	0	.250	.250	.250	.250
	Luce & Expert Pos. Func.	.120	.109	.120	.071	.118	.164	.106	.120	.071	.286	.386	.328	.369	.369	.131	.131

Table A3.1 Continued

SUBJECT	TYPE OF RESULT	CONSERVATION POLICY ALTERNATIVES															
		GROUNDWATER									SURFACE WATER			FARMING PRACTICES			
		1	2	3	4	5	6	7	8	9	1	2	3	1	2	3	4
15	Highest Rating					X/2		X/2			X			X/2	X/2		
	Referendum Vote					X					X				X		
	EBA Predictions	.163	.163	.163	0	0	0	.511	0	0	.397	.367	.227	.500	.500	0	0
	EBA & Expert Pos. Func.	.031	0	.031	0	0	.765	.133	0	.039	.242	.562	.196	.351	.351	.149	.149
	Ratings	.164	.110	.027	.137	.219	.110	.219	.041	.096	.412	.294	.294	.377	.377	.057	.189
	Luce Predictions	.159	.159	.159	.047	.072	.069	.166	.072	.098	.370	.364	.266	.374	.374	.126	.126
	Luce & Expert Pos. Func.	.107	.082	.107	.076	.115	.176	.122	.128	.088	.311	.427	.263	.305	.305	.195	.195
16	Highest Rating								X			X			X		
	Referendum Vote									X	X				X		
	EBA Predictions	0	0	.712	0	0	0	.288	0	0	1	0	0	.500	.500	0	0
	EBA & Expert Pos. Func.	.123	0	.123	0	0	.455	.282	0	.018	.106	.398	.496	.394	.394	.106	.106
	Ratings	.044	.044	0	0	.088	.176	.132	.265	.250	.488	.439	.073	.330	.667	0	0
	Luce Predictions	.087	.171	.182	.071	.095	.111	.130	.079	.076	.460	.270	.270	.310	.310	.190	.190
	Luce & Expert Pos. Func.	.125	.116	.125	.092	.122	.144	.120	.092	.065	.259	.359	.381	.328	.320	.172	.172

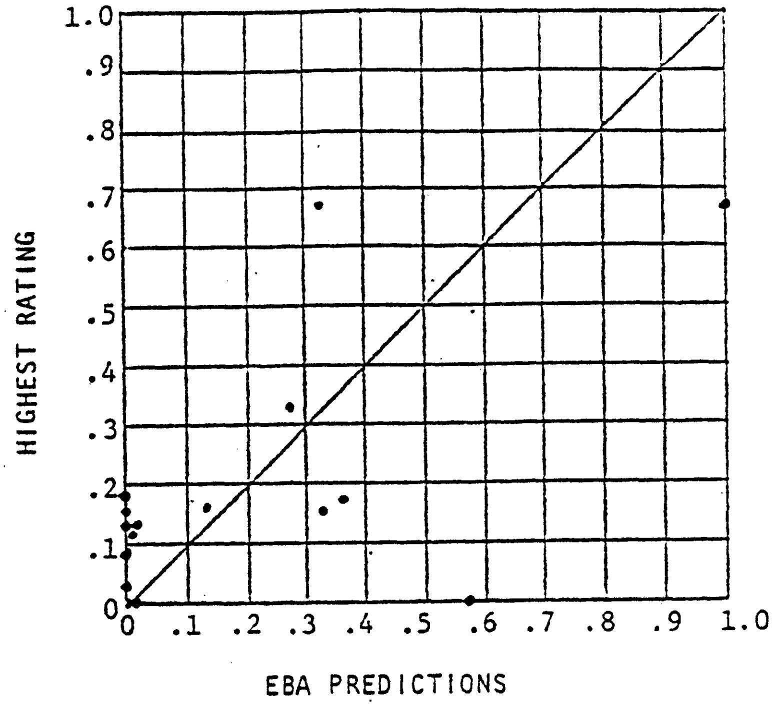


Figure A3.1 Comparison of the group's highest ratings with the EBA predictions (Raw Data Averaged).

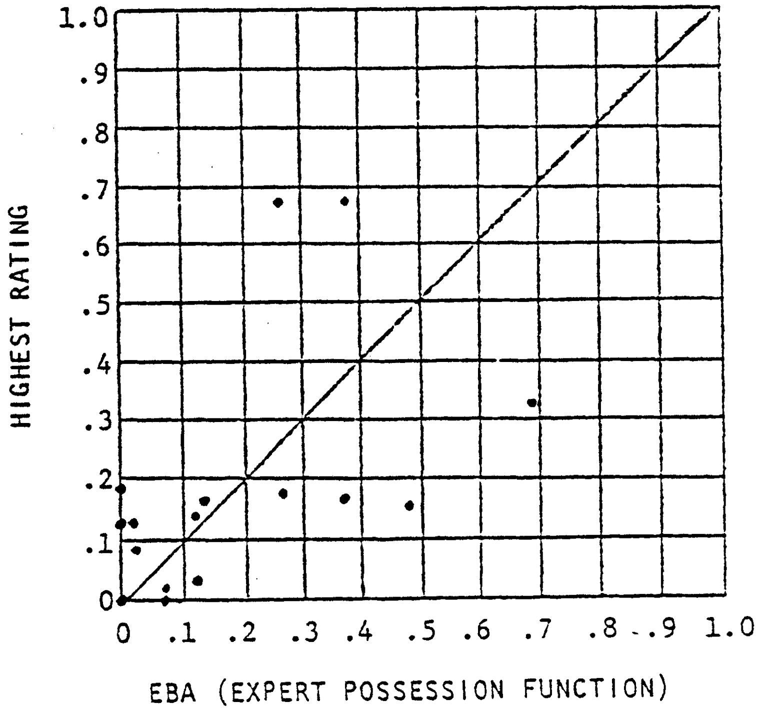


Figure A3.2 Comparison of the group's highest ratings with the EBA predictions using the expert's possession function (Raw Data Averaged).

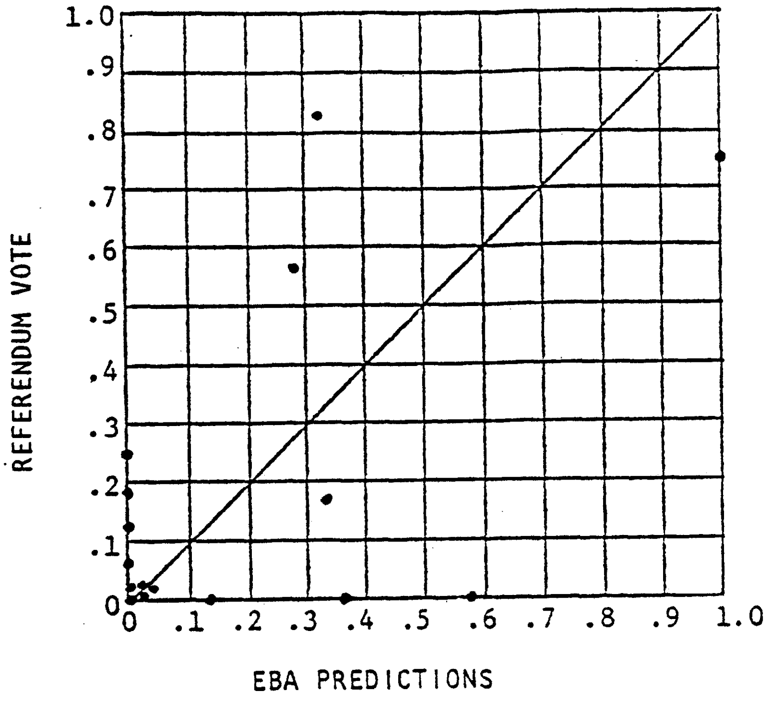


Figure A3.3 Comparison of the group's referendum voting with the EBA predictions (Raw Data Averaged).

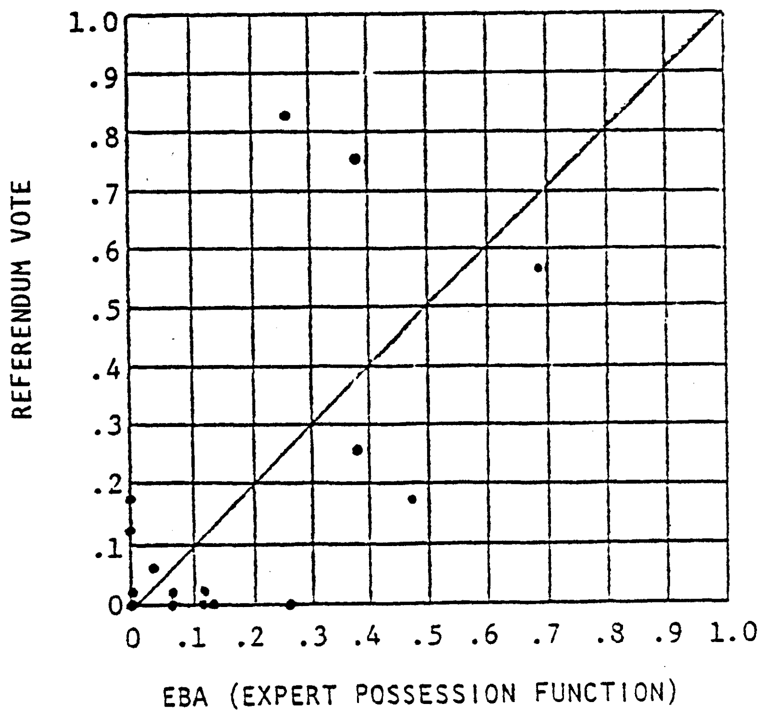


Figure A3.4 Comparison of the group's referendum voting with the EBA predictions using the expert's possession function (Raw Data Averaged).

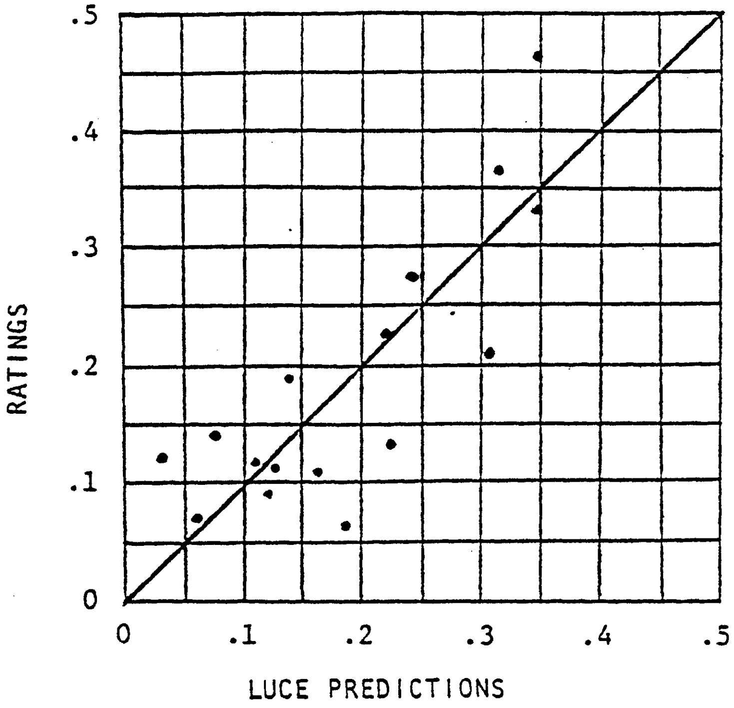


Figure A3.5 Comparison of the group's ratings with the Luce predictions (Raw Data Averaged).

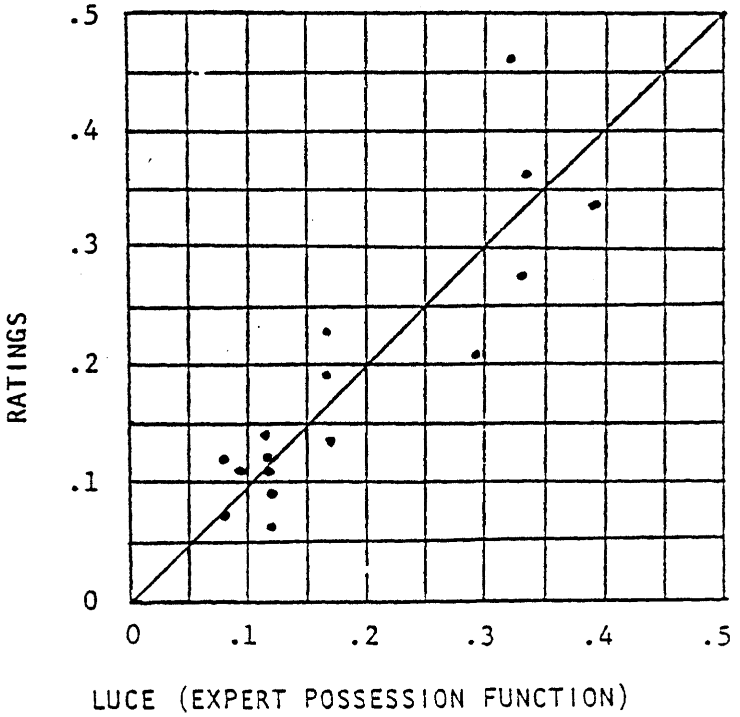


Figure A3.6 Comparison of the group's ratings with the Luce predictions using the expert's possession function (Raw Data Averaged).

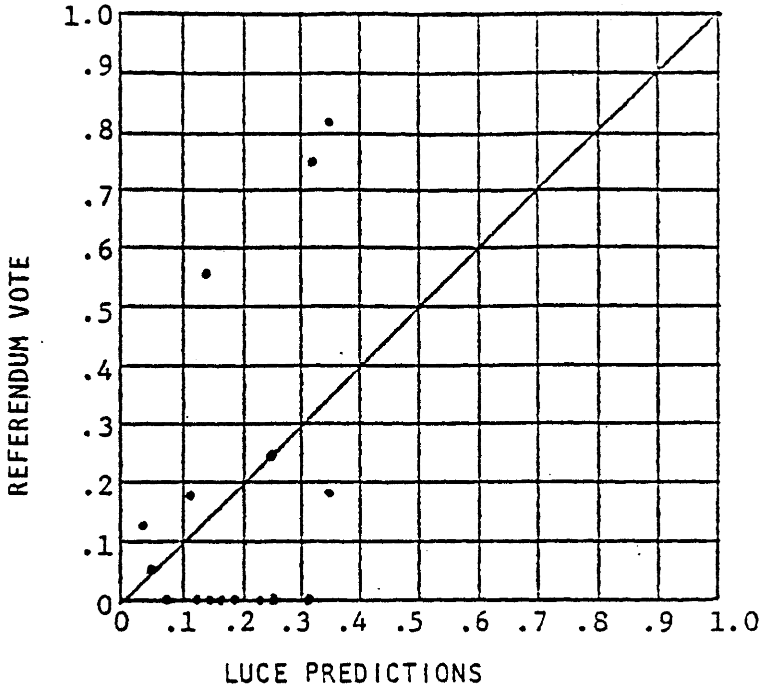


Figure A3.7 Comparison of the group's referendum voting with the Luce predictions (Raw Data Averaged).

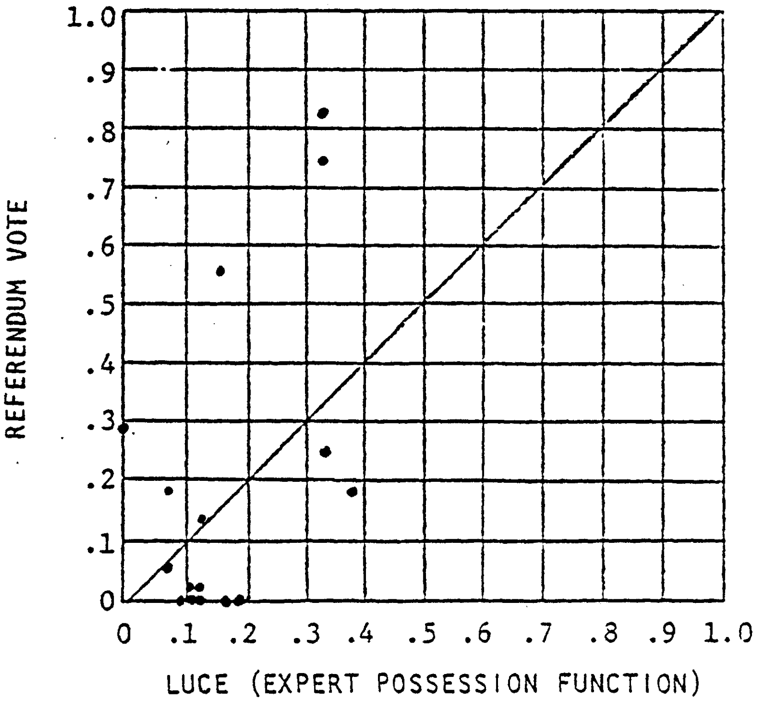


Figure A3.8 Comparison of the group's referendum voting with the Luce predictions using the expert's possession function (Raw Data Averaged).

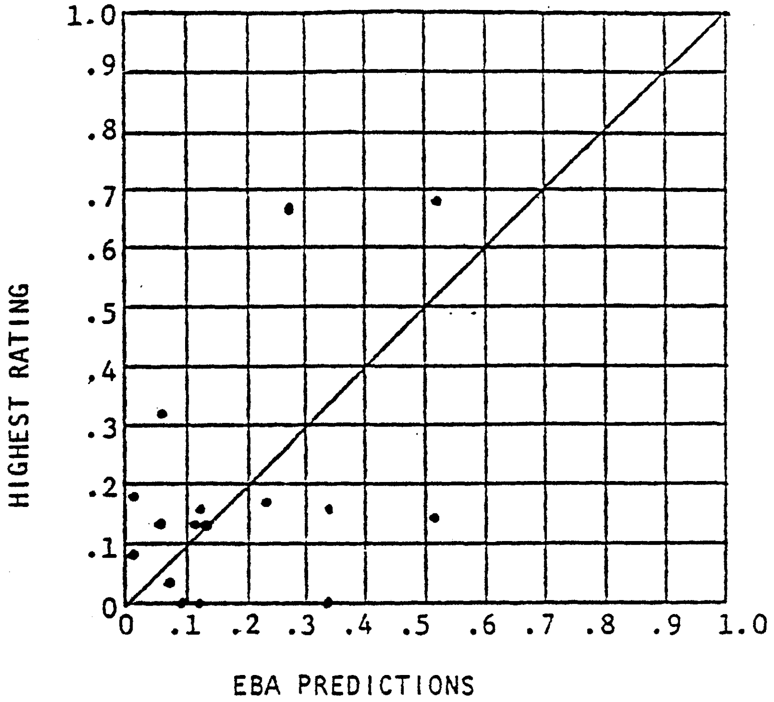


Figure A3.9 Comparison of the group's highest ratings with the EBA predictions (Model Results Averaged).

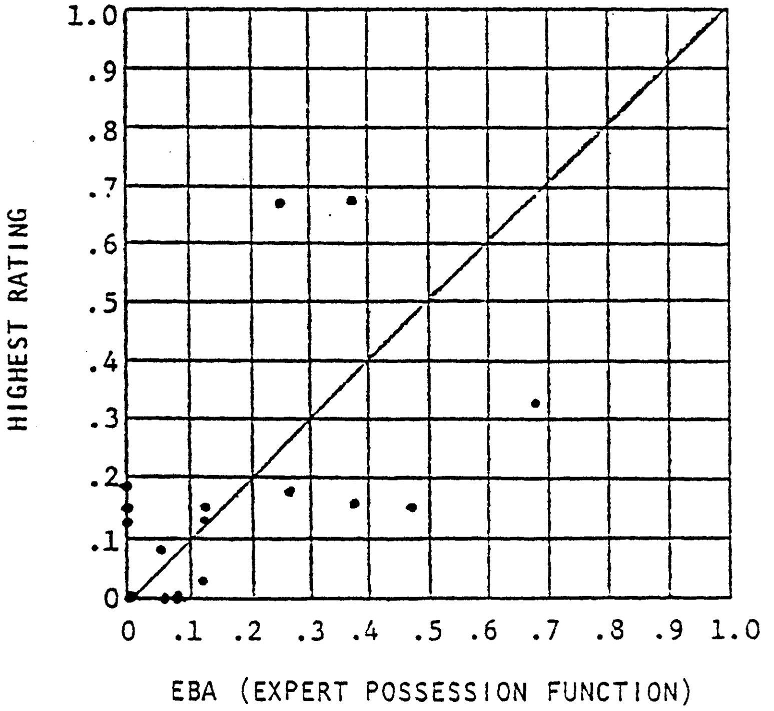


Figure A3.10 Comparison of the group's highest ratings with the EBA predictions using the expert's possession function (Model Results Averaged).

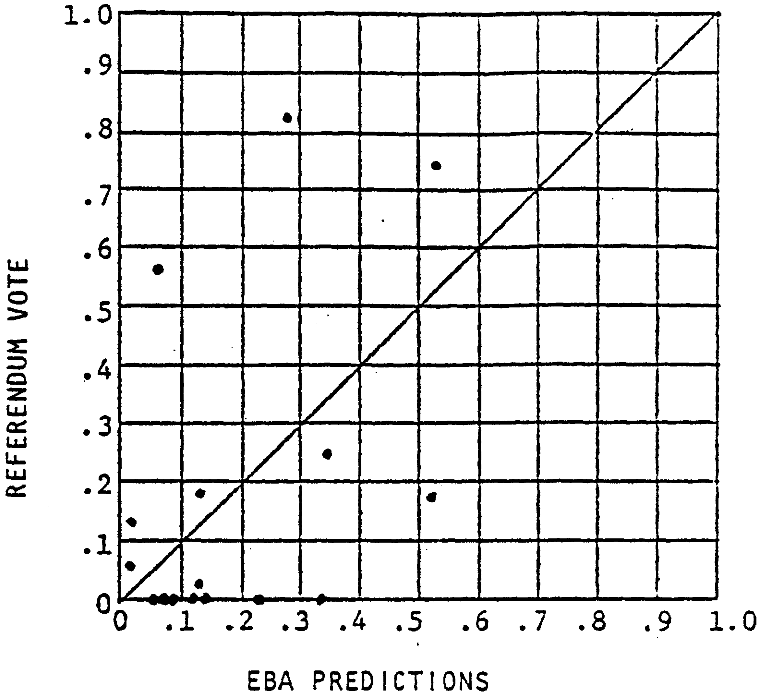


Figure A3.11 Comparison of the group's referendum voting with the EBA predictions (Model Results Averaged).

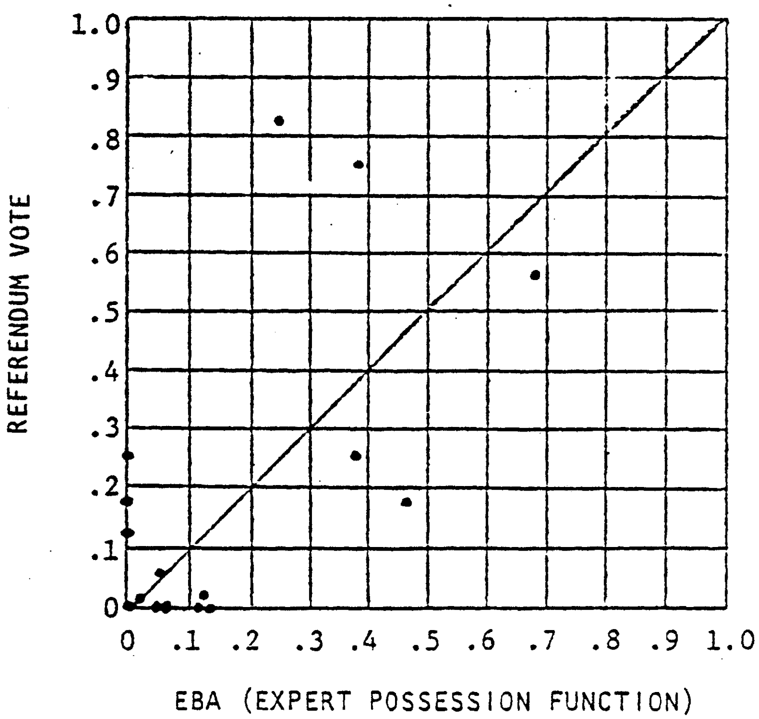


Figure A3.12 Comparison of the group's referendum voting with the EBA predictions using the expert's possession function (Model Results Averaged).

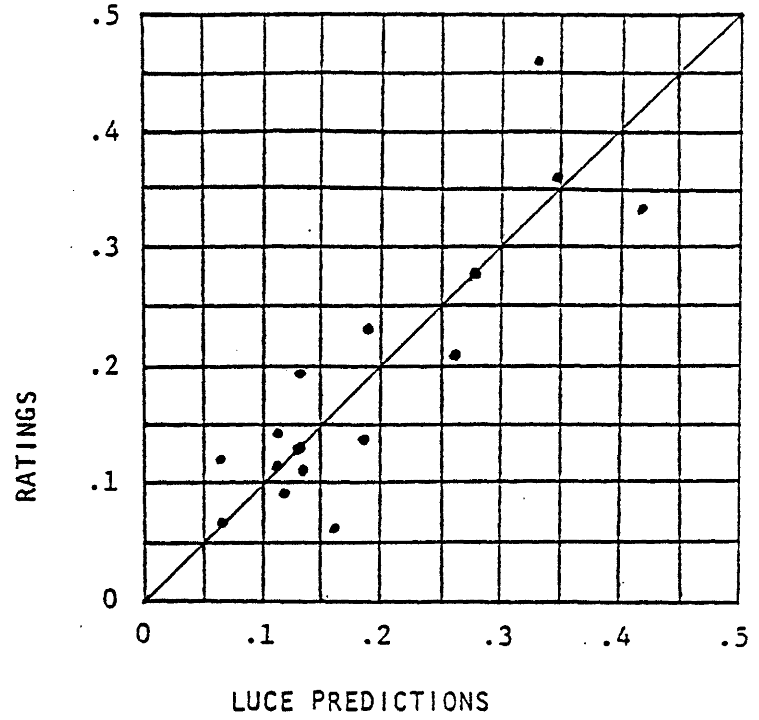


Figure A3.13 Comparison of the group's ratings with the Luce predictions (Model Results Averaged).

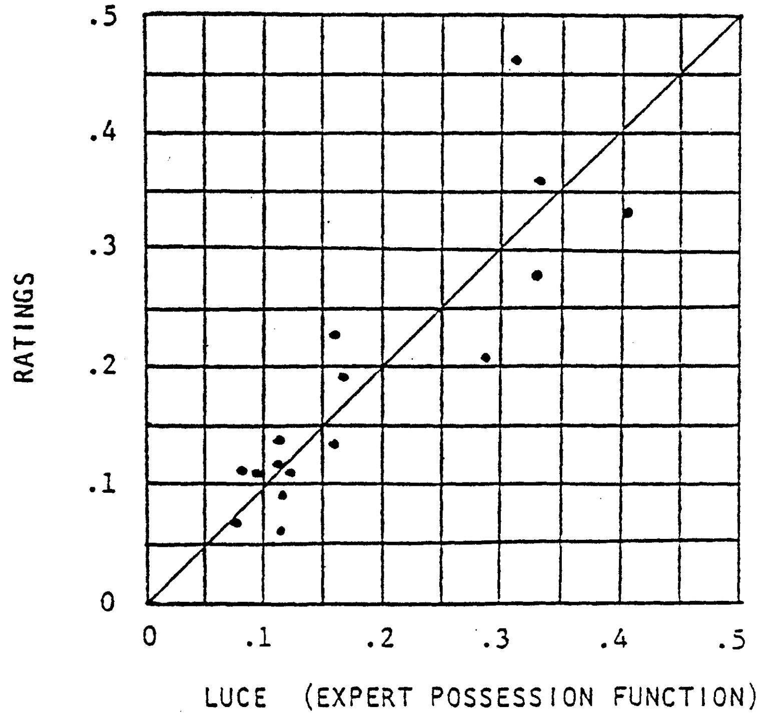


Figure A3.14 Comparison of the group's ratings with the Luce predictions using the expert's possession function (Model Results Averaged).

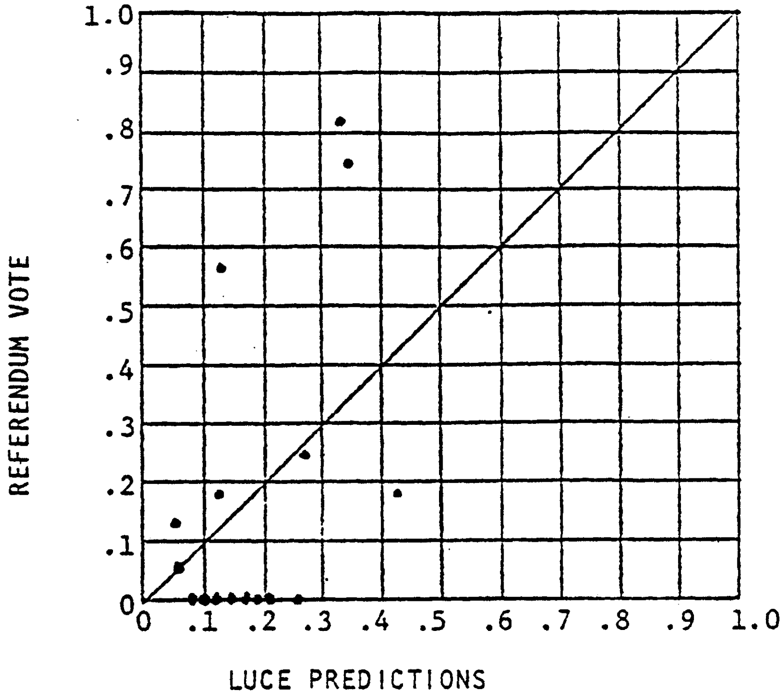


Figure A3.15 Comparison of the group's referendum voting with the Luce predictions (Model Results Averaged).

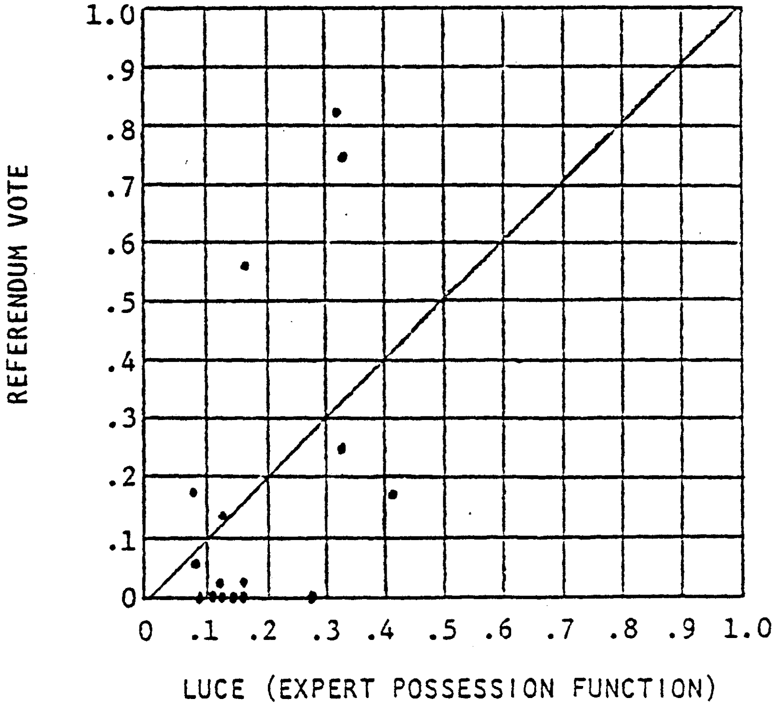


Figure A3.16 Comparison of the group's referendum voting with the Luce predictions using the expert's possession function (Model Results Averaged).

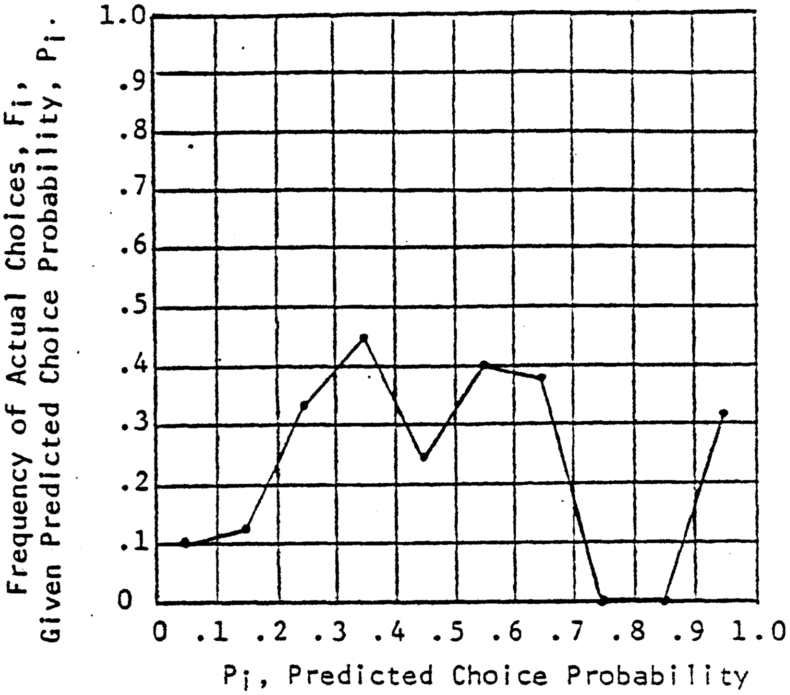


Figure A3.17 Graph displays the frequency of actual choices (subjects' highest rated alternatives) given predicted choice probabilities from the EBA model.

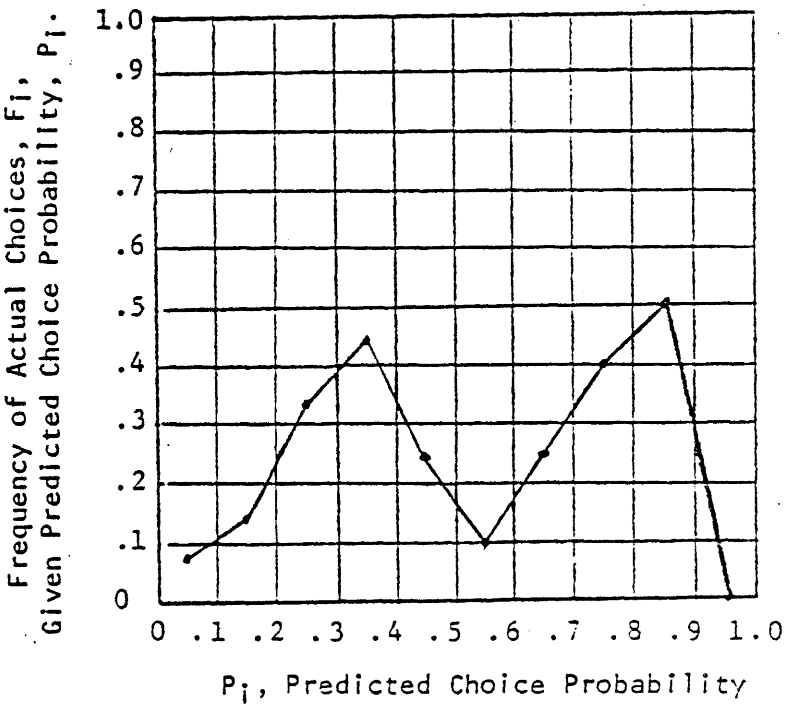


Figure A3.18 Graph displays the frequency of actual choices (subjects' highest rated alternatives) given predicted choice probabilities from the EBA model using the expert's possession function.

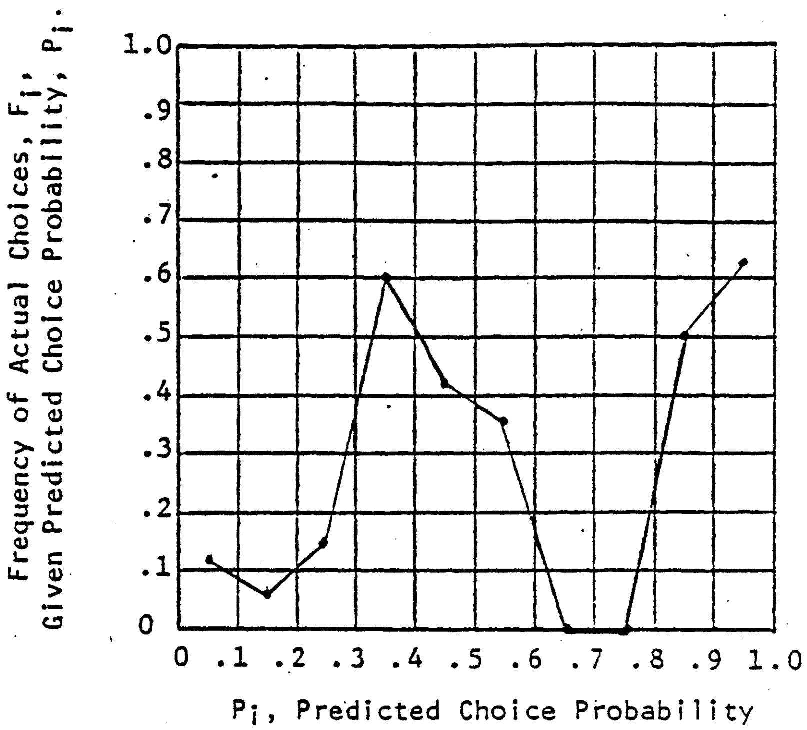


Figure A3.19 Graph displays the frequency of actual choices (subjects' referendum voting) given predicted choice probabilities from the EBA model.

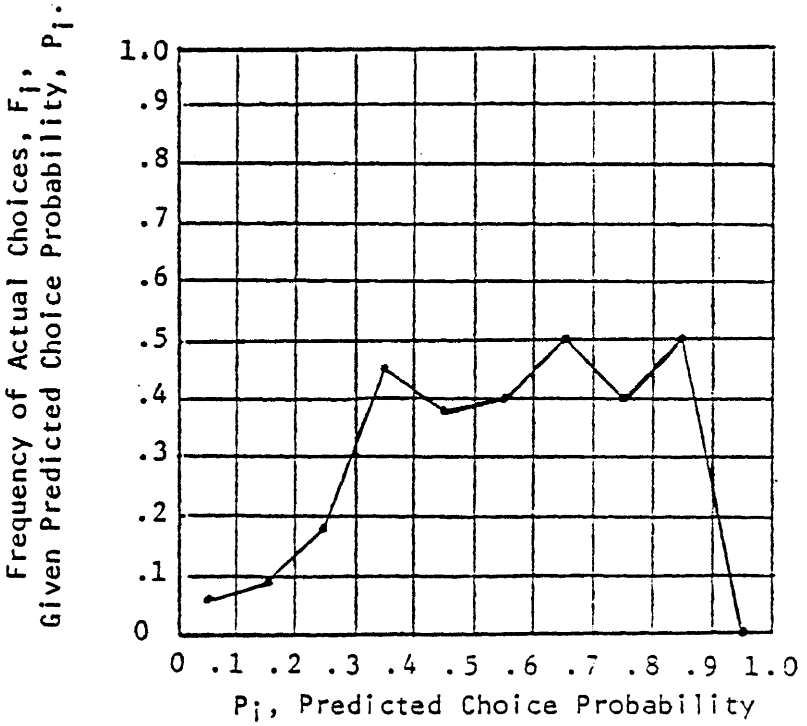


Figure A3.20 Graph displays the frequency of actual choices (subjects' referendum voting) given predicted choice probabilities from the EBA model using the expert's possession function.

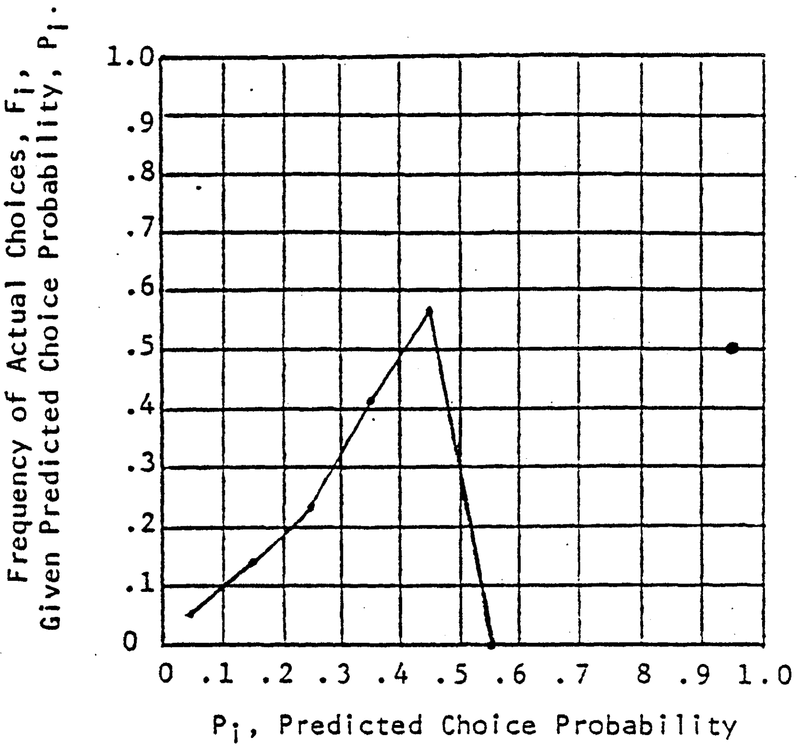


Figure A3.21 Graph displays the frequency of actual choices (subjects' referendum voting) given predicted choice probabilities from Luce's model.

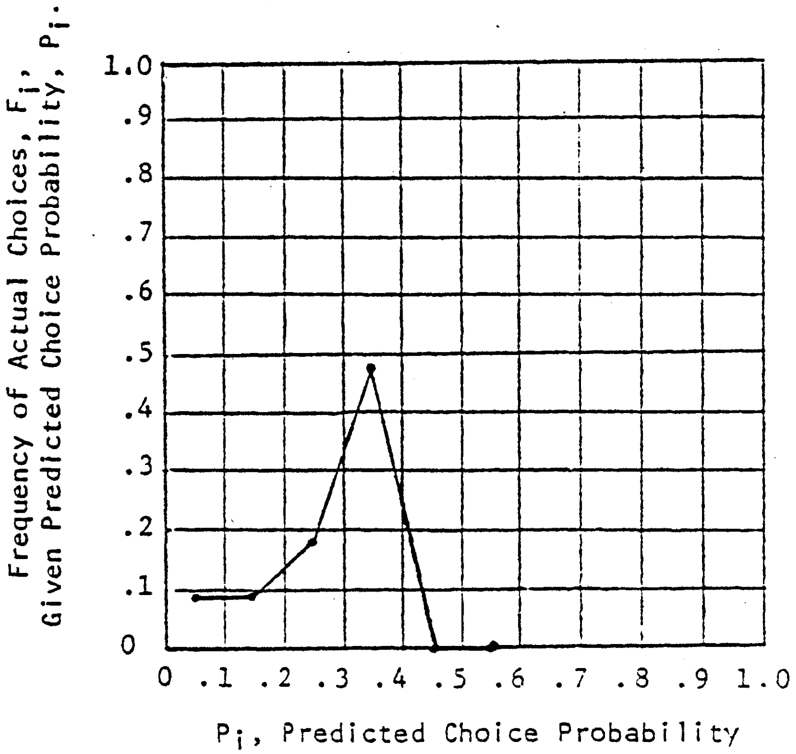


Figure A3.22 Graph displays the frequency of actual choices (subjects' referendum voting) given predicted choice probabilities from Luce's model using the expert's possession function.