8210587

Okimoto, Glenn Michiaki

OPTIMAL CONTROL FOR LAND USE DECISIONS IN HAWAII: MODEL FORMULATION AND POTENTIAL APPLICABILITY

University of Hawaii PH.D. 1981

University Microfilms International 300 N. Zeeb Road, Ann Arbor, MI 48106

OPTIMAL CONTROL FOR LAND USE DECISIONS

IN HAWAII

MODEL FORMULATION AND POTENTIAL APPLICABILITY

A DISSERTATION SUBMITTED TO THE GRADUATE DIVISION
OF THE UNIVERSITY OF HAWAII IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN AGRICULTURAL AND RESOURCE ECONOMICS

DECEMBER 1981

By

Glenn Michiaki Okimoto

Dissertation Committee:

Hiroshi Yamauchi, Chairman
Harold L. Baker
Gary R. Vieth
Frank S. Scott, Jr.
Goro Uehara

ABSTRACT

The potential applicability of systems control theory to analyze the empirical performance of agricultural land allocation among competing uses in Hawaii has been undertaken as part of this dissertation, The pattern and trends of land use redistricting were statistically analyzed using dummy variable techniques to account for periodic redistricting effects of five-year boundary reviews during the early stages of the State Land Use Control Program. This discrete feedback function of five-year boundary reviews was replaced by continuous annual feedbacks which are currently in effect after the major discrepancies in initial boundary designations for the land use districts (Urban, Agriculture, and Conservation) were corrected.

The study showed that the loss of Agricultural District Lands are overstated when the early redistricting adjustments are not correctly taken into account. The reported annual average rate of loss of Agricultural District Lands of 151,819 acres/year since the implementation of the State Land Use Law in 1962 to the present, actually amounts to a net 39,584 acres/year or about one-fourth of the reported level. The larger portion (112,235 acres/year) can be accounted for in increased Conservation District Lands which represent a store for future use. Most (94 percent) of the agricultural acreage actually lost went into the Urban District which gained 37,044 acres/year. The remaining 6 percent or 2,540 acres/year were simply redesignated into a new Rural District, a transitional type district, established in the early phases of the program. The relative

marginal rates of annual losses are even smaller and decreasing over time.

Although the loss of Agricultural District Lands may be grossly exaggerated by these numbers, it is important not to underestimate the significance of agricultural land losses. A major portion (over 70 percent) of the converted lands were high quality agricultural lands which are scarce in the Islands. Also, agricultural import dependency has risen to a very high level and is increasing in the State in spite of counteracting State policies toward agricultural self-sufficiency.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The Problem

Although rich in land resources, the United States is vulnerable to increasing losses of agricultural land through uncontrolled urban expansion and distorting influences of urban demands on rural land markets (Raup). Many newspapers, popular magazines, scientific journals and government publications have surveyed the agricultural land situation and concern about the loss is growing. In 1974, a USDA survey showed 382 million acres of crop land in the United States, down from a high of 459 million acres in 1950. Raup (1974), states that a majority of land is withdrawn from the agricultural base because of government programs and projects that promote urban land use. Highway and reservoir investments make suburbs feasible where they once were not possible. The financial incentives for urban investments also promote urban expansion. The law that permits the deduction of interest paid on borrowed money, as well as the deduction of property taxes when computing taxable income has encouraged urbanization.

This situation has greatly aided the economic growth of the United States by encouraging activities that add to the gross national product. However, in the past, the concern for agricultural land was evident but not as vocal nor well publicized. The United States has made great advancements in technology that has allowed greater productivity from less acreage. During this period enormous farm surpluses existed and the problem was not the loss of agricultural land but fair commodity prices.

However, the 1970's was a time of change. As foreign policy promoted the sale of agricultural products overseas, surpluses turned to shortages. The ecology movement, by limiting the amount and types of herbicides and pesticides allowed has had an impact on agricultural productivity. Also, major technological breakthroughs were extremely rare because of bureaucratic red tape in releasing chemicals and a lack of funding for basic research in our colleges and universities. Furthermore, as energy prices rise and availability becomes somewhat uncertain, the adequacy of agricultural land gains increasing importance. Also, people have recently realized that many types of land use are irreversible. It is possible to restore strip-mined areas to closely resemble the natural habitat before exploitation, and to remove homes from the land to start up an agricultural operation; but, more often than not, restoration is economically infeasible. However, given enough time, money, and technology anything is possible. Nevertheless, irreversibility of land use is becoming more of an issue because there is less and less good agricultural land available to substitute for the loss acreage. Thousands of acres of good agricultural land will not produce crops ever again.

From the national perspective, it is still difficult to believe that an agricultural land problem exists. With 382 million acres of land in production, how can there be a problem. The nature of the problem because of the nature of the resource, is more localized. The cumulative effects do not appear serious but they are. Almost every state has published a report describing the loss of agricultural land and the impact upon the local economy. Every report states some concern over the loss but stresses the need for careful analysis of the situation.

Still, enough people must believe that a problem exists, that 44 of the 50 states have adopted some for of differential assessment program for farmland protection (Untaxing Open Space). These types of programs affords tax-saving benefits to users of farmland, in the hopes that this is enough incentive for their preservation. Other control measures, i.e. zoning, transfer of development rights, are restrictive agreements which are often discussed in connection with land use control.

But, before preservation methods can be assessed for their impact and effectiveness, a land use accounting should be taken. Land use accounting involves the detailed analysis of physical land quality and capability to develop an adequate data base for decision making. In particular, accurate and regularly updated location and acreage data of lands in agricultural use by crop category must be calculated. This type of physical and bio-chemical survey of the land has been initiated. In Hawaii, work using LANDSAT satellite imagery has started and is being used to develop an interpretative system of land use. The ALISH system (Agricultural Lands of Importance to the State of Hawaii) of land quality rating surveys agricultural land and categorizes them into prime, unique, and other lands of importance. As yet, soil productivity ratings specific to individual crops and non-crop uses has not been incorporated into the system. The Land Study Bureau (LSB), however, in the late 1960's developed a system to classify crops using research findings and expert opinion to segregate land into A, B, C, D, and E productivity classes.

Of equal or greater importance is the rate of distribution of use over time. If social or economic conditions dictate that land be removed from agriculture, do we allow it? Or, how much of it do we allow? How much reserve agricultural land do we hold? Land use changes will still occur because land is needed for urban uses. How much land will we allow to convert in the present time period and how much should be saved for future time periods; in other words, intertemporal decisions are important. How do we answer or at least begin to answer some of these questions.

Context of Hawaii

Since 1962, the State of Hawaii has lost 151,819 acres or 7.1% of its agricultural land to other uses. Of this 151,819 acres lost, 37,044 acres were converted to urban uses. The Urban District increased by a substantial 32%. (See Table I for State totals and appendix for totals by counties.)

This is especially significant in light of the fact that much of this land converted to urban uses was high quality agricultural land. It is estimated that about a third of the acres converted to urban uses was high quality agricultural land. On Oahu, between 1962 and 1979, 6,104 acres of good agricultural land and 9,749 acres of poor land converted to an urban use (HIMAG).

Actual production loss, in terms of food producing capability, was minimal. The State has lost 210,000 actual farm acreage, most in pineapple, sugar cane and coffee, but this has not diminished production. Sugar cane production has not declined significantly (9.8 Million tons in 1962 and 9.2 M tons in 1978), even with a 10,000 acre loss of land. Pineapple production has diminished (.89 M tons to .675 M tons), but not in the same proportion as the acreage loss, 72,000 to 44,000.

TABLE I

ESTIMATED ACREAGE OF STATE LAND USE DISTRICTS
1962-1980

STATE TOTALS

Date	Total	Urban	Conservation	Agriculture	Rural
1962	4,111,500.0	115,155.5	1,863,630.0	2,126,014.5	6,700.0
1963	4,111,500.0	116,464.0	1,862,600.0	2,125,736.0	6,700.0
1964	4,111,500.0	117,800.0	1,862,642.0	2,124,400.0	6,700.0[a]
1965	4,111,500.0	118,285.8	1,861,642.0	2,124,853.0	6,718.3
1966	4,111,500.0	120,211.3	1,861,595.4	2,122,500.1	7,192.3
1967	4,111,500.0	120,447.1	1,861,607.0	2,122,230.6	7,214.4
1968	4,111,500.0	128,399.4	1,860,891.3	2,114,923.1	7,285.3
1969	4,111,500.0	140,163.3	2,009,086.7	1,955,875.0	6,375.0[b]
1970	4,111,500.0	140,697.3	2,008,915.8	1,955,528.4	6,358.5
1971	4,111,500.0	141,660.0	2,009,167.4	1,954,295.1	6,377.5
1972	4,111,500.0	142,499.5	2,009,217.8	1,953,414.8	6,376.5
1973	4,111,500.0	145,227.0	1,986,877.8	1,970,299.2	9,104.6
1974	4,111,500.0	147,472.0	1,986,428.9	1,968,727.2	8,871.9[b]
1975	4,111,500.0	148,921.4	1,976,995.7	1,976,695.4	8,887.5
1976	4,111,500.0	149,426.2	1,976,985.4	1,976,131.4	8,957.5
1977	4,111,500.0	149,262.9	1,976,995.7	1,976,327.2	8,914.2
1978	4,111,500.0	151,012.5	1,976,931.4	1,974,339.5	9,216.7
1979	4,111,500.0	151,929.6	1,976,105.9	1,974,229.8	9,234.7
1980	4,111,500.0	152,199.2	1,975,865.1	1,974,195.5	9,240.3

[a] As adopted.

[b] After five year boundary review.

(Statistics of Hawaiian Ag)

The agricultural sector was pressured by population growth to produce at more than capacity. Population growth was the highest in the nation. Presently, there are almost a million people living in Hawaii, up from 632,000 people just 20 years ago, with the majority residing on Oahu (79%). One noteworthy trend is that population growth is moving away from Oahu towards the neighbor islands. In 1970, 82%, of the population resided on Oahu, this was the peak of the downward trend since 1920 (see Table VIII in the appendix).

In order to sustain and support a burgeoning population requires outside assistance. Such is the case for Hawaii. Inshipments of all the major commodity groups increased. Imports of red meats, fresh market vegetables and melons more than doubled over the past 20 years. Where once locally grown products supplied 50% of the market, now they supply 30% or less, as in the case of chickens and broilers.

This situation places Hawaii in a tenuous and vulnerable position, at the mercy of forces outside of our control. Transportation services become extremely important. Shipping strikes have bared supermarket shelves within a matter of days because of consumer tendencies to panic and hoard commodities. Although, the same situation would have occurred within a matter of months because only a 3-4 month supply is stored in grocers' warehouses.

Recent airline strikes also show how vulnerable Hawaii is. When United Airlines struck in 1979, drastically reducing the volume of tourist inflows, hotel occupancy rates dropped as did tourist dollars. First Hawaiian Bank conservatively estimated the loss at 1-4 billion dollars.

Other frequently voiced constraints are the inadequacies of land, water, capital and labor, as they affect agriculture, and the pervasive energy concerns. Agricultural interests must be viewed with respect to overall state conditions. The amount of land available for agricultural purposes is interrelated with the amount used for urban purposes. These relationships also depend upon the general economic atmosphere of the State and nation as a whole.

Many economic and social factors affect land use changes. Population growth, rise in real personal income, desire for single family dwellings, energy prices and a myriad of other forces affect land use. State policymakers must work within and sometimes without the system to control land use changes in attempting to attain certain State goals and objectives for the welfare of the people. These goals and objectives are sometimes not clearly defined, which only adds to the problem.

The Hawaii State Plan adopted in 1978 set forth goals for the State in areas of the economy, the physical environment, and physical and social well-being. These reflect ultimate ideal end states and describe desired social, economic, and physical conditions to be sought for Hawaii's people.

The goals of the State, as perceived by the Plan, are to achieve, (1) a strong viable economy, characterized by stability, diversity and growth that enables the fulfillment of the needs and expectations of Hawaii's present and future generations, (2) a desired physical environment characterized by beauty, cleanliness, quiet, stable natural systems and uniqueness that enhances the mental and physical well-being of the people, and (3) physical, social and economic well-being, for individuals and families in Hawaii that nourishes a sense of community responsibility of caring and of participation in community life (State Plan).

The priority actions dealing with land seek to utilize Hawaii's limited land resources wisely in order to insure the protection of the environment and the availability of shoreline, conservation land and other limited resources for the future. Also, they seek to accommodate urban growth in existing urban areas while maintaining agricultural lands in agricultural designation.

In order to reach the state goals by way of the priority actions, State decision makers require tools to aid in their decision making. The problem for research is to find appropriate dynamic analytical methods that can explain the "ex-post" data experience and can help to define "ex-ante" decision issues, and to formulate decision models for such purposes. Because these "ex-post" and "ex-ante" problems are essentially in the context of dynamic time related scenarios, the analytical tools selected must be capable of handling time as an explicit variable. In other words, analytical tools are needed to address questions and issues that are intertemporal in nature.

Objectives

The objectives of this study are:

1) To identify and review analytical approaches for addressing problems of intertemporal allocation of scarce lands.

2) To select and test certain promising methods (tools, models) for their potential applicability to the land use experience in Hawaii.

3) To develop conclusions and implications for the potential applicability of the selected methods.

4) To suggest or recommend alternative approaches or methods that might also have promising applicability to the intertemporal land allocation problem.

Procedures and Scope

Procedure 1 (relating to Objective 1): The identification and review of analytical approaches for addressing problems of intertemporal allocation of scarce lands will consist of a literature survey reviewing the various methods. Included in the discussion is the technique of optimal control theory, dynamic programming, graphical techniques, adaptable management techniques, and an analytical institutional economic approach of conservation economics. The discussion is not meant to be exhaustive but merely to introduce several intertemporal analytical techniques that have been used in the area of resource management.

The institutional economics approach is presented to better understand the nature of conservation economics in order to fully realize the affects of institutional focus on time oriented decisions.

Procedure 2 (relating to Objective 2): Different specifications of selected methods will be discussed and the appropriateness of each to the present land use situation determined. Actual data when available will be used to clarify and exemplify certain relationships. Most of the data manipulation will be through the use of ordinary least squares. The different specifications arise because of the nature of the resources and the socio-economic environment of Hawaii. Land is recognized as having both stock and flow components. The stock component is basically, the locational attributes, while the flow component is the quality attribute.

The socio-economic structure of Hawaii plays a major role in determining the proper specification for model formulation; the market structure, whether monopolistic or perfectly competitive, also have effects on the variables chosen and the subsequent solution. The social and economic environment of Hawaii is largely determined by historical and social events and trends. These trends and events are reflected in the social and political atmosphere and are, thus, seen in the laws that govern land use.

The institutional framework of Hawaii's land use will be described in order to set the stage for this analysis. It is important to realize the impact that certain historical events have had on present laws and how these laws have affected present conditions. The data base that will be utilized is the yearly acreage totals in the State of Hawaii's Land Use Districts of Agriculture, Urban, Conservation and Rural from 1962-80 as enacted by the Land Use Law. The sum of the acres in these four districts equal the State's total of approximately four million.

Procedure 3 (relating to Objective 3): The results for meeting this objective are directly derived from the analysis in Objective 2. Conclusions and implications for further study can only be determined after the study is completed. The nature of the solution should be one that is fairly comprehensive and that can be of use in explaining relevant trends and other phenomena.

Procedure 4 (relating to Objective 4): Using the methods discussed in Objective 1, suggestions or recommendations of alternative approaches that might also show promising applicability to the intertemporal land use problem will be presented. Application of another of the suggested approaches will be made in order to more thoroughly analyze the land use situation in Hawaii and to better utilize the available data. The complexity of the approach will be minimized so that the analysis does not get entangled in theory without any relevance to the problem.

The Nature of Research

Among the social sciences, economics has long suffered from a superiority complex. The economist's view of his field has been one of a discipline that was rigorous and precise with an advanced pragmatic methodology leading to a highly developed theoretical structure (Klein). Economists pride themselves on belonging to the most "scientific" of the social sciences. The justification for this conviction lies in the growing resemblance of the analytical tools used in economics and in the natural sciences. Essentially, in the use of mathematical techniques in theoretical analysis and the development of sophisticated mathematical and statistical techniques in empirical studies. Today, mathematical formulations of economic theory (dynamic analysis, i.e., optimal control theory) and the application of sophisticated econometric methods constitute the mainstream of the science of economics (R.A. Gordon).

Science, in one definition, states: "A systematic knowledge of the physical or material world" (Webster). Most definitions of science consist of these same two parts: 1) systematic knowledge about; 2) the real world. If economics is a science, it must not only develop analytical tools but must also apply them to a world that is observable or that may be in the future through improved means of measurement.

Without in any way demeaning the very real accomplishments of quantitative procedures in advancing knowledge in critical areas, there is a tendency to ignore important real world problems. The models can cope with large numbers of variables in ever more elaborate specifications, but cannot cope with underlying questions of direction and meaning of goals and objectives for the system. This is a question of relevance. Is the science of economics becoming too rigorous and sacrificing relevance? (Klein)

In this dissertation, there is an attempt to achieve a balance between rigor and relevance by discussing the theoretical framework and searching for practical applications and interpretations. Important in the analysis is the institutional framework, how it has developed and how it is changing. To what extent does the changing institutional environment affect the relevance of the analytical tools that we use and the assumptions that we make? Why do we ask too few questions about why and how the institutional environment has changed in the way that it has and what are its internal dynamics that will lead it to change in a particular way in the future? The institutional impact must not be overlooked or underestimated.

As R.A. Gordon stated in his address to the AEA convention in 1975, let one credo be: "relevance with as much rigor as possible," and not "rigor regardless of relevance."

CHAPTER II

INTERTEMPORAL ANALYTICAL METHODS: A SELECTED LITERATURE REVIEW

Intertemporal analytical methods that have been applied in the area of resource management include optimal control models, dynamic programming, graphical techniques, adaptive management techniques and institutional economics. Brief overviews of these methods follow in order to familiarize and introduce the reader to methods that may be useful in making intertemporal decisions. The analytical institutional economics approach is described in detail because its concepts and principles pervade throughout this dissertation. The social and political considerations are inextricably woven into the economic framework and a knowledge of conservation economics is useful and vital in the analysis.

Optimal Control Theory

Optimal control theory is a set of mathematical techniques that tell us how to choose among alternative policies so as to best regulate or control a system. Optimal control theory was first developed for use in solving problems in the physical and chemical sciences. Economics and other fields have borrowed this technique and have applied it to various types of problems, i.e., shortrun economic stabilization, economic growth, corporate strategies and investment portfolios. In recent years increasing efforts have been made in the resource economics area as well.

In the area of economic stabilization, Pyndick and Chow showed that optimal control theory could be applied to a national macroeconomic model. Given certain policy objectives and available controls, a system could be designed to simulate the structure and control theory applied. Wilfred L'Esperance applied the general approach to the state of Ohio's econometric model. This illustrated the usefulness and nature of optimal control in the area of stabilization policy.

The theory of optimal control has just recently been given popu- law publicity, especially when Business Week published a report of Pyndick's approach. However, its origin dates back to the early 1960's beginning with Bellman's principle of optimality in the United States and the maximum principle of Pontryagin, et al. in the Soviet Union (1962). Since then, optimal control theory has gained widespread acceptance for its applicability to a global class of problems.

Some of the more recent applications in the area of resource management were attempted by Krutilla and Fisher, and Joun and Schwind. Krutilla and Fisher used optimal control theory in developing an allocation model for the economics of unique amenity resources. They studied the allocation of land between development and preservation in the Hell's Canyon hydroelectric dam case by estimating and comparing net social benefits of each use over time. The concept of irreversibility is involved in this case. Depending upon the direction that the relative benefits between development and preservation move over time, dictates the decision to preserve or develop.

Joun and Schwind have used the optimal control model to evaluate land use alternatives at the metropolitan fringe of Honolulu. They have taken the model and have shown that it can provide a framework relevant to the practicing land use planner. It is used to estimate streams of discounted benefits and costs that evolve from a specific parcel of land, location, quality and size, if preserved or developed. Again, the relative direction of movement of the cost and benefit streams over time dictates the decision.

The solution to the control problem can be considered as an extension of the method of Langrange multipliers to dynamic optimization. The maximum principle approach is the solution generally chosen. The maximum principle has been used in computing optimal controls in many important mathematic, engineering and economic problems (see appendix).

Dynamic Programming

Dynamic programming is a numerical technique that provides a solution to the control problem by arriving at optimal control policies (Intrilligator). It is based on a "principle of optimality" which states that at any point in a sequence of decisions, one should choose the policy that maximizes the sum of the benefits received from this decision plus the future benefits obtainable as a result of this decision (Bellman). In other words, it is a trade-off between present and future benefits. It is similar to optimal control theory.

Dynamic programming has found wide use in pest management schemes, water resource systems, forestry, fisheries, and management of animal populations.

The result of a dynamic programming solution is a feedback control law. Where there is uncertainty in the dynamics of the system so that the optimal control policy of the future will depend upon the state of the system at that time, a control policy that falls under this definition is called a feedback law. For instance, a control law that expresses conversion rate of agricultural land as a function of remaining acreage instead of time, can be considered a feedback control. An optimal feedback policy is more desirable than an optimal policy (Walters & Hilborn).

The major shortcoming of dynamic programming is that it can only handle a few (4 or 5) state variables. The number of outcomes that arise in the solution process increases geometrically with each time period analyzed. A small two state variable and one control variable case with ten possible values for each gives 1,000 possible outcomes for each time period. This is known as the "curse of dimensionality" (Bellman). However, the feedback characteristic of the solution often makes it extremely useful in solving problems that, using other techniques, may have been intractable.

Graphical Techniques

When the control actions involve a small set (i.e. one or two) continuous variables, a graphical technique called control space optimization has been used. Beverton and Holt popularized this technique in the study of fisheries management (Clarke). The graphs generated were called yield isopleth diagrams. Such diagrams, can be generated analytically, or more often by computer simulation. These types of diagrams specify optimum equilibrium policy and are not a feedback law.

The principle advantages of control space diagrams are their ease of generation and simple presentation. They do not require an explicit objective, since selection of the optimal policy is done from the diagrams. They deserve close attention because they seem to be one of the most effective methods for incorporating simple optimization into real world management (Walters & Hilborn).

For more complex models, with several continuous variables, a fixed form or policy space optimization is a technique that has been used. It is a multi-dimensional extension of the control-space optimization. When the fixed form approach is used with a well defined objective function, numerical computer searches across many control variables can be used to find the best combination. A near optimal feedback policy is obtained. Graphical presentations are difficult because of the many dimensions.

Adaptable Management Techniques

In the realm of natural resource management, the element of uncertainty always pervades. In this class of problems where either the probability distribution has not been assessed or is believed to be changing over time, three management approaches have been used. These are (1) deferred action, where it is assumed that ecological systems cannot be managed until basic research is conducted to determine key relations; (2) passive adaptive, which uses previous experience and available studies with similar systems to construct a best possible model; then manage the resource as if this model were correct expecting new information to improve the model and by learning through mistakes; and (3) active adaptive, to meet all management decisions as deliberate experiments that have dual effects, short- and long-term benefits and costs.

Walters and Hilborn describe and comment on the approaches. The deferred action approach leads us to believe that observations of an undisturbed system can somehow be extrapolated to the novel experimental situation created by management. This implies that functional and numerical relationships can be established by laboratory studies or by observation in the field. It also implies that observations will ultimately determine the response by management to the new situations created. This is a lot of wishful thinking. Usually, proponents of this system defer any decision until the collection of good baseline data can be completed with which one can compare management effects. However, consider ecological relationships where there is a stock-harvest relationship. The baseline data that is generally observed and collected is near the natural equilibrium point. How many natural equilibrium points are worth collecting? Some baseline data is certainly available, but it is a long way from baseline to understanding.

The ecological management process relies on adaptive policies of learning by doing. The concern is on how to optimize the adaptive process. Both passive and active adaptive management approaches may be useful. The uncertainty element over time is involved in each approach, making either one appropriate for the given situation.

The passive adaptive approach managed systems are monitored to produce a time series of state indicators. These indicators do not show a complete or accurate picture of the time system state. These indicators are then fed into an algorithm intended to filter the data to produce improved estimates. Simultaneous estimation methods may be utilized. These estimates provide the basis for control or action decisions. In passive adaptive policy, this model is assumed to be correct and is then managed as such. Mistakes are expected and are used to improve the model's management capabilities.

Passive adaptive is the general process of formulating models (which may be no more complex than trend relationships), making best possible predictions and revising the model as new data becomes available. In the real world, some learning is apparent but certain management responses are counter-adaptive. These are generally originated from a fear of change. What "worked" in the past should work now. New interpretations are slow to be assumed until older analyses begin to produce large errors and infrequent parameter revision are potential pitfalls in the pursuit of adaptive approaches by management.

Active adaptive management is the process of deliberate experimentation. For example, a fish population may be deliberately over-exploited in order to determine maximum sustainable yield.

When management or development begins to disturb a system that is poorly understood, two distinct types of benefits are generated: short-term and long-term. However, there is generally a trade-off between these benefits. We would learn most rapidly by introducing large disturbances into the system, but we run high risks and costs by doing so. The problem of balancing the short-term and long-term benefits is known as the dual control problem (Feldbaum). This problem has not yet been fully resolved even for simple systems (i.e. 4 or 5 state variables), although theory has been available since 1960.

The probability distribution assigned to any possible future outcome and therefore the optimal decision will be based upon the entire history of system observations. The optimal feedback policy becomes a function of many variables (each with past observations) rather than just the current state estimate and a stable probability distribution. Here again, however, the "curse of dimensionality" enters the picture. Now, instead of exploring future values of several discrete levels of a few state variables, it becomes necessary to explore many possible values of all earlier observations. Such a model has yet to be applied, but may soon appear. Adaptive feedback techniques are expected to be the model of the future (Walters & Hilborn).

Analytical Institutional Economics Approach

There are several important goals in optimization analyses. The most important is to produce management policies that are better than those currently in use. Three important but not directly sought after results are also produced. The first is a better understanding and a clearer application of the functional relationship that exist within the system that must be realized in order to manage the system at all. It is necessary to determine answers to initial questions about system behavior and interactions. These answers often provide new insights to the system. Second, another important result is a better understanding of the objectives of management. Optimization requires an objective function. Usually, one of a few objectives must be chosen from the many available. Looking at several objective functions leads to insight about the inevitable conflict of objectives. Third, the simple exercise of identifying feasible control actions often lead to a different perception of the real problem. Frequently, it is found that political and economic constraints completely dominate all biological considerations.

The last point is extremely important. In the field of conservation economics, institutional and political consideration are the prime reasons for certain management policies. All too often institutional or economic forces determine management policies. Discussion of the conservation economic approach follows.

Conservation Economics

Conservation economics attempts to understand the distribution of resource use over time in terms of the relationship between technological knowledge, individual motivations and social institutions. Conservation economics serves as a basis for formulating and implementing public policies that aim to protect or change a given time distribution (Ciriacy-Wantrup, 1952).

Conservation in this context does not mean non-use, or static use, or even wise use. For these terms are highly misleading and are of little value especially in dealing with stock-vs.-flow resources. Conservation is concerned with the "when" of use; a resource's intertemporal distribution of use. Conservation, more specifically, is defined in terms of changes in the intertemporal distribution of physical rates of use.. For conservation the redistribution is in the direction of the future, while for depletion the redistribution is in the direction of the present. Conservation implies the comparison of at least two time distribution of use rate. Comparisons of use rates for adoption of different new technologies with the old technology to find which is more conservative can be made.

In terms of determining an optimum state of conservation, several quantitative methods are available, i.e. present value techniques, benefit-cost analysis, and differential calculus techniques. However, the optimum state is heavily influenced by economic forces; a study of these forces and their effects is the key to conservation economics.

An understanding of these forces is necessary for explaining the past behavior of resource users and for predicting the future behavior of resource users. Also important is the understanding of the process by which choices are made by a population. Economic forces may hinder or aid such policies.

Among those economic forces of importance are interest rates and related forces, uncertainty, prices and price supports, and social institutions of tenancy, credit, taxes, and market form.

Interest Rates: Among economic forces affecting conservation, interest rates and related forces are some of the most powerful and consistent. Interest rates are used for planning purposes, for making comparisons between net revenues occurring within different time periods.. Present value analysis utilizes interest rates to discount future net revenues to the present. An increase in interest rates, by definition, implies a progressive decrease in future revenues. Thus, planning agents would tend to redistribute net revenues in the direction of the present.

However, there are situations in which a planning agent would base a decision not based upon a perfect market, such as monopolistic conditions allowing discrimination. This causes the spread between rates for disinvestment and investment to be large and variable from time, place and individual. It often is more economical for planning agents to deplete rather than sell assets when business declines if there are no ready markets for their sale. They may also find it more economical to conserve assets if funds are scarce. It is an individual choice frequently based on hunches that incorporate a precise rate of discount.

Uncertainty: These hunches, presuming the existence of uncertainty, are generally subjective. However, the overall goal of a planning agent is to avoid immoderate losses. Thus, a range of outcomes are guessed and a choice is made. To allow for uncertainty in planning decisions, a planning agent may discount for it. This may be accomplished by raising the discount rates or by attaching a probability to expected net revenues. Hedging, pooling and spreading arrangements are other means to allow for uncertainty. These methods shift the incidence of uncertainty to others or among more people. Flexibility in planning is another way to allow for uncertainty. Keeping time planning horizons short to facilitate faster changeovers in case of new technologies or other changes allows for more flexibility.

Increases in uncertainty will decrease present value of future revenues moving use rates in the direction of the present--depletion. Conversely, decreases in uncertainty will lead to conservation.

Prices and Price Supports: The effects of prices, as an economic force affecting conservation policy and decisions, although substantial, are unpredictable at best. The amount of the price change occurring in different time intervals and the number of planning intervals involved stipulate the effects of the price change. The type of technology involved also determines what effects a change in price may have. Conservation decisions are different if a country is in a horse-and-plow type rather than a tractor type technology. These effects are evident in relationships between marginal revenue and marginal costs and the technology used.

The effects of a price change depends on the specific set of assumptions. Assume that a change in prices is expected to occur at a certain point in the future and continue indefinitely. Also that each period's revenue is independent of the others. In this context, if the price of the product being produced is expected to be higher in some future time period then this would induce planning agents to shift use rates in the direction of the future--conservative. In other cases, where prices are not expected to last indefinitely, i.e., during the upswing of a business cycle, planning agents will tend to aim production at the peak of the cycle even if this is depletive.

There are no hard and fast rules about the effects of prices on conservation decisions. The context within which these changes occur determine the effects of price changes upon use rates. The time distribution effect of price changes must not be overlooked if these are to be recommended as policy.

Social Institutions: The economic forces of interest rates, uncertainty, and prices are largely determined by social institutions. These social institutions influence conservation decisions and are not static conditions. They can be changed. Policy makers have some control over institutions and in this way can control conservation decisions. Among the most important social institutions are property rights and its treatment, tenancy, credit, taxation, and market form. Each will be briefly discussed.

The social institution dealing with property rights is probably the most important. Out of this comes the other institutions of tenancy, credit and taxation. Property rights are commonly described as a bundle of rights over which one has control. The strength and type of control generally determine the effects on conservation decisions.

When property rights are ill-defined or unstable for any number of reasons, users of the resource will not have any incentive to conserve. This may happen under conditions where there is political unrest or economic uncertainty. Welfare economics plays an important role when externalities evolve or common property situations exist. Government regulations allow some control over depletion conditions. The civil law statutes requiring compensation for damages from damaging party, zoning ordinances and regulations prohibiting certain uses are ways by which government can control property rights.

Tenancy: The effects of tenancy upon conservation decisions are mainly through instability, incidence, fixity and market imperfection. Instability is a result of uncertainty. In the area of agricultural land leases, local customs and traditions are significant. The tenant is unsure of the length of time he will have the use of the land. In Hawaii, some farmers are on month-to-month leases; not knowing whether the lease will be extended for any period of time. There is no incentive to (1) conserve the soil, or (2) adopt new technology (invest). Written longer-termed lease contracts clearly spelling out each party's responsibility will reduce uncertainty and instability.

The incidence and allocation of costs and revenues upon tenant and owner are important. Who pays what proportion and who receives what proportion? Again fair, equitable lease arrangements must be made to reduce the friction between tenant and owner.

The fixity of rents are discussed because of their undesirable attributes. Fixed rents remain unchanged regardless of the income level of the tenant. Usually, the smaller the property, the greater (per acre, or per square foot) the rent.

In a tenancy situation there are other ways by which a less than optimum state of conservation can exist. The economic strength of the owners may be formidable and imperfect markets may exist. A policy to transform tenants into owners is in line with the objectives of conservation policy.

Credit: The credit system affects the state mainly through uncertainty, fixity, and imperfect markets. The uncertainty factor becomes evident when creditors become wary during times of economic instability and recall the loan before it is actually delinquent. This may cause uncertainty in tenure and consequently lead to depletion.

Fixity of rates tend to guide the state of conservation to depletion. This is especially true during depressions, during which receipts are less and payments are unchanged. This is not usually offset during the boom years of the cycle. These fixed charges are usually regressive with income. The debtors in lower income groups pay higher interest rates than debtors in high income groups. The prime interest rate is a good example of this. Debtors that have the best financial condition and the greatest ability to repay are given the lowest interest rate. Others pay considerably higher. This is largely due to a risk factor, however, it does show the depletion affects of a regressive charge.

Taxation: The practical significance of taxes in resource conservation are probably greater than tenancy and credit. Like the other institutions, the tax system has highly significant but unrecognized effects on the state of conservation. Taxation, for this reason, can be an obstacle for conservation. While on the other hand, it is used more frequently because it can be more easily employed than tenancy and credit. The effects of taxation on the state of conservation are more complicated than those of tenancy and credit. These complexities have similarities to those already encountered in dealing with prices.

The assumptions that are necessary are similar to those that were made in connection to prices. The first is the assumption that a given tax change is expected to last indefinitely or at least over the entire planning period; also, the interrelation between use rates will not be affected because taxes are not generally imposed on depicting or conserving services specifically. They are usually a revenue raising mechanism for government and are applied broadly.

If the tax change is not expected to last indefinitely, then the rates of use tend to be distributed over time toward those periods that have the most favorable tax situation. This redistribution is of importance in conservation policy. Appropriate variation of taxes over time with or without public announcement of planned future changes can encourage or discourage conservation. Overall policy goals are needed in this case.

Inherent in all types of taxes are either progressive or regressive tendencies because most tax bases vary over time. Generally, a progressive tax tends to equalize the tax base between time intervals, while a regressive one tends to accentuate the differentials. The effects of those taxes are opposite. Whereas, one may be conservative, the other is depletive depending upon the resource under consideration.

Again, as with prices, it is difficult to obtain any concrete results that hold regardless of the situation. It is enough to say that taxes do have an effect on the state of conservation and this effect cannot be overlooked in policy matters. Taxes do shift the use of productive services and even taxes that are usually regarded as neutral (i.e., income taxes) can have decisive effects upon the state of conservation.

<u>Market Form</u>: The form of the market, whether monopolistic or

atomistic, in which products of resource users are sold and services bought is an important institutional force in resource utilization. Many laws, administrative agencies, customs, attitudes and special arrangements decisively affect the market through the number of participants allowed. The number of participants allowed affect market behavior and the state of conservation.

Under the usual economic analysis of monopoly, the demand curve for the industry is the demand curve for the firm and the marginal revenue curve lies below the demand. This situation would reduce the quantity produced by the firm and increase the price when maximizing total revenue. However, in the case of perfect discrimination, the quantity produced would be the same as if it were supplied under perfect competition only the revenues received would be greater.

The effects of interest rates and uncertainty, two key economic forces, upon market form are different. Interest rates are generally lower for larger firms and these larger firms are generally, but not always, found under monopolistic conditions. It can be stated the imperfections in the credit market are less severe under monopolistic conditions. In dealing with uncertainty, it is sometimes contended that the monopolistic conditions reduce the uncertainty associated with long range investing. This reduction in uncertainty has tendencies toward conservation.

These cases are generally for pure monopoly versus pure competition. If gradations in monopoly are introduced, i.e., oligopoly, then we cannot conclude that output would indeed be restricted. Conservation, then, is not a necessary condition of monopolistic situations especially if oligopolists are uncertain about the actions of other oligopolists in the industry.

Since most real-life conditions can be described as oligopolistic, conservation policy aimed at changing market form is not a reliable tool. If such an attempt is made, then moving to a more monopolistic situation would tend to be more conservative. However, it is the traditional policy of the United States to prevent pure monopolies and promote perfect competition. This policy is backed by public opinion and embodied in statutes. Therefore, it is highly unlikely that there will be a move toward a more monopolistic economy.

Planners must work within the framework presented using the tools available to move in the direction desired.

<u>The Safe Minimum Standard</u>: In terms of conservation decisions, public and private policy makers are under the influence of the same economic forces, especially that of uncertainty. These planning agents are often faced with choices between possible losses of various magnitudes and probabilities. Generally, the possibility of a larger but less probable loss can be avoided by the acceptance of smaller but more likely ones. In private decision making, avoidance of losses which are immoderately large, thus entailing bankruptcy is of great interest.

In public decision making a similar situation exists. Governments are also confronted with choices between possible losses of varying probabilities and magnitudes. The possibility of immoderately large losses, ones that threaten the survival of the group, are of greater concern to government planning agents. In the field of conservation, the economic irreversibility of depletion of the important class of resources characterized by a critical zone is one such possibility.

After a certain point--i.e., if more and more acres of land or plant and animal species are affected--irreversibility of the depletion of these resources severely limits opportunities for adaption and limits the development potential of a society. Such limited and narrowing forces direct development toward specialization rather than diversification. Specialization tendencies have been held responsible for retarded growth, in another sense--a dead end (Toynbee, Krocker).

However, we do not know where this point is. Economic irreversibility is uncertain. It depends upon present technology, wants and social institutions. These are in constant change. There is also the uncertainty about whether irreversible conditions will actually lead to immoderate social losses. Furthermore, it is uncertain whether specialization will be the cause for stagnation and elimination of the group.

The decision to avoid the social risk of irreversibility, however, is not dependent upon the immoderateness of the loss. This is only one special case. The choice is between larger less probable losses or smaller more probable losses. These smaller more probable losses are connected to what is called a safe minimum standard of conservation. This standard is achieved by avoiding the critical zone. The critical zone is characterized by those conditions brought about by human action, which would make it uneconomical to halt or reverse depletion. A safe minimum standard is essentially an increase in the flexibility of a society.

The physical conditions that characterize the critical zone for individual plant and animal species can be simply described as a destruction of the breeding stock or natural habitat. The determination of exact numerical levels is a biologist's nightmare but is conceptually feasible in economics. The critical zone of groundwater depletion may occur during periods of sustained overdraft and measurable by the salt balance level of the water. Irreversible depletion of soil resources may be the result of massive erosion.

In terms of agricultural land use, a critical zone may be defined as that level of agricultural land use and resultant production from such, that is unable to produce enough agricultural goods to sustain a majority of the population. When this situation occurs, a society will be highly dependent upon outside influences and susceptible to their whims and fancies.

A practical definition of a safe minimum standard would entail defining it in terms of conservation practices designed to avoid the critical zone. The great variety of resources and physical conditions make it impractical to define a safe minimum standard in terms of a single use rate. For agricultural land use it may be to maintain a viable agricultural sector by maintaining a certain amount of land in agricultural use, i.e., acres planted/year.

The main advantages of defining the safe minimum standard are its great adaptability to local conditions, easy understanding by resource users and its economic administration by government agencies.

The main disadvantage is that the suitability of conservation practices for avoiding the critical zone must be established first. This takes time for observation and analysis.

The safe minimum standard is a useful concept allowing practical use of conservation economics. This concept can be applied to many different types of resources. One area that it may apply is the land use planning field. Is there a safe minimum standard for land use and have governments explicitly or implicitly recognized the existence of one when making policy?

CHAPTER III

INSTITUTIONAL SETTING FOR THE HAWAII CASE STUDY

"Aloha aina" translated broadly means love of the land (Pukui) and expresses the feeling that early Hawaiians had for their islands. In connotes love, not only for the physical aspect, but also the spirit or "mana" that the land was believed to possess. The relationship between the people, the land, and its uses was one of harmony and respect. Boundaries were not demarcated by artificial markers but by natural phenomena such as streams, mountains and ridges. Accordingly, land was not forced into an "unnatural" use but was allowed to be used as best as nature provided. Climate, soil, and topography were some of the factors considered in determining land use. This feeling of "aloha aina" still pervades deep within Hawaii. It is with this appreciation of the land that the State Land Use Law was conceived and instituted. This chapter provides a historical review of land use in Hawaii and some of the major events that led to enactment of the State Land Use Law in 1961.

Historical Background

Under the ancient Hawaiian Land System, land ownership and possession as we know it today was nonexistent. Rights to land were usufructory and revocable at any time by the king. The land was naturally divided by islands and controlled by the reigning alii or king. His powers were deemed god sent.

Each island was divided into large districts or mokus with no particular justification for the divisions. The king, after keeping some of the best land for himself, would divide each moku into smaller units called ahupuaas. An ahupuaa was, ideally, but not necessarily, a wedge of land extending from the mountains to the ocean. Thereby, affording its users a variety of land use benefits, i.e. fish from the sea and taro from the land. The sizes of ahupuaas varied roughly from 100 to 1,000 acres. Favored lesser chiefs were appointed as konohikis or administrators of each ahupuaa. The ahupuaas were further divided into ilis. The divisions were made by the discretion of either the konohiki or alii. The arable portions of the ilis were divided into moos and were set aside for cultivation only. This was once again divided into smaller units called pauka and also set aside for cultivation. The patches of land that were cultivated by an individual tenant were called koeles. A parcel of land cultivated by a tenant-farmer for himself and his family was called a kihapai. This was the basic customary land system in Hawaii before the arrival of Captain Cook.

After the "discovery" of Hawaii by Captain Cook in 1778 and the arrival of the missionaries, new pressures for change were placed upon this system. Many of the people who frequented the islands were aggressive sailors, traders and merchants who were accustomed in their homeland to own land in fee simple. They challenged the right of the king to dispose the land at will. In 1839, a Bill of Rights was enacted which was the beginning of a fundamental change in the Hawaiian Land System. In 1840, a constitution was adopted which changed Hawaii from an absolute monarchy to a constitutional monarchy.

In 1848, the Great Mahele in land division occurred. It ended the feudal system of land tenure, making ownership rights irrevocable and transferrable. By this time Hawaii was experiencing an economic boom. Buildings were sprouting up everywhere. In Honolulu, construction had extended far beyond the immediate harbor area. No longer was Honolulu a flat scrabby stretch of land but now consisted of several hundred buildings.

Beyond Honolulu, lay vast acreages of gently sloping lands with potential for agriculture. Artesian wells discovered in 1879 opened the way for irrigated sugarcane on an increased scale. The first Reciprocity Treaty with the United States in 1875 provided for the duty free entry of Hawaiian sugar into the United States. This gave the islands a great advantage over other foreign producers competing in that market. Sugar was dominant in every way in the late 1800's and early part of the twentieth century. And, after the Reciprocity Treaty had expired in 1887, the United States revised its tariff policies and Hawaii's position was no longer favorable. There was a push for annexation and in 1900 Hawaii became a territory of the United States.

Under the conditions of the Organic Act, a governor was appointed by the president of the United States, a voteless delegate to Congress in Washington, D.C. was elected, a bicameral legislature was initiated in Hawaii and universal suffrage for all who held citizenship status under the Republic of Hawaii was mandated. The Organic Act ceded all of Hawaii's public lands to the United States, but remained for administrative purposes under the possession, use and control of the Territory of Hawaii. When Hawaii became a state, much of this land was returned to the state so that, at the present time, about 400,000 acres remain with the federal government and about 1,920,000 acres are state owned.

In 1895, the Hawaii republic established its policy for public lands in the Land Act. This allowed public lands to be administered by a commission. The charge to the commissioners was that they were authorized to "lease, sell or otherwise dispose of the public lands, and other property, in such a manner as they may deem best for the protection of agriculture and the general welfare of the Republic." It was not unusual that during this time, large areas of public lands were sold or leased to the plantations.

In 1903, the Territorial Legislature passed a law (Act 44) allowing the governor to set aside forest and water reserves, and a continuing preservation program resulted. Even today, such reserves amount to more than a million acres.

The plantation business, during the territorial period, became the paramount industrial activity. Around the plantations revolved almost every activity of life in Hawaii. Other commercial enterprises, such as banking and transportation as well as general merchandising depended a lot upon sugarcane.

Another major accumulator of land in the early twentieth century was the United States government. Not only were crown lands and government lands appropriated but additional areas were "set aside" for defense purposes.

Economic growth continued but it was not until after World War II that there was unprecedented growth. The rate of population increase was the highest in the nation. More people meant added demand for real estate. This lead to rising land values and profits, encouraging speculation. Scattered, ill planned subdivisions sprouted everywhere as prime agricultural land gave way to other uses. Statehood accelerated these trends.

These problems were addressed by the State General Plan which was enacted in 1957. Hawaii was the first of the fifty states to have such a plan. The Land Use Law was the result of this first General Plan.

Framework of the General Plan

During the preparation of the General Plan the following general land use problems and corresponding solutions became apparent. These were:

1. Development of land for urban uses, tended in many cases, in areas where it was uneconomical for public agencies to provide proper support and adequate service facilities. Consequently, there was a lag in the provision of such facilities.

2. Development of land for urban uses occurred, in many cases, on the State's limited prime agricultural lands while adequate lands on all islands existed to accommodate urban growth forecast for the next 20 years without employing lands suitable for intensive cultivation.

3. Development of urban areas should be encouraged in an orderly and compact manner in order to provide for economy and efficiency in siting public services and facilities.

4. Land not required at any given time for urban or intensive agricultural uses should received special attention in regard to land classification.

Origin of Underlying Issues

The underlying basic conditions common to all the islands were rooted in the following basic conditions common to all the islands: (1) the usable land area is scarce, (2) the ownership of land is highly concentrated, and (3) the government is centralized.

At first glance of the data, it might appear as if the problem of land scarcity does not exist in Hawaii. The total state land area is about 4,000,000 acres with a large amognt of that in open space. In 1978 there were 1,200,000 acres in forest reserves, 1,150,000 acres in grazing lands, and about 500,000 acres were pali or barren. Also, there were about 384,000 acres in agriculture or other open space uses. (Data Book, 1978)

However, the inherent nature of the demand for land creates a situation of scarcity. Land as an economic resource has at least two major components--location and productivity. The location factor becomes evident because of the fixity of the land. Land cannot be transported to meet demands in different areas. This is readily apparent on Oahu where 76% of the total state population currently resides on only 9.5% of the total land area in the State. Urban lands are two to three times more expensive than comparable mainland areas and land costs make up 47% of the sales price of new homes. All of this is happening while thousands of acres on the Big Island (Hawaii) go unused.

The agricultural productivity aspect of land also causes a situation of scarcity. A lot of Hawaii's prime agricultural lands (as defined by LSB) are also on Oahu where the pressures for their conversion to urban uses are the greatest. Prime agricultural land can also be considered as prime urban land because of their level topography, ideal climate and availability of water. These are major contributing factors to the land scarcity situation.

The concentrated ownership situation also underlies the land use problem. Collectively, land owned by the federal and state governments, and the major landholders (those with over 500 acres) constitute 93.7% of the total land owned. Small farmers, businesses and homeowners constitute only 6.3% of the total state land area. In the western states, Hawaii ranks as the state with the greatest concentration of ownership (see Tables II and III). This concentration distorts the market creating a oligopoly-like situation in which large land holders can withhold or slowly release the land in order to receive a higher price. They can also control the ownership of the land by not selling lands in fee but by allowing temporary transfers of use rights only through leases. This can influence the market heavily, creating a situation of contrived scarcity and artificially high prices.

The centralization of government has meant that the state government performs a number of functions that are left to local jurisdictions in most American states. Health, education, and welfare are administered by the State, as well as agriculture, forestry, airports, and harbors. This situation makes possible a more advantageous distribution of revenues and investment than might be the case under independent county governments (Lowry).

It is with this historical, social and economic background of Hawaii in mind that the Land Use Law was formulated. It was not a radical divergence from existing institutional practices or cultural beliefs but a culmination of several legislative trends.

The Land Use Law

The State Land Use Law is contained within Act 187, and is

TABLE II

SIZE OF HOLDINGS: CONCENTRATION OF LAND OWNERSHIP, ALL LAND, BY STATE, WESTERN STATES

STATE AND REGION	PROPORTION OF ACREAGE HELD BY Largest 5 Percent of Owners	Largest 1 Percent of Owners
	Percent	
Hawaii	98.2	97.2
New Mexico	90.7	70.3
Wyoming	90.6	59.0
Oregon	90.3	73.5
Nevada	89.4	73.8
Washington	87.1	65.9
California	87.0	68.3
Idaho	86.1	60.0
Arizona	84.7	74.4
Utah	84.2	59.4
Colorado	83.2	49.7
Montana	64.0	32.5
West	91.2	70.5
U.S. Total*	75.1	48.0

* Revised, exluding Alaska.
Source: 1978 ESCS Land Ownership Survey

TABLE III

SIZE OF HOLDINGS: CONCENTRATION OF LAND OWNERSHIP, FARM AND RANCH LAND, BY STATE, WESTERN STATES

STATE AND REGION	PROPORTION OF ACREAGE HELD BY Largest 5 Percent of Owners	Largest 1 Percent of Owners
	Percent	
Hawaii	99	89
Nevada	89	73
New Mexico	78	50
California	72	45
Arizona	67	46
Oregon	67	47
Wyoming	67	31
Utah	66	41
Idaho	62	33
Washington	62	31
Colorado	51	26
Montana	47	22
West	72	43
U.S. Total*	52	30

* Revised, excluding Alaska.
Source: 1978 ESCS Land Ownership Survey

amended by Acts 205 and 32. Amendments to the law governing the assessment of real property are contained in Acts 201, 267, 277 and 296. These acts, passed over a period of years have some goals that were initially declared in Act 187.

That is: "...to preserve, protect and encourage the development of the lands of the State for those uses to which they are best suited for the public welfare and to create a complementary assessment basis according to the contribution of the lands in those uses to which they are best suited" (Session Laws, Act 187).

Act 187 provided for the districting and classification of all the lands in the State into three general land use categories: Agricultural, Urban and Conservation. A later amendment added the Rural district bringing the total to four land use districts.

The Agricultural district includes lands with a high capacity for intensive cultivation with a minimum lot size of one acre for subdivisions. The delineation of actual boundaries was based upon (1) a soil productivity rating and land classification system developed by an agency (the Land Study Bureau) created for that purpose, (2) existing land uses, (3) topography, and (4) expert opinion. Generally, superior lands for agricultural production, grazing or other agricultural uses were zoned agricultural. Other lands with limited potential or with some limiting factors were zoned agricultural, rural or conservation depending upon location.

Urban districts are generally defined as lands characterized by city-like or urban uses with sufficient reserves to accommodate foreseeable growth. Exact boundary lines were obtained from aerial photographs with the advice of local county officials. Further, land use zoning within urban districts were left to county governments.

Conservation districts are primarily comprised of lands in the existing forest and water reserve areas. Also included are those areas which require preservation of natural wildlife, for recreation and parks, and historic sites. Areas subject to flooding, erosion, tsunami, land-slides, volcanic activity and steep topography are also included.

Rural districts are defined as lands comprised primarily of small farms intermingled with low density residential lots with a minimum size of half an acre. Permitted uses are similar to those in the Agricultural district.

To administer the Land Use Law, the Act created the Land Use Commission. It has the job of classifying all lands both public and private throughout the State into the established land use districts. Other responsibilities include supervising and adopting these classifica-tions within each county; changing district boundaries upon petition by the State, county or private parties; approving or denying special uses within districts; making amendments to existing regulations; con-ducting comprehensive five-year reviews; and classifying and establish-ing shoreline setbacks.

However, the situation is not very simple. The administration of land use controls in Hawaii is complex. Several department and govern-ment levels have authority along with the Land Use Commission. The county governments of Hawaii, Kauai, Maui and Oahu, the Department of Planning and Economic Development, the Department of Land and Natural Resources, and the Department of Taxation are all integrally involved. Also, the various public, playing a variety of roles (i.e. property owners, lessors, developers, conservationist, etc.) are all involved. There are a number of conflicting interests to be resolved and the problems neither begin nor end with the district delineations but merely continue.

In 1973, major amendments were made affecting the tax treatment of agricultural lands. These were encompassed in Act 175. In spite of the fact that the Land Use Law provided tax incentives for any agricultural use, despite the district classification, if these lands were dedicated possibilities existed for subverting the laws' purposes. Rollback or retroactive taxes and penalties must be paid if the dedication is broken but this has not deterred conversion of agricultural land. The dedication provision, at times, runs counter to the policies of the Land Use Commission whenever land classified as suitable for urban growth is dedicated to agriculture for any length of time. One of the Act 175 amendments tightens the definition of eligibility for tax privileges so that lands of marginal productivity cannot qualify for preferential tax.

The agricultural land preservation objective of the Land Use Law is strengthened by another 1973 amendment. This amendment provides that all agricultural land, whether dedicated or not, shall be taxed at its value in an agricultural use, regardless of its value in other uses. Dedicated lands were to be assessed at a value equal to one half of the assessed use values. Rollback taxes and penalties were increased to deter further conversion. Also, as part of an administrative rather than a legislative procedure, a reassessment of agricultural lands was initiated. The reassessment created a larger gap between use value and market value. Landowners could now see just how much more rollback taxes and penalties must be paid if the land was redistricted and how much higher the actual property taxes would be. This added more strength to the preservation of agricultural land.

However, the Land Use Law did not preclude the possibility of any land use changes. Many rezoning petitions were received by the Land Use Commission and a large majority of these were approved. This pattern of land use changes between districts will be examined in a following chapter.

The Hawaii State Plan

In 1975, the Hawaii State Legislature formally recognized the continuing need to wisely use Hawaii's limited resources. Chapter 225 of the Hawaii Revised Statutes allowed for the development of a comprehensive statewide plan to express the desired long-range future for Hawaii, and for the establishment of a system for policy plan formulation. The State Department of Planning and Economic Development was commissioned to formulate such a plan. From 1975 to 1977 a series of surveys, studies, councils, workshops and hearings were held to inventory and review existing goals and objectives of the people of Hawaii. In 1978, the Legislature passed the Hawaii State Plan. On May 22, Act 100 of the 1978 session became law.

It is within these historical, social and institutional contexts that Hawaii's land use policies have evolved.

CHAPTER IV

PATTERNS AND TRENDS IN LAND USE DISTRICT CHANGES

Time series analyses in this chapter consist of three basic components: trend, periodical and residual components. Our focus will primarily be on the trend and periodical components. The trend component will be explained by using a time variable. The periodical component will explain the effects of the 5 year Boundary Review by using dummy variables.

Dummy variable approaches are used to represent various factors, such as temporal, spatial and qualitative effects. Under the heading of temporal effects, shifts of behavior relations between one period and another are sometimes postulated. The land use case in Hawaii would come under the heading of temporal effects. For example, the trend function might be postulated to show an upward shift during the Boundary Review years. This case may be handled by the specification of appropriate dummy variables.

To analyze changes within and between State land use districts, ordinary least squares regression equations were estimated. These equations consisted of using acreage time series of urban land as the dependent variable and time as the independent.

Trend analyses of the State's and Oahu's land use district acreage show some interesting results.

Urban District

The Urban District for the State (SURB) is gaining land at the rate of 2,395 acres per year. The functional relationship is:

$$\text{SURB} = 112{,}756 + \underset{(12.98)}{2{,}395}\, T_i$$

$$F = 168$$ (t-statistic is in parenthesis under the estimated coefficient)

$$\bar{R}^2 = .9031 \text{ (adjusted } R^2\text{)}$$

T_i is the time variable, $i = 1, 2, 3, \ldots, 19$ (1=1962)

[See Figure 1]

Much of the changes occurred during the five year Boundary Reviews. The five year Boundary Reviews adjusted acreage between districts if previous designation were deemed improper.

If the effect of the Boundary Reviews are taken into account, the functional relationship becomes:

$$\text{SURB} = 114{,}864.0 + \underset{(10.77)}{15{,}017.0}D + \underset{(10.67)}{1{,}171.5}T_i$$

$$F = 701, \ \bar{R}^2 = .9873$$

[See Figure 1]

The effect of the Boundary Review years was accounted for by the use of dummy variables (D) in the regression equation.

The use of dummy variables directly affect the intercept coefficient. It is known that the Boundary Review had a direct impact upon the acreage rezoned in that year, but its effect upon subsequent years' conversion rates are uncertain. Therefore, it was postulated that an upward shift of the structure occurred and remained high. The acreage in years following were based upon the higher baseline. The dummy variable vector was used to reflect this. The rate of conversion may be affected by the number of acres converted during the Boundary Review years.

The dummy variable vector, D, used in this case was a series of 0's, 1's and 1.1's. The zeroes represent the years up to and including the first Boundary Review, the ones represent the years from the first up to and excluding the second Boundary Review and the 1.1 represents all years since. 1.1 was chosen for the third dummy number because it explained the increases in acreage better than using 2's. For example, the upwards shift of the line was not double as it would have been shown if 0, 1 and 2's were used. Instead, the shift after the second review was smaller than after the first review.

This sequence of dummy variables also proved to be more significant than by using the other dummy vectors, i.e. if the structure of the system returned back to the original system after the Boundary Reivew then a dummy variable vector using zeroes and ones, with ones only in the two review year, (0, 1, 0) would have been shown significant. However, this specification showed a lower adjusted $\bar{R}^2$ and an insignificant dummy variable (t-statistic too low).

On Oahu, the Urban District (OURB) has gained 758 acres per year. The functional relationship is:

$$\text{OURB} = 73{,}822 + \underset{(15.31)}{758.04}T_i$$

$$F = 234, \quad \bar{R}^2 = .9283$$

[See Figure 2]

With the effect of the Boundary Review years accounted for the equation becomes:

$$\text{OURB} = 74{,}239 + \underset{(+10.50)}{3{,}956.0D} + \underset{(14.00)}{466.5T_i}$$

$$F = 929,\ \bar{R}^2 = .9904$$

[See Figure 2]

In this case, the dummy variable vector was a series of zeroes and ones. The zeroes represented the years up to and including the first Boundary Review and the ones in the years following. This vector was used instead of the previous dummy vector of 0, 1, 1.1 because the greatest increase on Oahu came in the first Boundary Review. The subsequent second review did not have many changes.

For the State and Oahu Urban District Land, the trends appear similar. There is a general increase in urban acreage each year but a slowing of this increase is evident when Boundary Reviews are accounted for. For the State, the first Boundary Review, statistically, rezoned 15,017 acres and the second added 10% making the total 16,518.7. This lowered the yearly increases from 2,394 acres to 1,171.5 acres. Oahu shows the same type of results. The first Boundary Review rezoned 3,956 acres while lowering the rate of change from 758 to 466 acres per year.

Agricultural District

For the Agricultural District in the State (SAG) the trend is (the functional relationship from 1962-80):

$$\text{SAG} = 2{,}134{,}350.0 - \underset{(-5.43)}{10{,}957.6T_i}$$

$$F = 29,\ \bar{R}^2 = .5700$$

[See Figure 3]

This shows a loss of about 11,000 acres per year.

However, if the effect of the Boundary Reviews are again taken into account (using the same dummy specification as Urban District Land (0, 1, 1.1) the relationship appears as follows:

$$SAG = 2{,}110{,}270.0 - \underset{(-18.00)}{171{,}544D} + \underset{(3.35)}{3{,}006.0T_i}$$

$$F = 459,\ \bar{R}^2 = .9600$$

[See Figure 3]

This shows an increase in the agricultural acreage during the years following a Boundary Review. The Boundary Review may have been much too severe, i.e. rezoning too much land out of agriculture and the ensuing years compensated for the drastic change. This is not wholly unlikely. After the massive redistricting in 1969, agricultural acreage has not been falling off at alarming rates. In fact the equation shows that it may be rising.

For Agricultural District Land on Oahu (OAG) the relationship was:

$$OAG = 159{,}994.0 - \underset{(-8.11)}{1{,}032.09T_i}$$

$$F = 66,\ \bar{R}^2 = .7833$$

Using dummy variables for the Boundary Review years:

$$OAG = 158{,}875.0 - \underset{(-19.02)}{10{,}639.0D} - \underset{(-5.03)}{248.15T_i}$$

$$F = 194,\ \bar{R}^2 = .9902$$

[See Figure 4]

The dummy variable vector in this case was also a series of ones and zeroes. Zeroes in the years up to and including the first Boundary Review and ones thereafter.

For the State and Oahu Agricultural District land the results are interesting. For one thing, on the State level the simple time trend statistical estimates show a loss of about 11,000 acres per year. But if we take the Boundary Reviews into consideration the effects are surprising. The reviews immediately rezoned 171,544 acres to other non-agricultural districts. This is to be expected. However, the rate of change, now, goes from a negative 11,000 acres to a positive 3,006 acres. This suggests that the rezonings may have been too severe and the circumstances in the State led to readjusted district acreages.

Oahu Agricultural District does show the usual results. The Boundary Review removed about 10,000 acres and the annual rates of change slowed from around -1,000 to -250 acres. The question still remains, however, as to how long we can continue to lose 250 acres per year before agriculture is no longer viable?

Figure 1 to 4 show plots of the estimated equations. The simple trend, the trend with dummy variable and the actual acreage figure are shown for Urban and Agricultural District for the State and Oahu. These graphs show how the dummy variable affects the estimation proportion of the trend equation and just how close the estimates relate to the actual averages.

In each case, the Boundary Reviews lowered the rate of conversion, so that Urban District changes increased slower and Agricultural District changes also decreased slower. If the larger changes were

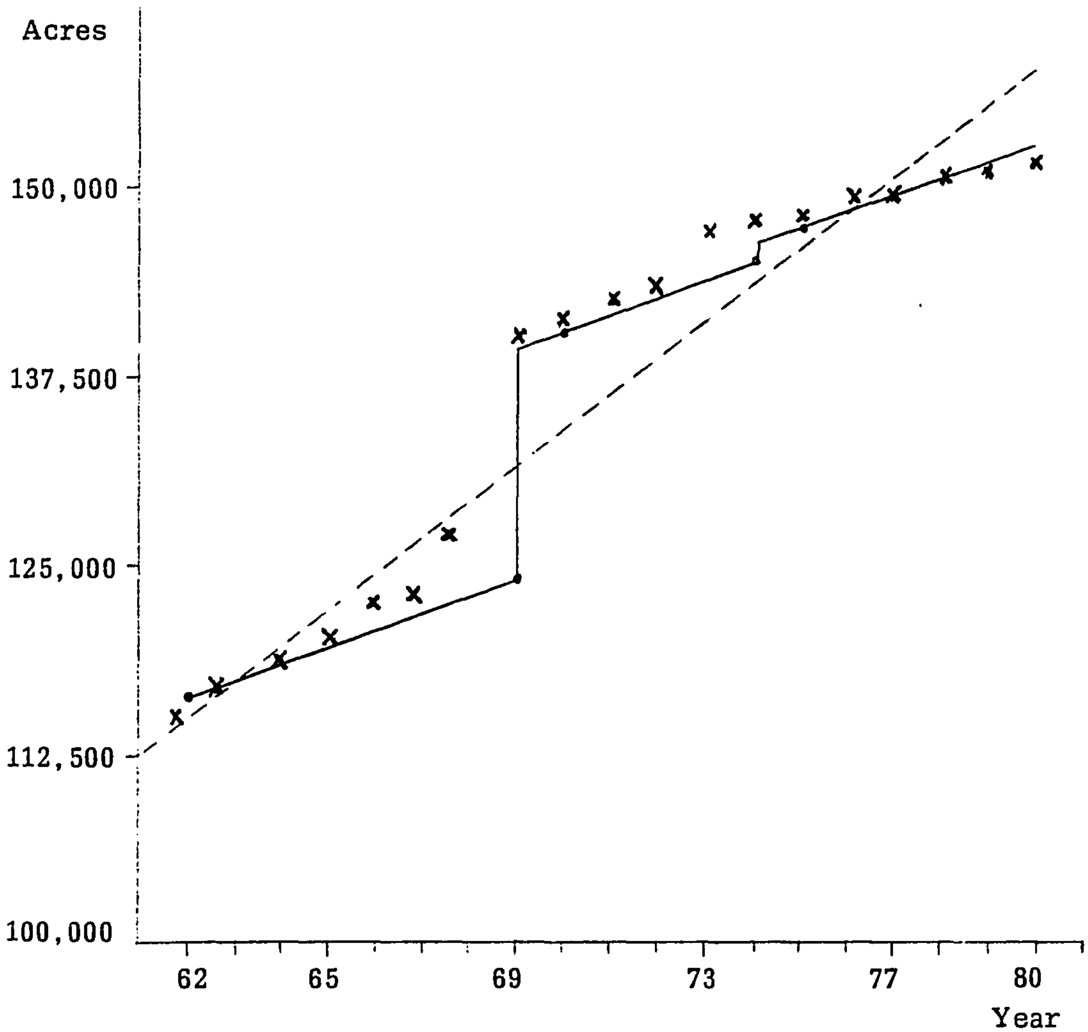

Figure 1: State Urban District (SURB)

------- Simple trend (SURB = 112,756 + 2395 T_i)

——— Trend with dummy variable
(SURB = 114,864 + 150,017D + 1,171 T_i)

x actual

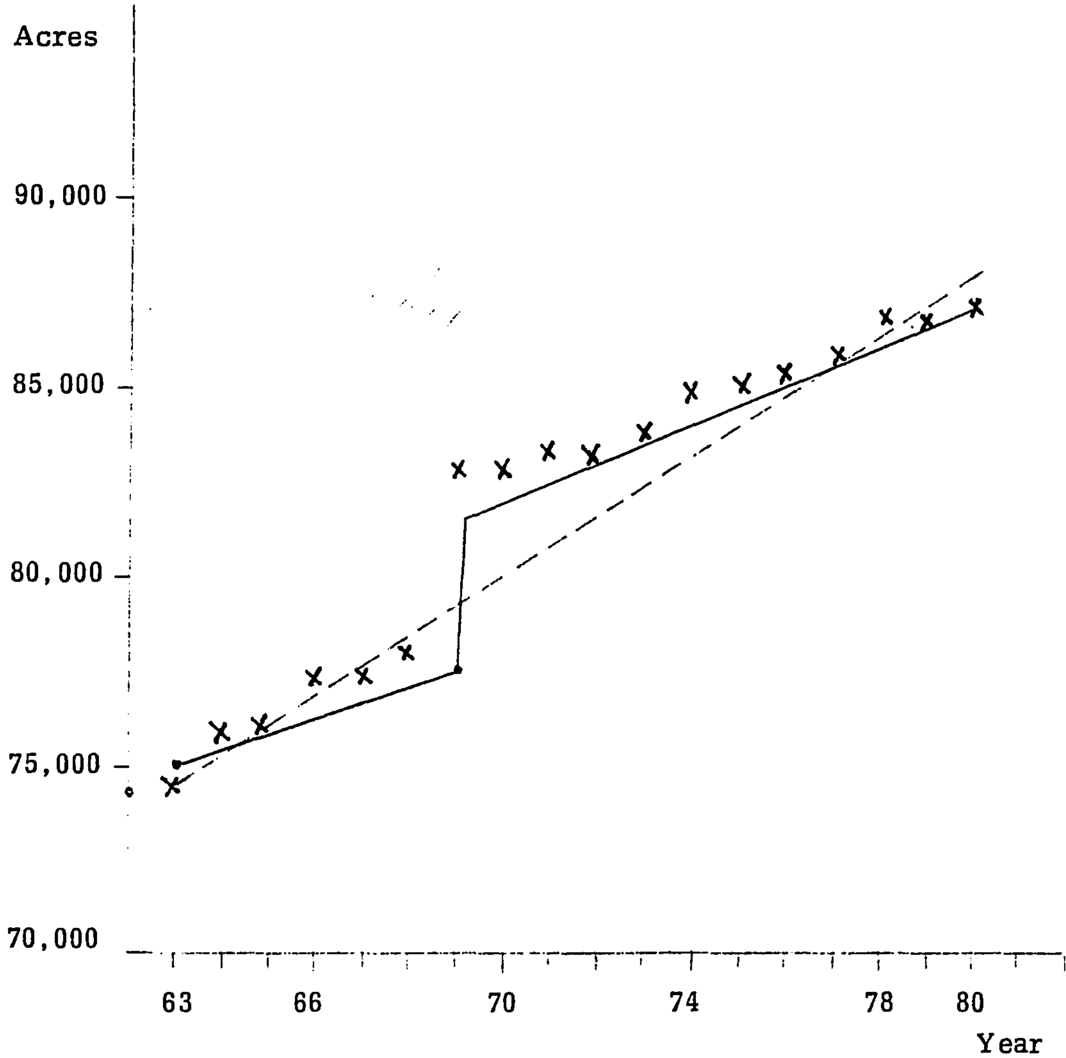

Figure 2: Oahu Urban District (OURB)

------- Simple trend (OURB = 73,822 + 758 T_i)

——— trend with dummy variable (OURB 74,239 + 3956D + 466 T_i)

x actual

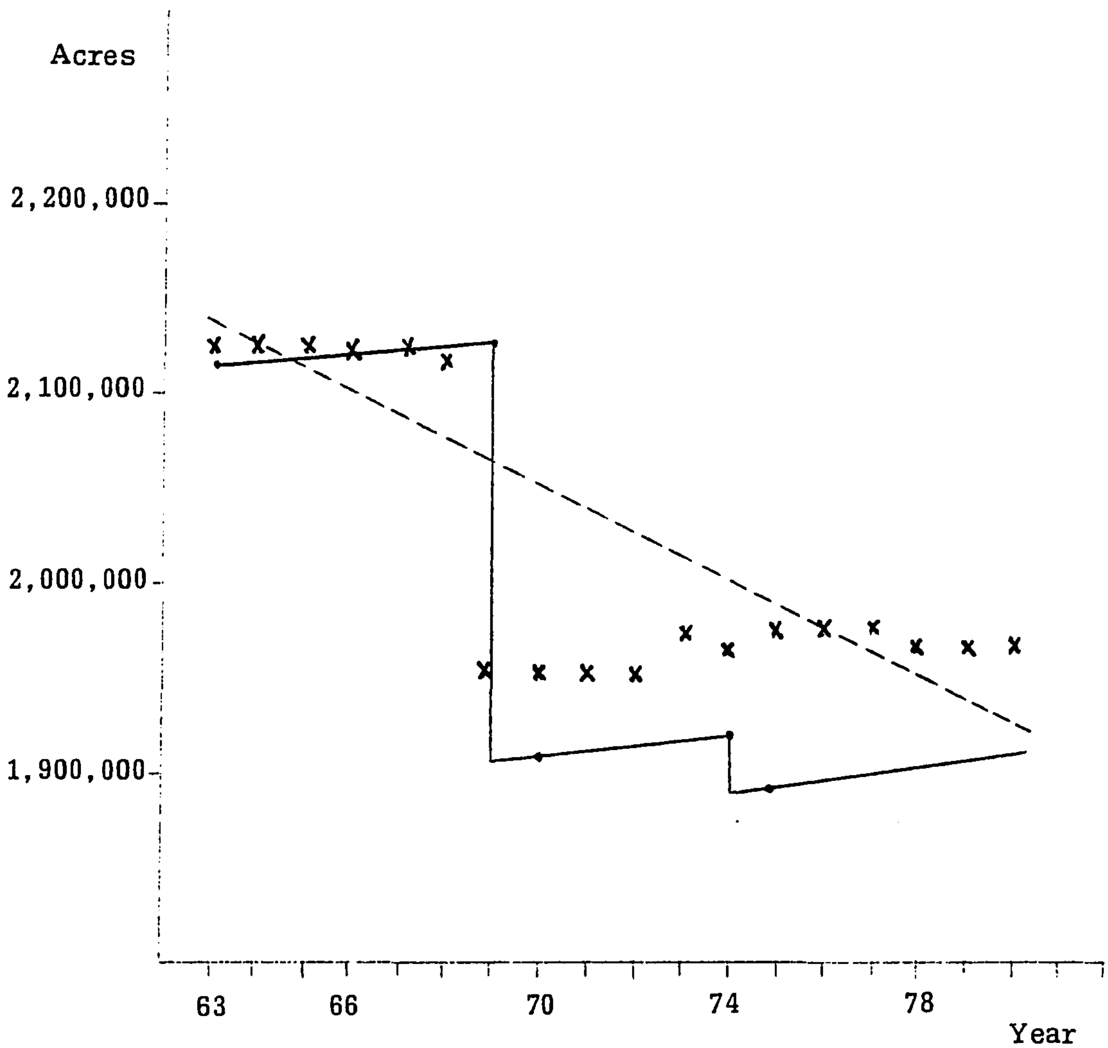

Figure 3: State Agricultural District (SAG)

------- Simple trend (SAG = 2,134,350 - 10,957 T_i)

——— Trend with dummy variable (SAG = 2,110,270 - 171,944D + 3,006 T_i)

x actual

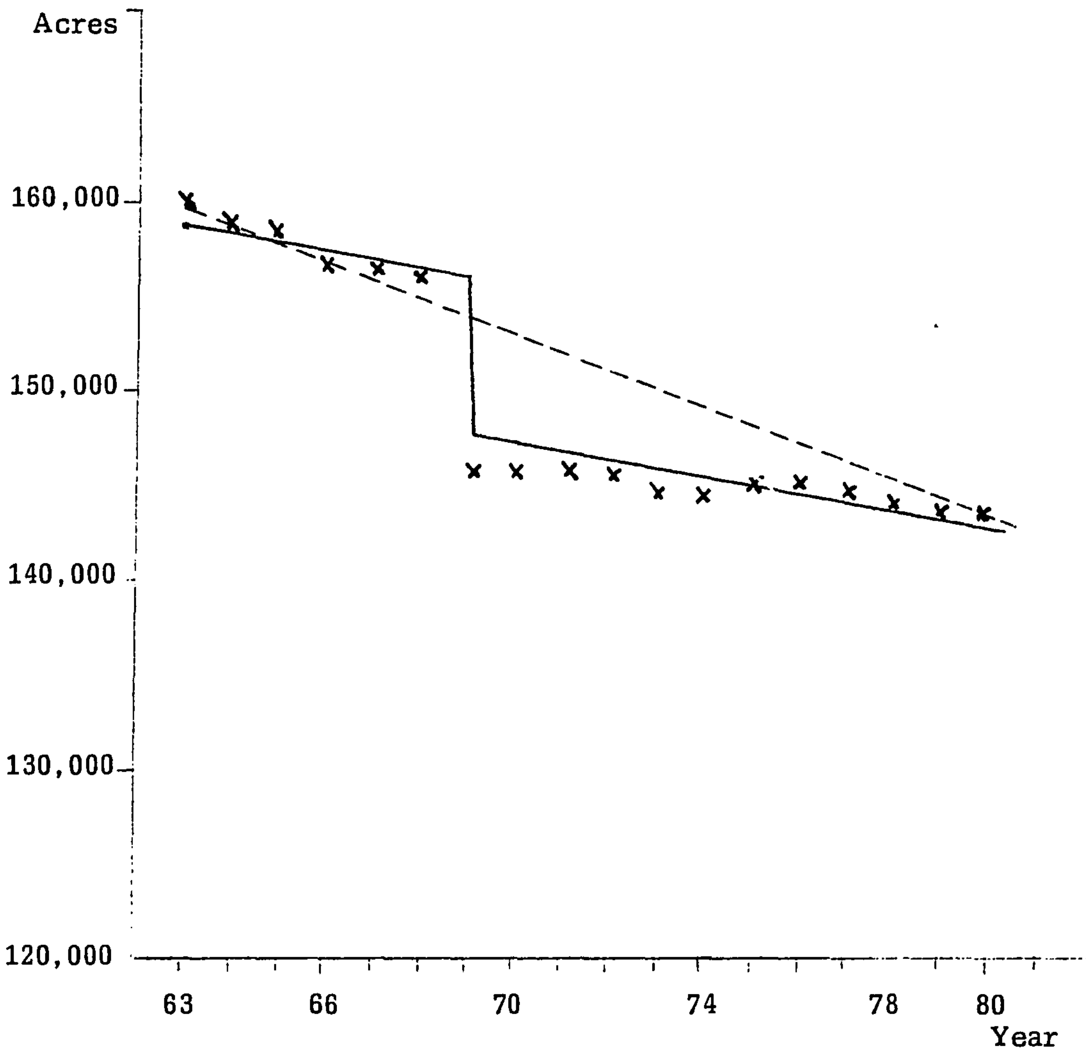

Figure 4: Oahu Agricultural District (OAG)

------- Simple trend (OAG = 159,994 - 1,032 T_i)

——— Trend with dummy variable
(OAG = 158,825 - 10,6390 - 248 T_i)

x actual

allowed to occur gradually (without Boundary Reviews) over the previous years according to "normal" conditions, the trend pattern may be curvalinear and show a leveling off of conversion (note actual acreage points).

The trend differences between Boundary Review and non-Boundary Review equations do not suggest that the acreages would have changed more slowly if the boundaries were not adjusted. But, they do indicate the strong impact that such action can have? This implies that the strength of institutional changes are great. Note that, for the most part, the number of acres rezoned after the Boundary Reviews slowed considerably. This implies that the reviews rezoned "enough" lands to lessen the need for more changes immediately.

One of the problems that the LUC faced was the delineation of the boundaries. The law, when initially ratified and the boundaries that were first adopted may have been inaccurate, in the sense that lands along the shoreline that were once designated Agricultural (but were clearly Conservation) were later changed to Conservation. The first Boundary Review corrected this oversight. Parts of the change were mandated by the Coastal Zone Management Act which created setbacks and rezonings along the shores (Yasue).

Agricultural Versus Urban

The relationship between changes in the Urban and Agricultural Districts deserves closer study. How do the changes in these two land use districts compare and what can our trend analysis tell us?

For the State, the equations for the Agricultural and Urban

Districts were (with Dummy):

$$SAG = 2{,}110{,}270 - 171{,}544D + 3{,}006T_i \quad [D = (0,\ 1,\ 1.1)]$$

$$SURB = 114{,}864.0 + 15{,}071D + 1{,}171T_i \quad [D = (0,\ 1,\ 1.1)]$$

Summing the total acreage changes using the previous equations over nineteen years shows that the Agricultural District has lost a total of 134,590 acres, changing from 2,113,276 to 1,198,686. This is very close to the actual acreage changes. The Urban District, statistically, changed from 116,035 to 153,631 or a 37,596 increase.

In other words, the Urban District increased by much less than the Agricultural District decreased. The differences is 96,994 or almost a hundred thousand acres. The trade-off between agricultural land and urban acreage is not one-for-one, but far less, almost one-for-four. The Urban District gained one acre for every four acres lost by agriculture. If conversion to the Urban District is to be considered as an irreversible loss of agricultural land then this loss can easily be overstated.

Agricultural land has gone into other uses besides Urban. The major use is Conservation. If the acreage gain in the Conservation District is accounted for then the loss of Agricultural land appears less serious. Much of the loss of Agricultural land was compensated for by gains in the Conservation District.

In fact, early five year Boundary Reviews corrected for initial designations that later proved irrational. If corrective factors are reflected by adjustments in the initial designation, the loss of

Agricultural District lands appears much smaller.

Statewide, in the "unpopulated" districts, the Agricultural District has lost 151,819.0 acres while the Conservation District has gained 112,235 acres over the past eighteen years.

-151,819	Agricultural acres lost
+112,235	Conservation acres gained
- 39,584	Net Agricultural acreage lost

This leaves a net loss of 39,584 acres lost if all Conservation District land gains were from Agriculture.

This is exactly what was gained in the "populated" Urban and Rural Districts between 1962 and 1980.

+37,044	Urban acres gained
+ 2,540	Rural acres gained
+39,584	Acreage gained

To find the proportion of total Agricultural District lands lost by islands, we must net out the loss to Conservation.

	1962 Agricultural	Change in Conservation 1962-80	1962 Agricultural Land Base (Actual)
Oahu	159,652	+3,496	156,156
Maui	277,526	+20,938	256,588
Hawaii	1,311,992	+69,462	1,242,530
Kauai	172,500	+25,658	146,842
State	2,126,014	+122,235	2,013,779

This also shows that the loss of Agricultural land may be overstated. In 1980, there were 1,974,195 acres in the Agricultural District, using the corrected acreage of 2,013,779 acres there was a net loss of 39,584 acres rather than the 151, 819 acres using uncorrected figures.

In actuality, therefore, only 39,584 acres were lost rather than the 151,819 reported. Most of this 39,584 acres changed to an urban use (the Urban District gained 37,044 actual acres). Although the loss of agricultural lands may be exaggerated, the impact of the actual can still be substantial in light of the fact that much of this land was high quality agricultural land.

Oahu shows similar trends. The trend equations for Oahu were:

$$OAG = 158{,}875 - 10{,}639 - 248.1T_i \qquad [D = (0,\ 1)]$$

$$OURB = 74{,}239 + 3{,}956D + 466.5T_i \qquad [D = (0,\ 1)]$$

Statistically, over the nineteen year period the Agricultural District has lost 15,014 acres changing from 158,626 to 143,522. The Urban District has gained 12,353 acres going from 74,705 to 87,058.

The 2,751 acres not changed to urban has gone to the Conservation District. Oahu shows more of a one-to-one situation. About 82% of the agricultural land losses can be accounted for in Urban District gain. This is significant because a large proportion of the high quality agricultural lands are on Oahu.

The Land Quality Aspect

Of greater importance than the acreage component is the quality aspect. The loss of the best agricultural lands have greater impact upon the productive capabilities of the agicultural sector than the loss of marginal lands. The use of high quality agricultural lands for urban purposes reduces the costs of development because of the ease of workability and the locational advantages. This lowers the cost of housing. As important as the identification of the high quality land is, it has not been until recently that a comprehensive program has been developed and incorporated into policy (see Appendix F), although the Land Study Bureau (LSB) did classify lands by quality ratings as early as 1968. A need remains to continue the organization of data on different classes of agricultural use accroding to land quality in a similar way as the early Land Study Bureau work.

CHAPTER V

OPTIMAL CONTROL THEORY ALTERNATIVE MODEL FORMULATIONS

For any intertemporal analytical technique that might be utilized to analyze land allocation decisions in Hawaii, the problem of model formulation is critical. In this chapter we will address this problem in the context of optimal control theory. The model must conform or agree with the social, institutional, political and economic conditions that prevail in society, and must also be consistent with the resource in question. Solutions will differ depending upon the model form chosen therefore, proper selection is important.

The approach in this case is from two standpoints, one from the standpoint of market structure and the other from the standpoint of the nature of the resource. The market structure aspect will be developed using two polar extremes; perfect competition and monopoly. The monopoly model will be analyzed with and without costs involved. The nature of the resources aspect will be developed along the lines of the stock-flow definition of conservation economics.

The analysis proceeds by examining the effects of market structure on the nonrenewable or stock characteristic of land. In these cases, land will be assumed to have no flow characteristics. The flow aspect evolves from the renewable soil productivity characteristics of land. This will be taken separately. The potential applicability of each of these models will be discussed in the following chapter.

A Simple Linear Model of Stock Resources: Competitive Market

In a simple linear model of stock exploitation, first advanced by Hotelling in 1931, the necessary conditions for an optimum can be derived.

Let $x = x(t)$ denote the reserves of agricultural land in Hawaii at a particular time, t. We assume that the initial reserves, $R = x(0)$ are known. $q = q(t)$ denotes the rate of conversion from agricultural to urban. Thus the state equation is

$$\frac{\partial X}{\partial t} = -q(t) \qquad \text{where} \quad x(0) = R$$

and $$x(t) \geq 0 \qquad \text{where} \quad 0 \leq q(t) \leq q_{max}$$

To begin, we assume no development costs or costs of conversion and that the market is competitive, with price $p = p(t)$ a known function of time. The problem in this case is to optimize the time of converting agricultural to urban uses. The State's objective, therefore, would be to maximize the present value

$$PV = \int_0^\infty e^{-rt} p(t)q(t)\,dt \qquad \text{where} \quad q_{max} = \infty$$

The solution to this problem is clear. It is simply to sell or convert all agricultural land reserves, R, at time $t = T_\infty$. The State would maximize the present value at such time. The problem reduces to maximizing:

$$e^{-rt} p(t)R \qquad \text{with respect to} \quad t \geq 0 .$$

Therefore, by differentiation we have

$$\frac{\dot{p}(T_\infty)}{p(T_\infty)} = r$$

where the rate of change in price over time is equal to the discount rate for the optimal conversion date T_∞ .

Now, if $q_{max} < +\infty$, the maximum principle can be used to determine the solutions. The Hamiltonian becomes:

$$\begin{aligned} H_T &= e^{-rt}\, p(t)q(t) - \lambda(t)q(t) \\ &= [e^{-rt}\, p(t) - \lambda(t)]q(t) \end{aligned}$$

The necessary condition $\frac{\partial \lambda}{\partial t} = -\frac{\partial H}{\partial x} = 0$ implies $\lambda(t) = \lambda =$ constant. Therefore $\lambda = e^{-rt}\, p(T)$. In this case the control $q(t)$ switches from q_{max} to 0 at $t = T$. We then have

$$q(t) = \begin{cases} 0 & \text{when } p(t) < \lambda e^{rt} = e^{r(t-T)}\, p(T) \\ q_{max} & \text{when } p(t) > \lambda e^{rt} = e^{r(t-T)}\, p(T) \end{cases}$$

As long as $p(t)$ is greater than the non-discounted shadow value then conversion continues at the rate of q_{max} . However, if $p(t)$ is less than the non-discounted shadow value, then $q(t)$ becomes zero. In other words, if the value of land in urban uses is greater than its value in an agricultural use then conversion should continue. Conversion will continue at q_{max} as long as $p(t) > e^{r(t-T)}p(T)$. This occurs between T_0 and T . The length of the conversion period, $T - T_0$, must satisfy

$$\int_{T_0}^{T} q_{max} \, dt = q_{max} (T - T_0) = R$$

The Fundamental Theorem of Stock Resources

An analog to the foregoing theory is that, generally speaking, the real price of a stock resource in a competitive market can be expected to increase over time at the rate of interest, r . If $p(t)$ increases at a slower rate, landowners would attempt to dispose of their stock immediately because a better return is available elsewhere. If $p(t)$ were to increase at a faster rate than r , landowners would tend to hoard stocks. They are obtaining a better return on investment by holding the land. Forces in a competitive market would tend to adjust real price levels over time such that

$$\frac{\dot{p}(t)}{p(t)} = r(t) .$$

This result has been called the fundamental theorem of exhaustible resources (Hotelling). Unfortunately there is very little evidence to either support or refute this theorem (Clark).

A Model of Stock Exploitation: Monopolistic Market

As discussed in an earlier chapter, landownership in the State is heavily concentrated. This concentration lends monopolistic powers to the major landowners and creates a monopolistic market structure within the State. The perfect competition model cannot or does not incorporate this particular aspect of the land market. A slight modification of the model is necessary in order for it to accommodate this aspect. Let us now examine a model when the perfect competition assumption is removed and a monopolistic condition is imposed.

The demand curve is $p = p(q)$, q being the rate of conversion in acres per year. Ignoring the costs of development, the objective functional becomes:

$$J\{q\} = \int_0^\infty e^{-rt} q(P(q))dt$$

where $\frac{\partial x}{\partial t} = -q$, $x(0) = R$, and $q(t) \geq 0$.

In this case, the price is a function of q , the rate of conversion. Unlike the competitive case where price was independent of the conversion rate.

Assume all reserves R will be converted at some finite time, T , to be determined. Therefore,

$$q(T) = 0 , \quad x(T) = 0 \quad \text{for} \quad t > T$$

The conversion rate at the end of the time period is zero because all of the reserves are exhausted.

The Hamiltonian

$$H = e^{-rt} qP(q) - \lambda q$$

the necessary conditions

the maximum principle

$$\frac{\partial H}{\partial q} = e^{-rt}\, MR(q) - \lambda = 0$$

because H is non-linear in q

$$MR = \text{marginal revenue} = \left(\frac{\partial}{\partial q}\right) \cdot [qP(q)]$$

the adjoint equation implies

$$\frac{\partial \lambda}{\partial t} = \lambda = \text{constant}$$

so that

$$\lambda = e^{-rt}\, MR(q(T))$$

the transversality condition $H_T = 0$ yields $\lambda = e^{-rt}\, P(q(T))$.

Therefore, we have

$$\begin{aligned} P(q(T)) &= MR(q(T)) \\ &= \frac{\partial}{\partial q}\,(qP(q))_{q=qT} \\ &= P[q(T) + q(T)]P'(q(T)) \end{aligned}$$

which implies that

$$q(T) = 0 \, .$$

Then by substitution $MR(0) = P(0)$.

$$\lambda = e^{-rt}\, P(0)$$

Thus, at $t = T$ the shadow price $\lambda(t)$ equals the highest possible price that can be obtained for the resource. The conversion rate $q(t)$ must satisfy the maximum principle

$$MR(q(t)) = \lambda e^{rt} = e^{r(t-T)}P(0)$$

This can be called the monopolistic analog of the fundamental price theorem. It says that the marginal revenue grows at the same pace as the rate of discount.

What this means in terms of the conversion rate is that the monopoly would convert at a slower rate than a perfect competitor. We would see a smaller total conversion and a higher price (see Figure 5). To find the rate of conversion a monopolist would equate MR to MC and receive price Pm (monopoly price) which is higher than price Ppc (the perfect competition price) and produces q_m (monopoly quantity). Note that q_m is less than q_{pc} (the perfect competition quantity)

Monopoly Model with Costs

The perfect competition and monopoly models discussed characterize the different solutions that evolve from the application of optimal control theory to contrasting market situations. In order to simplify the analysis, costs were explicitly ignored, which in reality must be accounted for. Let us take the monopoly model one step further and introduce costs into it and determine how this affects the solution.

In general, the costs of conversion (development), $c(x,q,t)$, are expected to depend upon the rate of conversion $q(t)$, the level of the remaining stock $x(t)$, and on time t. It is mathematically

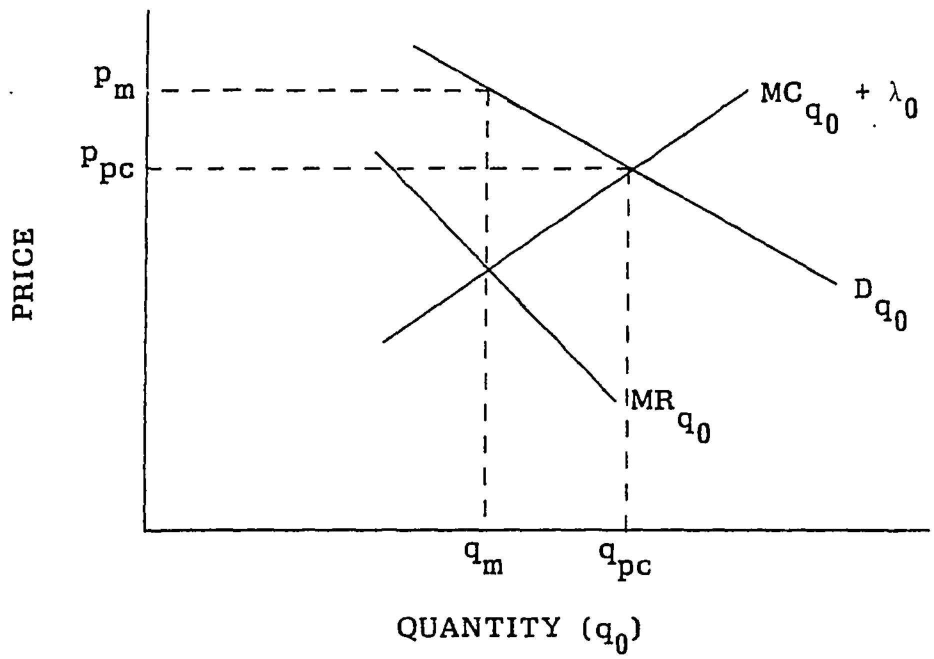

Figure 5: Price and Quantity of Monopolist and Perfect Competitor

difficult to handle the case with three independent variables, therefore we will assume, $c(x,q,t) = c(q,t)$, where costs are independent of the remaining level of stock. The following model applies in a monopolistic situation with a non-linear cost function and when $p = p(q,t)$, price being a function of the conversion rate and time.

The objective functional

$$J\{q\} = \int_0^\infty e^{-rt} [q(t)P(q,t) - c[q(t),t]dt$$

is subject to:

$$\frac{\partial x}{\partial t} = -q \; ; \; x(0) = R \; ; \; x(t) \geq 0 \; ; \; q(t) \geq 0$$

The Hamiltonian is,

$$H = e^{-rt}[qp(q,t) - c(q,t) - \lambda(t)q]$$

$$= e^{-rt}\{[p(q,t) - \lambda e^{rt}]q - c(q,t)\}$$

$$\lambda = \text{present value shadow price}$$

The necessary conditions:

the maximum principle

$$\frac{\partial H}{\partial q} = e^{-rt}[MR - MC - \lambda] = 0$$

the adjoint equation

$$\frac{\partial \lambda(t)}{\partial t} = \lambda \quad \text{implies that } \lambda(t) = \lambda \text{ constant.}$$

According to the maximum principle the optimal conversion rate $q = q^*(t)$ must maximize H over the control set $q \geq 0$ for each time period, $t \geq 0$.

$q^*(t)$ is the unique solution of

$$\frac{\partial c}{\partial q} = MR - \lambda e^{rt}$$

provided this equation has a positive solution otherwise $q^* = 0$.

To solve for the optimal conversion rate $q = q^*(t)$, we must first determine the shadow price λ . If the exhaustion date is finite, T , then this can be easily accomplished.

Recall that

$$\frac{\partial H}{\partial q} = e^{-rt}\{MR[q(t)] - MC[q(t)]\} - \lambda = 0$$

Rearranging

$$\lambda = e^{-rt}\{MR[q(T)] - MC[q(T)]\}$$

at time T , $MR = p$ and

$$MC = \frac{\partial c}{\partial p}(0,T) \qquad \text{where } t = T \text{ and } q = 0$$

therefore

$$\lambda = e^{-rt}\left[p(T) - \frac{\partial c}{\partial p}(0,T)\right]$$

Thus, if T is known, then the optimal policy, $q(t)$ can be deduced. The determination of T , however, is not simple. Also, the determination of the shadow price becomes progressively more difficult as the models become more complex. This is to be expected because the solution to the problem via the maximum principle reduces to the problem of determining $\lambda(t)$. In exhaustible resources models, $\lambda(t)$ is constant so that the computation can be relatively easily accomplished.

In this case, the analog to the fundamental theory of Hotelling states that the marginal revenue and marginal cost must grow at the same rate, r .

The Stock Quality Model of Land

So far, only the stock or site aspects of land have been discussed. The quality of agricultural land plays an important role in the timing of conversion. If there are choices between several distinct qualities of agricultural land, clearly the most profitable one will be converted first.

Land quality differentials in this stock model are handled differently from the flow (or renewable) model approach. In the stock quality model land is being drawn from a finite stock of certain qualities of land. There is no mechanism for increasing the amount of a certain quality of land, as there may be in the renewable model case. As the stock of a certain quality is diminished, there is no way to replace it.

Assume that there are only two sites of land denoted by x_1 and x_2 of different qualities denoted by E_1 and E_2 . $E_{i=1,2}$ is measured by the effort required in the conversion of the respective sites. The resulting rate of conversion is $\theta_i E_{i=1,2}$ where θ_i is a coefficient representing quality. That is, $\theta_1 < \theta_2$ or θ_2 is of a better quality than θ_1 . Also assume that total effort is a constraint or $E_1 + E_2 \leq 1$

with $E_1 \geq 0$ and $E_2 \geq 0$.

The owner of the two sites faces a given price p (assumed to equal 1) and wishes to maximize.

$$J\{E_1, E_2\} = \int_0^\infty e^{-rt} [\theta_1 E_1 + \theta_2 E_2] dt$$

The present value of the sum of the return from both sites is subject to:

$$\frac{dx_i}{dt} = -\theta_i E_i$$

$$x_i(0) = R_i$$

$$x_i(t) \geq 0 \qquad \text{for } i = 1, 2$$

The Hamiltonian becomes:

$$H = e^{-rt} (\theta_1 E_1 + \theta_2 E_2) - \lambda_1 \theta_1 E_1 - \lambda_2 \theta_2 E_2$$

$$= (e^{-rt} - \lambda_1) \theta_1 E_1 + (e^{-rt} - \lambda_2) \theta_2 E_2$$

The necessary condition:

the maximum principle

$$\frac{\partial H}{\partial E_i} = (e^{-rt} \lambda_i) \theta_i E_i$$

the adjoint equation

$$\frac{\partial H}{\partial X_i} = -\theta_i E_i$$

Intuitively, the solution to this system is where $E_1^* = 0$ and $E_2^* = 1$, or where $E_1^* = 1$ and $E_2^* = 0$, or where $E_1^* = E_2^* = 0$.

In this case, because x_1 and x_2 are both positive, a unit of effort expended in the conversion of x_2 produces greater revenue than effort devoted to x_1. For instance, high quality agricultural land is inherently easier to convert to an urban use because of its level topography, availability of water and favorable climatic conditions. The optimal solution (E_1^*, E_2^*) must satisfy:

$$E_1^* = 0 \ , \ E_2^* = 1 \quad \text{for} \quad 0 \leq t \leq T$$

$$E_1^* = 1 \ , \ E_2^* = 0 \quad \text{for} \quad T_1 \leq t \leq T_1 + T_2$$

$$E_1^* = 0 \ , \ E_2^* = 0 \quad \text{for} \quad t > T_1 + T_2$$

Thus, the better quality land x_2 will be converted until it is exhausted at time T_1, then the lower quality land x_1 will be converted. At a time greater than $T_1 + T_2$ the entire stock of land will be exhausted.

Summary of Stock Models

Table IV shows the comparative differences between the various models presented. In each case the objective function, maximum principle, adjoint equation and fundamental theorem is summarized. The stock quality model only accounts for the choice of use if different qualities of land exists, but only in the stock sense. The land does not have any renewable components. The renewable components will be discussed in the following section.

TABLE IV

SUMMARY OF MODELS FOR EXHAUSTIBLE RESOURCES

Perfect Competition	Monopoly Without Costs	Monopoly With Costs	Quality
OBJECTIVE FUNCTIONAL			
max $\int_0^\infty e^{-rt}p(t)q(t)\,dt$	$\int_0^\infty e^{-rt}qP(q)\,dt$	$\int_0^\infty e^{-rt}[q(t)P(q,t)-c[q(t)]]\,dt$	$\int_0^\infty e^{-rt}[\theta_1E_1+\theta_2E_2]\,dt$
Hamiltonian			
$H=e^{-rt}p(t)q(t)-\lambda(t)q(t)$	$H=e^{-rt}qP(q)-\lambda q$	$H=e^{-rt}[qP(q,t)-C(q,t)-\lambda(t)q]$	$H=e^{-rt}(\theta_1E_1+Q_2E_2) -$ $\lambda_1\theta_1E_1-\lambda_1\theta$
NECESSARY CONDITIONS			
Maximum Principle			
$\frac{\partial H}{\partial q(t)}\, e^{-rt}p(t)-\lambda(t)=0$	$\frac{\partial H}{\partial q} = e^{-rt}MR(q)$ $- \lambda = 0$	$\frac{\partial H}{\partial q} = e^{-rt}MR-MC-\lambda = 0$	$\frac{\partial H}{\partial E_i} = (e^{-rt}\lambda_i)\theta_iE_i =0$
Adjoint Equation [$\frac{\partial\lambda}{\partial t}$ implies λ = constant so that]			
$\lambda = e^{-rt}p(T)$	$\lambda = e^{-rt}MR(q(T))$	$\lambda = e^{-rt}[P(T)\frac{\partial c}{\partial p}(O,T)]$	$\lambda_i = -\theta_iE_i$
Fundamental Theorem			
$\frac{\dot{p}}{p} = r$	$\frac{\dot{MR}}{MR} = r$	$\frac{\dot{MR}}{MR} = \frac{\dot{MC}}{MC} = r$	

A Model for Flow Resources

Definitions

Land is endowed with not only stock but renewable [flow] characteristics. A resource can be considered renewable if different units become available for use in different time intervals, and it is possible to maintain use indefinitely provided that the flow continues.

In one class of flow resources human action does not significantly affect flow in future intervals. Solar and other cosmic radiation, winds and tides fall under this category. The duration of these flows may be assumed infinite. The problem is not availability but utilization, i.e. the development of proper technology. In a second, more economically important class of flow resources, human actions in any given interval may change some or all future rates of flow. These changes affect time patterns of revenues and costs and therefore future rates of use. This second class of resources can be further subdivided into two subclasses according to the existence or non-existence of a <u>critical zone</u> in the decrease that is caused by human action.

A critical zone is a more or less clearly defined range of rates below which a decrease in flow cannot be reversed economically under present foreseeable conditions. Often, this reversal is not only uneconomic but also technologically impossible. The flow rate does not have to be zero for economic irreversibility to occur, i.e. if highly complex ecological relationships are affected. Economic irreversibility also depends upon technology, tastes and preferences, and social institutions. These are in constant change. What is irreversible now may not be at some future date. The other subclass is flow resources without a critical zone. An example of this is precipitation caused by human action.

Land as a Flow Resource

In the previous sections, where land was considered strictly in its stock component, the conditions of the resource was that its total physical quantity could not increase significantly with time. However, land also has flow components, flow components with a critical zone.

The flow components of land are primarily realized in its renewable soil productivity attributes with support from avaialble technology and management. Certain land quality characteristics are attributable to physical aspects which are largely uncontrollable by man. For instance, the formation of soil horizons, temperature, and sometimes water regimes fall into this category. These land qualities can limit or enhance agricultural productivity. Other land qualities, i.e., soil fertility, soil pH and organisms related to land conditions are, to some extent, controllable by means of proper management and available technology. The critical zone of land resources, in terms or a specific site, is reached when productivity is decreased to such an extent that it is impossible under present technology to restore the productivity. For example, if severe gully erosion were to make the land unworkable or if sheet erosion were to remove all of the topsoil, a critical zone for that use would be reached.

Context of Hawaii

From the statewide point of view, total land acreage is fixed. However, by looking at the productivity of certain agricultural sectors and possibly at the entire agricultural industry, an idea of the renewability of land can be seen with a possible critical zone. In this sense, it is the physical biomass that can be reaped over time by utilizing appropriate inputs that is indicative of the renewable aspect of land.

As far as total farm acreage is concerned, over the past 20 years, it has declined by 210,000 acres net, form 2,500,000 in 1962 to 2,290,000 in 1979. However, in this same period, production volume and value has increased. Some of the losses of agricultural acreage were recouped by rezoning Conservation District of Rural District lands to agricultural. This can only have occurred to a limited extent and is minimal in terms of its impacts upon productivity. Major gains in productivity were primarily due to new technology and motivated management.

Much of this acreage loss was in the large scale plantation agriculture sector of sugar cane and pineapple. These inductires are larger and are more able to adopt new technology because of their economies of scale. In sugar cane, new drip irrigation methods use water more efficiently thereby increasing yields. Also to a lesser degree, lands lost to urban uses were replaced by less productive acreage or by rezoning other land in an attempt to maintain production.

The renewability or flow component of land, therefore, depends upon the nature and amount of inputs, and the rate of harvest. The relationship between these factors determine the productivenss of the land. Changes in these relationships may alter the productiveness of the land. Changes in these relationships may alter the productive capabilities of the land to such an extent that a critical zone is approached and overall productivity declines.

Optimal Control Approach to Flow Resources

Control theory application to renewable resources are most highly developed for forestry and fishery resources. Can such approaches be adopted for analyzing land use changes in Hawaii when land is viewed as a renewable resource? A first attempted at such a adaptation is presented in this section.

Basic Relationships

In the State of Hawaii, five land quality classifications have been developed by the former Land Study Bureau. These designations are based primarily on topographic, climatic and other inherent features of the land. The allocation of land within the quality classes appears as follows:

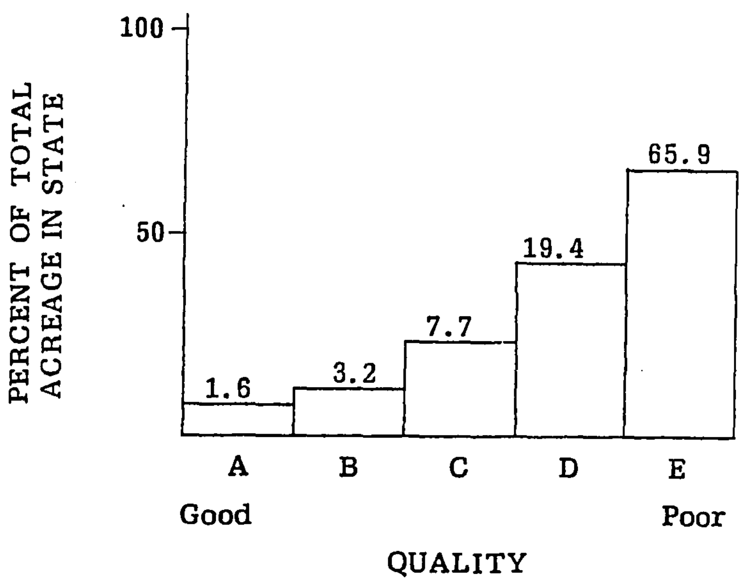

Figure 6. Percentage of Total Acreage in State by LSB Quality Class

Source: Land Study Bureau, 1968

There is a greater percentage of poorer quality land available than good quality land. Theoretically, initial development would occur on the good quality land. After the initial development of the good quality lands, the annual production, $R_0(t)$, could be maintained by additional capital and labor inputs, $L(t)$, per given stock size, $S(t)$. This idealized yield-effort relationship can be seen as follows:

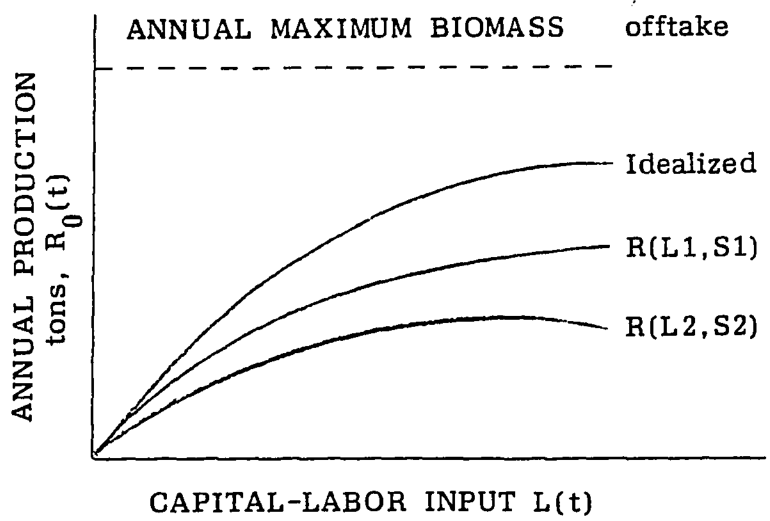

Figure 7. Theoreized Yield-Effort Relationship

If $L(t)$ were expanded without limit over the entire A and B acreage, then the annual maximum production could be approached. Of course, this may not be economically efficient, i.e., $mc > mr$. In fact, increasing inputs may actually reduce the production generated from the land. For example, adding too much fertilizer may injure or kill the plans, or over-plowing may compact the subsoil inhibiting drainage.

Generally, all of the acreage will not be used. But it is usually easier to produce more, the more acreage that is available or the bigger the production area for any given level of capital labor input. Therefore the curves would appear below the ideal. The stock S_1 is greater than S_2 in Figure 3.

The relationships between stock size and agricultural productivity can be seen by the following graph:

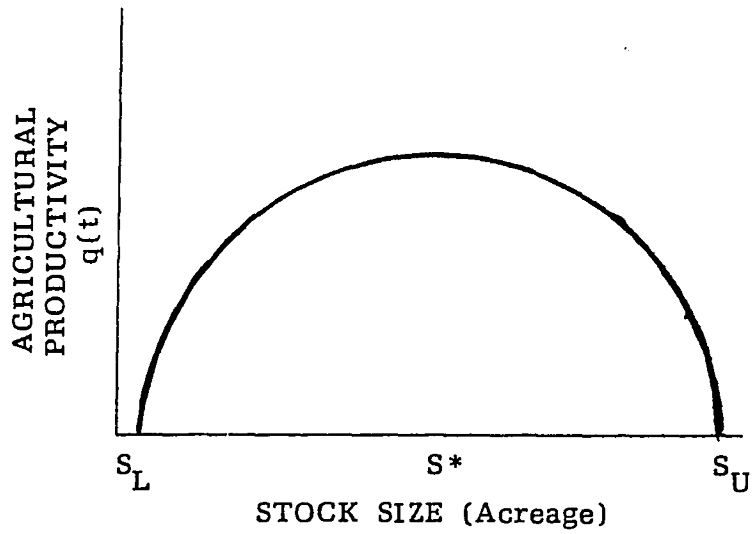

Figure 8. Agricultural Productivity as Related to Stock Size

S^* is the stock or acreage associated with the maximum productivity. It represents the maximum agricultural output that could be sustained indefinitely given a level of capital and labor inputs without decreasing the inherent fertility of the land by decreasing acreage or abusing the soil. At S^*, the productivity is what is known as the maximum sustainable yield.

At S_L, the lower limit, the size of the agricultural district is too small to support an economically viable commercial industry. The diseconomies of scale are great and therefore productivity is low. As more acreage is added, S_L approaches S^* and the economies of scale become important and productivity increases.

As acreage increases past S^*, this means that less inherently fertile lands are being used or diseconomies of scale are once again entering into the picture and productivity declines. Past S_U, the upper limit, the capital and labor available cannot support the size making overall productivity negative.

Optimal Land Management Over Time

Assume that the production function is as follows:

$$R_0(t) = g(L(t), S(t), t)$$

The returns from the stock is a function of $L(t)$, the capital-labor inputs, $S(t)$, the size of the stock and, t, time.

The productivity is a function of the size of the stock:

$$q(t) = q(S(t))$$

The stock accounting identity is:

$$S(t) = S(0) + \int_0^t (q(t) - R(t))dt$$

where the size of the stock in time period t is a function of the initial level of the stock plus additions due to changes in productivity $(R(t))$.

The problem is now to maximize:

$$L(t) = \int_0^\infty \left[\int_0^{R_0(t)} D[(\eta_0 t)d\eta - w \cdot L(t) \right] e^{-rt} dt$$

where D is a revenue function and w is cost of inputs. Maximizing L(t) is analogous to maximizing net revenues.

The Hamiltonian is:

$$H = \int_0^\infty D(\eta,t)d\eta - w \cdot L(t) + \lambda(t)[q(t) - R_0(t)]$$

Maximizing with respect to L(t) (maximum principle):

$$p(t) = \frac{w}{\frac{\partial R_0}{\partial L(t)}} + \lambda(t)$$

$$= MC(t) + \lambda(t)$$

P(t) is the price of the agricultural output, MC is the marginal cost of producing agricultural goods and λ is the shadow price per unit of output. λ represents the optimized intertemporal opportunity costs of one additional unit of agricultural output, i.e. future costs that would take the form of increased costs and reduced productivity. λ must accurately reflect the intertemporal opportunity cost.

An idealized social planner attempting to manage the use of land and the resultant productivity would recognize this intertemporal opportunity cost and would adjust the productivity rate at each point in time such that the last unit of productivity generated an apparent price profit of $\lambda(t)$; apparent because it is offset by the present value of the future opportunity cost. However, an outsider looking in would see this profit and if there is additional investment this would reduce profits and stock falls below a desirable level.

An intuitive implication of this model is that the stock should be adjustable to a level at which carrying forward one more unit will yield an increase in net return equal to that return that could be gotten in other investments. For example, when the discount rate is high in relation to rate of return on added stock, stocks would be drawn down until the rates are equal. It is possible that total elimination of the stock is most economical. If discount rates are low, net returns should fall as stock productivity is increased.

Maximization of net present value by employing a optimum dynamic strategy need not (but may) imply elimination of the stock. Does this mean that economists would recommend this elimination under appropriate market conditions? Social decisions take place under a multi-objective or multi-criterion framework of which economic net benefits are one criterion. A responsible economist would generate information on the present value of land in agricultural use under a variety of conditions. If the highest present value of net benefits appears to be generated by a pattern of land use that would eventually eliminate agricultural land use, this should be stated along with other information. The planners would then understand the trade-offs involved and proceed with their decision.

CHAPTER VI

POTENTIAL APPLICABILITY OF OPTIMAL CONTROL THEORY: MODELS TO THE CASE OF LAND USE IN HAWAII

In the previous chapter several models were discussed depending upon market forms and the stock-flow nature of the land resource. In this chapter, using empirical data where available, an attempt is made to appraise the potential applicability of these various models.

The Perfectly Competitive Model

One of the divergences of this model from actual experience is the solution to the problem when $q_{max} = +\infty$. (i.e. maximum conversion is positive and infinite). The conversion or selling of all of the agricultural land reserves in the state at time infinity ($t = T_\infty$) is not only unrealistic but makes no sense. Decisions to convert are made by individuals with different incomes, different time preferences, and for different reasons. Conversions do not occur all at once, but in various increments over time depending upon the various factors (not necessarily limited to economic) which influence individual decision-making.

In the case of $q_{max} < +\infty$, the solution here is a "bang-bang" switching function where $q(t) = q_{max}$ when the price $p(t)$ is greater than the non-discounted shadow value, and $q(t) = 0$ when $p(t)$ is less than the non-discounted shadow value. Given that $p(t) > \lambda e^{rt}$, an individual has two choices, convert or not to convert. Theory tells him to convert. For the individual with single parcel of land the decision rule means all or nothing, when $p(t) > \lambda e^{rt}$, $q(t) = q_{max}$.

From a statewide perspective, neither of these solutions are appropriate. We do not know when T_∞ is and even if this were known, it would not be in the State's best interest to allow conversion of all agricultural reserves at such an unknown future date. It is desireable that the State hold a certain amount of agricultural land insure future food producing capabilities.

The switching between q_{max} and zero is not seen on the statewide level. Land use conversion from agricultural to urban occur more or less continuously at a rate of about 10,000 acres per year. The five-year boundary reviews tend to convert larger acreages; but during subsequent years, the annual rate is, again, about 10,000 acres.

The assumption of perfect competition in the Hawaii land market is not realistic. In looking at the structure of the land market, a highly concentrated one is evident. The State, County and Federal governments together are the largest landowners, controlling about 48% of the total land area, another 45% is controlled by fewer than 40 landowners, each with 5,000 acres or larger, and only about 7% is owned by the rest of the populace. This concentrated structure affords its larger participants oligopoly-like power. Without social controls, prices might be manipulated for private profits by the amount and timing of land conversions. The State of Hawaii formed the Land Use Commission (LUC) in an attempt to counteract the power of the large private owners and to mitigate the otherwise oligopolistic effects in the State. The LUC has jurisdiction over the amount and timing of acreage conversion and is thereby, vested with great potential for influencing the movements of land prices in Hawaii. The legal and economic limits of the LUC's decision-making power are vitally important in balancing the social interests in the

State. Allegations that LUC decisions have been based on political rather than economic motivations are not uncommon (Lowry). In any case, the landownership pattern and institutional framework in Hawaii both depart considerably from the perfect competition model. This does not preclude the possibility, however, that the fundamental principle of the model may have potential applicability in analyzing our Hawaii case.

Potential Applicability of the Fundamental Theorem to the Case of Hawaii

The fundamental theorem states that, at the optimum, the relative rate of change in prices ($\dot{p}/p$) should be equal to the discount rate, (r).

$$\dot{p}/p = r$$

Prices, in our case, are interpreted as conversion prices which, in principle, should reflect the value of development rights net of all transaction costs and the foregone value in agriculture. The discount rate, (r), might be the opportunity cost of capital or the rate of time preference. This depends upon the level of decision-making. The operational potential of this principle depends not only on data availability, but also on the purpose of application since the latter is crucial in specifying the definitional details of the data requirements.

For the moment let us sidestep this crucial issue and experiment with some crude price data obtained from the Multiple Listing Service of the Honolulu Board of Realtors. The results of this experiment might be helpful in confronting the more crucial question of purpose.

In column (2) of Table V, the annual average prices (in current terms) of all properties sold on Oahu are given for the 12 year period covering 1967-78. This includes all properties sold and recorded in each year--for single family dwellings, condominium units, income and vacant properties combined. These prices cannot be interpreted as conversion prices, but may be somewhat indicative of the direction and rates of change of such prices. Although the absolute levels are not important, further manipulation of the data is necessary to avoid problems of inflation, wide annual fluctuations in the raw data, and to arrive at relative rates of change in real terms.

Consumer prices indices for Oahu are used to deflate the current price sources--this is shown in column (3). Relative incremental price changes throughout this series is given in column (4). Three year moving averages are computed to dampen the annual peaks and troughs, column (5). Indexing to the base year 1967 helps avoid any possible misinterpretations of the absolute levels of these prices, column (6). Finally, in column (7) the relative rates of changes in prices (indexed) are obtained from the simple trend coefficient 0.02095 for the series in column (6). What can we say from these results?

Theoretically, if $\dot{p}/p < r$, landowners would tend to liquidate their landholdings immediately and if $\dot{p}/p > r$ landowners would tend to hoard their stocks. Over time, the relative changes in prices would adjust toward the discound rate, r. Column (4) of Table V shows this adjustment process occurring in the State. In 1968-69 the discrete incremental time rate of change was 4.18%. This was probably greater than the perceived effective rate because during that year prices rose, indicating that either supply was withheld from the market or demand increased because

TABLE V

AVERAGE SELLING PRICES OF PROPERTIES SOLD ON OAHU
1967-1978

(1) Year	(2) Current Prices ($)	(3) Deflated Annual Ave.($)	(4) $\frac{\Delta P}{P_{t-1}} x100$	(5) Prices 3-yr Moving Ave. ($)	(6) Index of Deflated 3-yr Moving Ave. Price	(7) $\frac{P_I}{P_I} x100$ (%)
1967	38,410	38,410				
1968	42,546	40,988		40,200	1.060	1.98
1969	46,333	42,703	4.18	40,960	1.066	1.97
1970	44,755	39,190	- 8.23	43,740	1.139	1.84
1971	58,651	49,328	25.87	47,476	1.236	1.69
1972	60,810	53,910	9.29	52,799	1.375	1.52
1973	70,769	55,159	2.32	53,015	1.380	1.52
1974	70,918	49,977	-9.32	50,418	1.313	1.60
1975	71,485	46,119	-7.72	47,487	1.236	1.69
1976	75,483	46,365	0.05	46,659	1.215	1.72
1977	81,213	47,933	2.43	47,947	1.248	1.68
1978	82,076	49,985		-	-	

Properties sold include data for single-family and condominium properties for all years and income and vacant properties through 1977.

$y = 1.1116 + 0.02095t, \quad r = .56$

Source: Multiple Listing Service, Honolulu Board of Realtors.

land was a good investment. In the following year 1969-1970, $\Delta p_t/p_{t-1}$ was -8.23%. In this time period land did not appreciate as rapidly as other investments, thus owners tended to liquidate, increasing market supply and, thereby, decreasing prices. In other words, since prices did not rise as rapidly as the discount rate, land was not a timely investment. This adjustment process continues throughout the entire time series and is still occurring today.

The low instantaneous rates in column (7) may be indicative of low time preference rates which reflect concern for the future. This may be the result of strict and ever tightening institutional controls that preclude "normal" conversion.

The results in column (7) might also be interpreted in terms of an approaching equilibrium rate. The computed values of $\dot{p}/p$ fall in a narrow range between 1.84 and 1.98 with an apparent steady state level being approached in most recent years falling between 1.6 and 1.7. This may given an indication of what the "real" interest rate is in the land market. A word of caution, however, is required at this point. Such interpretations of these results may be dangerous since the results are developed for a linear rather than a non-linear or curvalinear trend which may be more realistic. By using a linear trend, simple arithmetic shows that a steady-state or "equilibrium" rate will be approached because if the marginal rate of change is constant and the linear trend is positive then the relative rate of change will decline steadily or converge on an equilibrium. A curvalinear trend, however, would show fluctuating relative rates depending upon the equation specification and the time variable.

Based on these preliminary experimental results, there appears to be potential applicability in this analytical approach. The actual realization of such a potential, however, depends upon further analytical retirements, in terms of both model formulation and data requirements.

The structure of the land market in Hawaii we said earlier resembled the oligopoly form. What is the potential applicability of the monopoly model in analyzing this oligopolistic land market? The monopoly model without costs represents the extreme case of market concentration and therefore may be the most sensitive in detecting non-competitive behavior.

In the previous chapter, the fundamental theorem in this model was stated in terms of marginal revenues instead of prices

$$\dot{mr}/mr = r$$

The optimal rate of agricultural land conversions should be where the relative time rate of change in marginal revenues are always lower than that of prices in the monopoly model. If conversion costs are zero, then marginal revenues are also zero at the optimum. The fundamental theorem equation breaks down to an undefined rate of discount.

$$0/0 = r \text{ undefined.}$$

No empirical analysis is needed to obtain this result, and it is difficult to see how such a monopoly model without costs which appears in the theoretical literature can have any validity to it at all.

Costs must be accounted for since, if there were no costs, there would be no economic deterrent to the eventual loss of all agricultural land. The monopolist can control prices down to the last unit of land. As long as there exists a willing developer who can afford the price; all agricultural lands are destined to be converted out. Also, the rate of conversion would be at a higher level than if costs were taken into account.

Figure 9 shows that, in time, all agricultural lands would be converted out if there were no costs involved. At time, t, the total amount of acreage available is Q_0; if there were no costs, the point where mr = 0 would determine the amount of acreage converted and the price. In this time period, would be Q_1 and P_1. At time, t_2, the same situation would exist, only this time there is only half the initial acreage. The amount of agricultural land would diminish with each succeeding time period until, in the limit, it is totally converted.

If such a prospect were not in the social interest, then the expectation would be for counteracting measure through public policy. The institutional structure provided by the Hawaii Land Use Law might be interpreted as providing the system of rules for controlling operating level decisions in the social interest; since we know, decision-making at this level in Hawaii is highly concentrated. In principle, the social costs of conversion should be taken into account in this institutional decision system and a model with costs as an explicit variable is needed.

Monopoly Model with Costs

The monopoly model with costs may be better suited to the land use control problem in Hawaii. There are both costs and benefits associted with the conversion of land. The benefits are connected with the returns from development and the remaining acreage of agricultureal lands. There is a stock or reserve of agricultural land that is being converted at a rate of q(t), which has both explicit and implicit value. In its "natural" state, agricultural land has explicit value in terms of its food producing capabilities and for its open space value. Implicitly, agricultural land value is due to its suitability for urban uses.

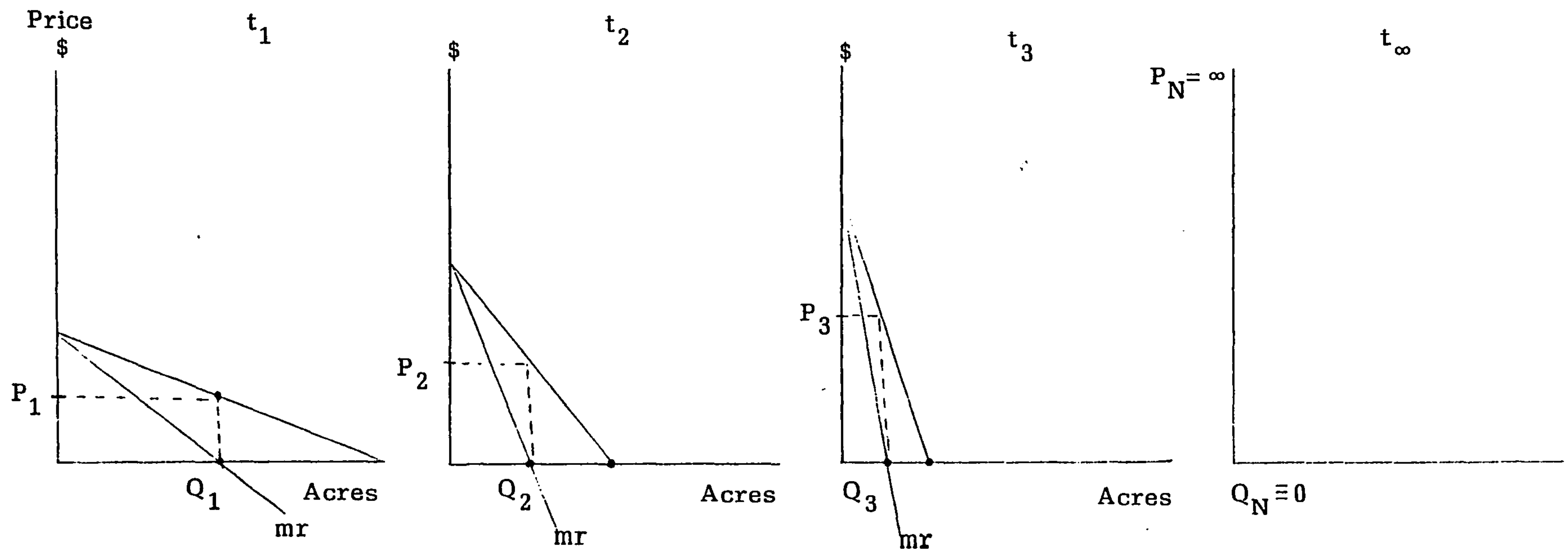

Figure 9: Agricultural Land Supply Under Monopoly without Costs

Notes:
1. In time infinity all agricultural lands are converted out.
2. Conversion rates are higher than if costs were taken into account.
3. Counteracting public measures are necessary to avoid total loss.

The benefits of agricultural land conversions (i.e. development) are associated with demand forces which in turn are reflected in economic growth in the State. In this sense, the construction, defense and tourist industries contribute to the benefits aspect of agricultural land conversion. The increase in construction activity is largely due to increases in population that demands more housing, and an increase in tourism that requires space for resort facilities. Defense spending is wholly exogenous. The decision to increase defense spending or to increase the number of military personnel is made in Washington, D.C., regardless of the economic conditions in Hawaii. Tourism has conflicting effects. On one hand, growth in the sector accompanies development of agricultural land. But on the other hand, as more and more acres of land are removed from agriculture, the attractiveness of Hawaii is reduced and decreases the growth of the tourism sector.

By converting agricultural land to an urban use, the costs are the foregone agricultural production, the decreased open space value and the loss of an option for the land, assuming that conversion to urban use is economically irreversible.

The problem with adding costs to the model is the quantification of these costs. The value of the open space cannot be easily measured because it is based on qualitative judgments and many factors account for its value. The loss of agricultural land is difficult to measure in terms of loss of future food producing capability. The future is always uncertain, and losing agricultural land may or may not have a detrimental effect on future productivity. The quality and the agricultural use of the converted land are also important. Certain uses and, of course, the loss of prime agricultural land would have different impacts upon the State than if other uses and non-prime land were lost.

Attempts have been made in this area by other economists, especially in measuring benefits from a wilderness. The results have not been conclusive. In the future, new methodologies have to be developed to estimate these benefits.

However, if it were possible to quantify all of the relevant factors and their "true" relationships, this would be the proper specification to use.

Relationship Between Land Prices and Conversion Rates

In spite of the complex conceptual and empirical problems that remain in properly accounting for and measuring the benefits and costs of agricultural land conversions, the monopoly model still suggests a positive relationship between land prices and conversion rates. Does such a relationship exist in Hawaii and if so can it be measured? Using aggregate statewide data, let us look into this issue from the perspective of existing institutional realities.

The Land Use Law was instituted in 1961 to control indiscriminate conversion of agricultural lands. But, it does allow for some conversion. Massive rezonings have occurred during the boundary review years, when rezoning occurred with and without the owner's request. This may provide a clue to answering the questions. It seems, by casual observation of the data, that whenever property values increased rapidly, more annual conversions were approved or more acreages were rezoned during the boundary reviews. Was this an administrative means to offset the oligopoly power of the major landowners?

In Figure 10, the time paths for real average prices and acreages converted can be seen. This may give us some indication as to whether the acreages rezoned had an effect on selling prices. Some people feel the opposite, that this relationship is reversed; in other words, price changes affect acreages rezoned. This is a dangerous theory to support because if it wre indeed true, then the larger the area zoned urban the cheaper the housing prices would become. Much of this expansion may occur at the expense of agricultural land (LUC, 1969). An analysis of these two relationships follow. Here, the issue of land quality is particularly relevant, but will be left for later discussion.

Regression analysis does not support the hypothesis of acreage changes affecting prices. By running a regression between changes in average real price and changes in urban acreage the coefficients were:

$$\text{Change in Average Prices} = (1081.44 + \underset{(2.704)}{2.21994}\ \underset{(\text{ Approved})}{(\text{Urban Acreage Change})_{t-2}}$$

$$R^2 = .5110, \quad F = 7.3155, \quad DW = 1.5453$$

This equation shows that the number of acres converted two time periods ago has a positive not negative effect upon today's prices. That is, the more urban lands available the higher the prices become. It is contrary to our initial thought.

Does the price affect the number of acres converted? Simple statistical analysis shows that prices do have an effect upon the amount of acres converted. If the price increases, the total amount of acres increases. The following equation shows

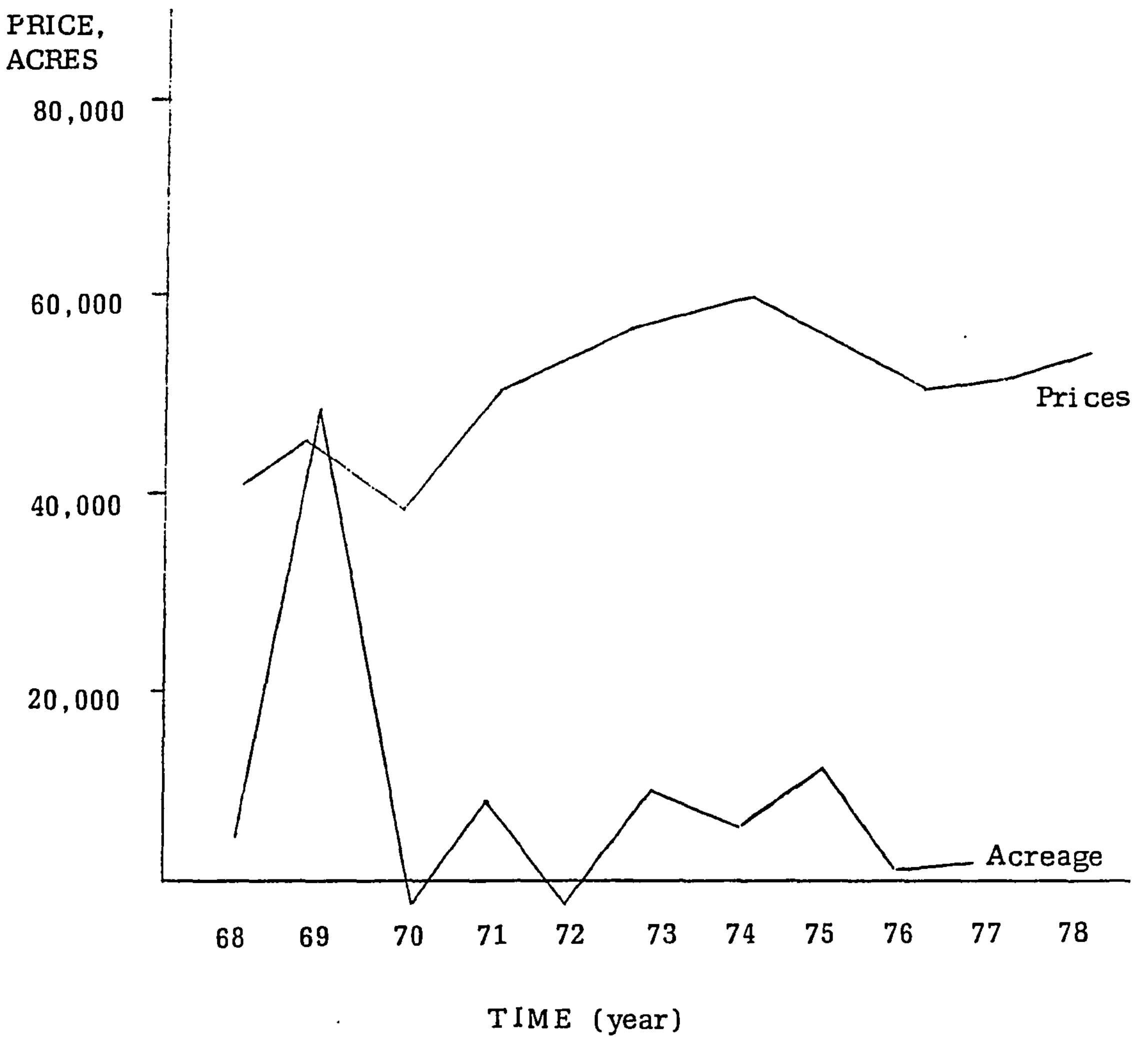

Figure 10: Real Average Price and Acreage Converted Over Time, 1968-77

$$\text{Total Urban Acreage} = 78{,}064.6 + \underset{(5.1618)}{.1213}\, P_{t-1}$$

$$R^2 = .7693, \quad F = 26.6800, \quad DW = .0572$$

that the total urban acreage is a function of the average price of sales lagged one time period. This indicates that as the price of housing increased, more conversions were approved by the State. The reasons for this are unclear although it may be because of conscious attempts to control housing prices through land conversions. Last year's prices determine how many acres are converted this year, the higher the price the more acres are converted in order to dampen the price increase.

On the other hand, this phenomena may be merely a reaction by the public, mainly developers, to price increases. As prices increase, developer's expectations of further price increases are reinforced; therefore more acreage is desired for rezoning to urban and the State is petitioned with more requests. It is just a matter of the number of petitions received that determines the amount of conversions and not a concerted effort by the State to control land prices, that is, the more acres that are petitioned for conversion, the more that will be approved. However, this indicates that price does have an impact upon total urban acreage because of public expections and not through purposeful manipulation by the State.

Simple regressions were performed to determine if price has an effect on the amount of acreage that are petitioned for rezoning. The change in requested acreage was postulated as a function of the change in price. Results show that there is no significant relationship between prices and requests. Developers do not seem to act on the basis of price alone.

The reaction by the State may be observed in their tendency to approve acreage rezonings. A simple regression was run between a ratio of approved and requested acreage (approved/required), and price to determine if a significant relationship exists between price and the tendency to approve requests. For example, if price increased the proportion would also increase. Again, however, there was no significant relationship. The proportion of acreage approved does not depend upon the price. Apparently, Land Use Commission approvals are not based solely upon the necessity to control prices in Hawaii, although if "enough" acreage were rezoned to urban this could have a dampening effect on prices. Decisions to approve are based upon the key criterion, "land use amendments shall be approved only as reasonably necessary to accommodate growth and development" (LUC, 1975). The State is mandated to maintain a ten year urban buffer for projected growth. Price increases and profit are major motives for rezoning requests, however, they do not significantly impact upon the decision.

The results of the preceding analysis do not suggest that the State is able to control prices or even has the desire to do so. In fact, the State may be inadvertantly maintaining high prices by not allowing all of the acreage requested to be rezoned. This may be the cost that the public must pay in order to achieve preservation goals.

Looking at price as a function of requests to determine if price would be affected if all of the acreage that were requested for rezoning were approved, in order to indirectly discover if the State does indeed affect prices, the following equation was estimated.

TABLE VI

TOTAL ACREAGE REQUESTED FOR REZONING TO URBAN: OAHU, 1963-1980

DATE	(%) APP/REQ	APPROVED	DISAPPROVED	TOTAL REQUESTED
1963	3.5	275.0	7,510.8	7,785.8
1964	24.6	177.0	603.1	720.1
1965	66.7	90.0	44.9	134.9
1966	64.9	1,490.1	807.0	2,297.1
1967	1.8	42.6	2,326.0	2,368.6
1968	18.3	550.1	2,449.0	2,999.1*
1969	31.8	1,014.0	2,173.9	3,187.9
1970	16.26	3.3	17.0	29.3
1971	25.4	221.4	651.7	873.1
1972	-19.9	-66.0	397.3	331.0
1973	70.8	866.4	357.3	1,223.7
1974	15.0	475.7	2,684.0	3,159.7
1975	103.9	1,093.1	-41.6	1,051.5
1976	18.5	72.6	320.0	392.6
1977	0.0	0.0	0.0	0.0
1978	84.4	1,230.1	227.0	1,457.1
1979	1.6	3.0	184.8	187.8
1980	100.0	175.3	0.0	175.3

* Excluding boundary change.
Source: Land Use Commission Records

ΔPrice = f(Δ Requests)

$$\text{Change in Real Average Price} = 3707.77 - \underset{(-2.473)}{2.62377} \text{ Change in Acreage Requested (t-1)}$$

$\bar{R}^2$ = .4663, F = 6.1167, DW = 1.3866

This equation states that if all of the acreage requested were approved then any increase in the number of acres requested in t-1 (i.e. rezoned) would have a negative impact of price changes in the present period. The State by not allowing all conversions may be inadvertantly maintaining high prices.

The statistical significance of this equation, however, is quite low. The t and F statistic and the R^2 do not reveal high significance. The results, more acreages lower prices, do not seem to be consistent with the real world. No definite conclusion can be drawn from this single equation.

The Flow Resource Model

In dealing with the renewability of land resources, the problem appears to become narrower and more site specific. It is difficult to aggregate State totals of agricultural productivity into meaningful and significant relationships. The diversity of the agricultural sector as signified by the variety of crops grown and the differences in farm size are some reasons that discourage aggregation. Also, physical units of agricultural output are not additive. For instance, tons of cane harvested and tons of pineapple are not comparable. Price in dollar amounts are, but may be subject to many more economic influences, i.e. demand and supply, rather than showing "true" productivity of the land.

TABLE VII

ACREAGE/ISLAND
AGRICULTURAL LANDS OF IMPORTANCE TO THE STATE OF HAWAII

	PRIME	UNIQUE	OTHER	TOTAL	LAND AREA
KAUAI					
acres	54,916	388	36,673	91,977	353,900
% of island	16	–	10	26	
% of state	18	1	6	9	
OAHU					
acres	55,563	9,006	29,990	94,559	385,300
% of island	14	2	8	24	
% of state	18	29	5	10	
MAUI					
acres	70,714	2,519	85,831	159,064	465,800
% of island	15	1	18	34	
% of state	23	8	13	16	
LANAI					
acres	–	16,969	8,149	25,118	90,500
% of island	–	19	9	28	
% of state	–	54	1	3	
MOLOKAI					
acres	7,726	763	29,603	38,092	165,800
% of island	5	–	18	23	
% of state	3	2	5	4	
HAWAII					
acres	115,391	1,675	452,298	569,364	2,573,400
% of island	4	–	18	22	
% of state	38	5	70	58	
STATE OF HAWAII					
acres	304,310	31,320	642,544	978,174	4,034,700
% of state	8	1	16	24	

Compiled January 1978
Source: Hawaii State Department of Agriculture

If we take a step downward and break up the agricultural sector into its components, i.e. sugar, pineapple, diversified agriculture and pasture, it is possible, at least for the larger sectors, to collect data. Sugar cane land productivity per acre was compiled for the years 1962-78 and compared to the total harvested cane acreage to try to determine if the stock size-productivity relationship holds true. Several specifications of the relationship were postulated and estimated, none were found to be significant. Although scanning the data showed that the maximum productivity (yield/acre) occurred when harvested cane land acreage was about 111,000 acres and lower productivity at lesser and greater acreages; regression analysis did not show any significant relationships. Using linear, quadratic and cubic specification did not change these results. Significance tests of estimated coefficients showed that the numerical estimates were not meaningful at a 95% level of confidence, t and F coefficients and R^2 were too low to be of any use. More site specific data, perhaps selected parcels by plantations, may be necessary to obtain meaningful conclusions.

CHAPTER VII

CONCLUSIONS

Optimal control theory was examined for its potential applicability to analyzing the problem of land use control in Hawaii and to develop a deeper understanding of this analytical technique. Land was separated into its two major components, the stock (non-renewable) and flow (renewable) components in order to determine how land use conditions affect decisions depending upon the nature of the resource. Several specifications of the model were discussed, ranging from a simple linear competitive model to, monopoly with costs, and a flow resource model.

Optimal control theory has been applied to economic allocation problems of a variety of resources, including fisheries, forestry and water, but actual modelling of a system has been limited due to problems of data, and empirical estimation cannot be relied upon for decisionmaking. However, control theory does provide useful concepts that can be of value in analyzing real world phenomena. Optimal control theory shows that static equilibrium conditions have their counterparts in intertemporal economic analysis.

One such concept is the fundamental theorem which relates the relative rates of change in resource values to the time rate of discount. The analysis showed that even if a complete model could not be developed the fundamental theorem could be potentially applicable. Using aggregate housing price data obtained from the Multiple Listing Service of the Honolulu Board of Realtors, the analysis shows that the fundamental theorem has potential for explaining certain real world occurrences.

The analysis determined a "real" interest rate of real estate was about 1.6% per year. This positive rate although quite low may indicate a low time preference rate which reflects concern for the future because landowners tend to preserve agricultural land by refraining from converting land to an urban use. This may be reflected in the strict and ever-tightening institutional controls that preclude "free" conversions in a "laissez faire" sense.

This result, however, must be viewed with caution, since it was developed using a linear rather than a curvalinear trend which may be more realistic. The example is only an experiment with an analytical approach to determine if there is potential applicability. There is potential in the approach, however, there still exists opportunity for further analytical refinement in terms of model formulation and data.

The fundamental theorem in the previous case was derived from a perfect competition model without costs taken explicity into account. A more appropriate model is one that directly accounts for an imperfect market structure and all costs involved. The problem with adding costs is the quantification of these costs. The value of open space cannot be easily measured because it is based upon qualitative factors. The loss of agricultural land is difficult to measure in terms of loss of future food producing capability. Attempts have been made in this area by other economists, especially in measuring the benefits from a wilderness. It was not in the intent of this dissertation to analyze this area in depth but merely to acknowledge all important factors.

In spite of the complex conceptual and empirical problems that remain in properly accounting for and measuring the benefits and costs of agricultural land conversions the monopoly model still suggested a positive relationship between land prices and conversion rates. The analyses showed that Hawaii wants to control indiscriminate land use, however, it was difficult to prove causality. The effects of land use decisions made by the State and those forces affecting those decisions could not be definitively explained, although several interesting insights were obtained. The most significant being that the state may be inadvertantly maintaining high land prices.

Hawaii was used as a case study to provide a convenient and relevant framework within which some of the principles of optimal control theory could be applied. The institutional structure was described in order to reconstruct the framework that has evolved over time that controls land use decisions.

Using the statewide land use districts of Agriculture, Urban, Conservation and Rural as the basis for analysis, this study has shown that the loss of Agricultural District lands have been overstated when the early redistricting is not correctly taken into account. Agricultural acreage loss since the implementation of the Land Use Law in 1962 is 151,819 acres, however, if changes to the Conservation District is taken into account then the actual acreage loss is 39,584, or about one-fourth of the reported acreage. Most of these acres were converted to the Urban District which gained 37,044. The remainder was converted into the Rural District; a transitional type district established during the early phases of the program.

Although the losses of Agricultural District lands are exaggerated, it is important not to underestimate the significance of these losses. A number of these lands were good quality agricultural lands and their uses are economically irreversible. A major portion (70%) of the converted lands were high quality lands which are scarce in the islands. Also, agricultural import dependency has risen to a very high level despite continuing state policies toward agricultural self sufficiency.

The patterns and trends chapter provided additional insights into the agricultural land conversion situation. Using simple regression analysis on time series data, statistical comparisons were made between boundary review and non-review years within a district; and between Urban and Agricultural districts using dummy variable techniques to account for the periodic redistricting effects of these 5 years reviews. The estimated equations indicated that institutional effects have an impact upon the system of land classification in Hawaii. In all cases, on including versus not including boundary reviews the rate of conversion changed significantly because of the massive redistricting during those years. In the case of Agricultural District land in the State the boundary review equation showed that the reviews may have been too severe, so that Agricultural District acreage actually increased after each review. The discrete feedback of 5 year boundary reviews have been replaced by continuous annual feedbacks which are currently in effect after the major discrepancies in initial land use designations were corrected.

Implications for Further Study

The land quality aspect is an important area in the study of agricultural land conversion and some discussion of its importance was included in this dissertation. The problem with land quality is not the absence of data because there are several good soil surveys that designate land quality, but the use of these surveys. The involved agencies must more thoroughly integrate land quality data into their decisions in order to fully utilize the available information.

An important requirement for economic analysis is to update and continue the kind of work that the Land Study Bureau (LSB) did in measuring productivity ratings of different quality agricultural soils by use categories. Now that the Soil Conservation Service soil survey has been completed for the State of Hawaii using the new USDA soil taxonomy, the relations between different uses and different quality soil need to be made more precise and updated. A major effort to refine and update ratings in relation to representative crop types is now overdue.

Another area where further analysis can contribute to solving agricultural land use problems is model formulation. The optimal control model presented provided a useful guide, a starting point for further research. Although the monopoly model with costs may appear suited to the land use situation in Hawaii, institutional realities and land quality must be incorporated for better model formulations. Problems like these will have to be resolved in the future. Also, other mathematical models should be studied for their applicability to the land resource problem. Dynamic programming, graphical techniques, and adaptive management methods should not be overlooked for possible utility, if meaningfully formulated.

An area for empirical improvement is the collection of data, especially relative price data. The prices of agricultural lands, relative to urban lands, must be compiled before a real discount rate can be determined which, in turn, can afford useful insights into the decisionmaking process. Related to this, is the question of income. How does income levels affect the discount rate and conversion of agricultural land? Personal income estimates are available, routinely collected and need to be included in the analysis.

Overall, optimal control theory shows promise in its applicability to the land resource problem, especially, in one of its analogs, the fundamental theorem. This concept has been shown useful and is a definite area for further analysis. This dissertation has merely scratched the surface in understanding a potentially valuable tool for land use analysis and decisionmaking. More facility with mathematical tecnhiques, as applied to the land allocation problem, is necessary so that a researcher can make definite statements about land use, and perhaps in a significant help the State in reaching some of its goals.

APPENDIX A

OPTIMAL CONTROL THEORY: CONCEPTS AND METHODS

Optimal control theory was first developed for use in solving porblems in the physical and chemical sciences. Problems of determining an optimum trajectory of a rocket through space given fuel, weight, speed and time constraints were some of the earliest applications of optimal control theory. Since then, economists and others have borrowed this technique and have applied it to various types of problems, i.e., short run economic stabilization, economic growth, corporate strategies and investment portfolios. In recent years increasing efforts have been made in the resource economics area as well.

Basically the control problem consists of six elements.

1. Time: t_1 = terminal time

   t_0 = initial time
2. State Variables: $x(t) = [x_1(t_1), x_2(t_2), \ldots\ldots, X_n(t_n)]$
3. Control Variables: $u(t) = [u_1(t_1), u_2(t_2), \ldots\ldots, U_n(t_n)]$
4. Equations of Motion: describing the relationship between x, u and t. Generally a set of differential or difference equations that represent the system that is to be controlled.

   $$\dot{x}(t) = f(X(t), U(t), t)$$
5. Determination of Terminal Time: broadly, the set of constraints on all the variables.
6. Objective Functional: in terms of, perhaps, a cost functional or performance index which is to be minimized or maximized.

In the application to policy planning case, the system is represented by an econometric model, i.e. a set of difference equations describing the relationships. A set of controls may consist of interest rates set at some level or not allowed to exceed certain boundaries. The initial and terminal values may be desired. The objective functional is a quantitative representation of a planner's goals, objectives and utilities.

In its most general form the equations appear as follows.

$$\max J = \int_{t_0}^{t_1} I(x(t),\ u(t),\ t)dt + F(x_1,\ t_1)$$

subject to: $\dot{x} = f(x,\ u,\ t)$

t_0 and $X_0 = x(t_0)$ given $(x(t),\ t)\ \varepsilon T$ at

$t = t_1$, $\{u(t)\}\ \varepsilon u$

x--State Variable

u--Control Variable

I --Some intermediate function shows the dependence of the functional relationship on the time paths of the state variables, control variables and time within the relevant period.

F--The final function shows the dependence of the functional upon the terminal state and terminal time.

The Solution to the Control Problem

Although there are three acknowledged ways by which to solve the control problem, the maximum principle is generally chosen over the calculus of variations and dynamic programming approaches. The maximum principle has been used in computing optimal controls in many important problems in mathematics, engineering and economics.

The general control problem restated:

$$\max J = \int_{t_0}^{t_1} I(x, u, t)\,dt + F(x_1, t_1)$$

subject to: $\dot{x} = f(x, u, t)$

$$x(t_0) = x_0$$

$$x(t_1) = x_1$$

$$\{u(t)\} \varepsilon U$$

where I , F and f are continuously differentiable functions; t_0 and X_0 are given parameters where initial starting points are known; t_1 or x_1 are given parameters, where either end point must be known, the other being determined by the given one; and $(u(t))$ is the control trajectory which belongs to the given control set, U.

The maximum principle approach to the optimal control solution can be considered as an extension of the method of Lagrange multipliers to dynamic optimization. In static optimization, the Lagrange multipliers are introduced, one for each constraint defining a Langrangian expression; finding a saddle point, maximizing with respect to choice variables and minimizing with respect to Langrangian multipliers. With the maximum principle the procedure is similar although more complex.

Let us proceed:

$$\max J = \int_{t_0}^{t_1} I(x, u, t)\,dt + F(x_1, t_1)$$

rewrite the constraints as

$$f(x,\ u,\ t) - \dot{x}(t) = 0 \qquad t_0 \geq t \geq t_1$$

Note: Constraint originally was $\dot{x} = f(x, u, t)$. Simple rearrangement now for each constraint add a new variable

$$y(t) = [y_1(t_1),\ y_2(t_2),\ y_3(t_3),\ \ldots\ldots,\ y_n(t_n)]$$

These are called costate variables and are the dynamic equivalents of Langrangian multipliers.

Now define a "Langrangian" function which equals the objective function added to the inner product of the langrangian multiplier vector and constraints.

$$L = \int_{t_0}^{t_1} \{I(x,\ u,\ t) + y[f(x,\ u,\ t) - \dot{x}]\}dt + F(x_1,\ t_1)$$

Integrating L by parts yields

$$L = \int_{t_0}^{t_1} \{I(x,\ u,\ t) + yf(x,\ u,\ t) + \dot{y}x\}dt + F(x_1,\ t_1)$$
$$- [y(t_1)x(t_1) - y(t_0)x(t_0)]$$

The first two expressions under the integral sign are known as the Hamiltonian function.

$$H(x,\ u,\ y,\ t) = I(x,\ u,\ t) + yf(x,\ u,\ t)$$

The Hamiltonian is defined as the sum of the intermediate function and the inner product of the vector of costate variables and the vector of functions defining the rate of change in the state variables.

Rewritten

$$L = \int_{t_0}^{t_1} \{H(x,u,y,t) + \dot{y}x\}dt + F(x_1,t_1) - [y(t_1)x(t_1) - y(t_0)x(t_0)]$$

for a maximum the Langrangian must vanish implying

$$\left.\begin{array}{lll} \dfrac{\partial H}{\partial u} = 0 & \text{at} & t_0 \leq t \leq t_1 \\[2ex] \dot{y} = \dfrac{\partial H}{\partial x} & \text{at} & t_0 \leq t \leq t_1 \\[2ex] y(t_1) = \dfrac{\partial F}{\partial x_1} & & \end{array}\right\} \text{more necessary conditions}$$

In summary, given a Hamiltonian $H(x,u,y,t) = I(x,u,t) + yf(x,u,t)$ and solving for trajectories $u(t)$, $y(t)$ and $x(t)$, max $H(x,u,y,t)$ for all $t_0 \leq t \leq t_1$

$$\dot{x} = \frac{\partial H}{\partial y} \qquad x(t_0) = x_0$$

$$\dot{y} = -\frac{\partial H}{\partial x} \qquad y(t_1) = \frac{\partial F}{\partial x_1}$$

These are the conditions necessary for a local maximum, in other words, the optimal conditions.

In other words (Dorfman):

$\dot{x} = \dfrac{\partial H}{\partial y}$ Specifies how x grows as a result of its current standing and the choices made.

$\dot{y} = -\dfrac{\partial H}{\partial x}$ The change in the y (shadow price) of x is equal to the rate that it contributes to useful output. The opportunity cost of x.

or	$-y = \frac{\partial H}{\partial x}$	x depreciates at the same rate that it contributes to useful output.
	$x(t_0) = x_0$	State variables are given (known) in the initial time period.
	$y(t_1) = \frac{\partial F}{\partial x_1}$	The value of the costate variable in the final time period is the result of the choices made during that period.

Sensitivity Analysis

The sensitivity of the optimal value of the objective functional to a change in the initial time t_0 is given by

$$\frac{\partial J^*}{\partial t_0} = -[I(x^*, u^*, t)]\, t_0$$

The optimum function is changed by the negative of the initial value of the intermediate function.

The sensitivity of J^* to changes in the terminal time, t_1 is as follows:

$$\frac{\partial J^*}{\partial t_1} = [I(x^*,u^*,t)]t_1 + \frac{\partial F}{\partial x(t_1)}\frac{\partial x^*(t_1)}{\partial t_1} + \frac{\partial F}{\partial t_1}(x^*(t_1),t_1)$$

The optimum is changed by the terminal value of the intermediate function plus the increase in the final function.

The sensitivity of the optimal value of the objective functional to changes in the initial state $x(t_0)$ is:

$$\frac{\partial J^*}{\partial x(t_0)} = y^*(t_0)$$

The optimum is changed by the initial value of the corresponding co-state variable. If the costate variable equals zero then this system would be insensitive to changes in the initial state variables.

APPENDIX B

AGRICULTURAL LAND: AVAILABILITY PRODUCTION AND VALUE

How have land use changes affected cultivated agricgltural lands and the amount of production from these lands?

Overall changes from the State level will be examined to encompass a broader perspective of these changes. Changes on Oahu will also be elaborated upon because it is the only SMSA in Hawaii. The pressures for change on Oahu are greater than on the Neighbor Islands because of the population and the relative smallness of the island. The nature of land use changes on Oahu may be different from the total change in the State.

As expected, the total farm acreage in the State fell from 2,500,000 to 2,229,000 acres to -210,000 acres. Almost all categories of agricultural use in the State lost acreage except for vegetable crops, macademia nuts and fruits. On Oahu, the pattern is similar. Total farm acreage has decreased from 163,000 to 149,000 acres with the vegetable crop acreage increasing slightly. Sugarcane acreage dropped from 2,289,000 to 2,188,000 acres, losing 10,100 acres. Pineapple lost 28,000 acres going from 72,000 to 44,000. Coffee land was reduced to 2,100 acres from 4,800. As stated earlier, vegetable crops gained 1,000 acres moving from 3,300 to 4,300 acres; macademia nut acreage dramatically increased from 4,100 to 11,400 acres; and other fruit acreage excluding pineapple grew from 3,300 to 5,300 acres for the State.

The pattern of land use on Oahu is similar. Total farm acreage decreased from 163,000 to 149,000. Sugarcane land showed little change moving from 35,200 to 34,000. Pineapple acreage showed the greatest decline going from 21,700 to 12,000 acres. Vegetable production acreage showed very little change: 1,200 to 1,400 acres.

Production

However, as far as production from the remaining acreage is concerned, the totals have not drastically diminished. For the State, sugar production volume has remained virtually the same, 9,813,000 tons of unprocessed cane in 1962 and 9,263,000 tons in 1978. Pineapple was the biggest loser, as was coffee production. Volume of fresh pineapple decreased from 13,392,000 pounds to 1,780,000 pounds. Vegetables and melons showed strengths, increased acreage and more production. The year 1962 showed 51,296,000 pounds produced and 1978 showed 71,990,000. Macademia nuts and other fruits reflecting the increased acreage, made gains.

On Oahu, trends do not appear favorable for agriculture. Sugarcane, pineapple, vegetables and melons, and fruits production all have shown declines. Sugar went from 1,794,000 tons of unprocessed cane to 1,427,000 tons. Pineapple from 270,000 tons in 1971 to 187,000 pounds down from 17,546,000 in 1962. Fruits (excluding pineapple) were down from 8,160,000 pounds in 1962 to 7,450,000 pounds in 1978.

As far as the volume of livestock marketing is concerned, the picture is similar. On the State level, the volume of pork and chickens produced and marketed in Hawaii showed no change. The volume of beef, milk, eggs and, surprisingly, honey products and beeswax increased.

Oahu showed decreases in beef and honey products and increases in milk and eggs. Pork and chicken production remained unchanged.

Value of Agricultural Production

In order to determine the nature and trend of total agricultural production, values must be placed upon the volume of production. Pounds of milk and beef, etc. are not additive, but dollars are.

Statewide, in current dollars, the value of crop sales stood at $306,389,000.00 in 1978, up from $133,001,000.00 in 1962, a 130.4% increase. However, in real dollars (1968 = 100) the dollar values were $146,800,000.00 in 1962 and $164,725,000.00 in 1978, a 12.2% increase. What appeared at first to be a tremendous growth turns out to be dismal. Twelve percent over a seventeen year period figures to be less than one percent per year and is quite low. As far as individual crops are concerned, the situation is similar: slow or no growth at all.

Note however that this low growth was reaped from less acreage. This indicates greater efficiency of farmers and the adoption of new technology. Hawaii is getting more production from less acreage. This fact lends a bit of optimism to the agricultural picture in Hawaii.

APPENDIX C

POPULATION AND LAND USE CHANGE

One of the most influential and important factors in land use change is that of population. Population growth in Hawaii, especially on Oahu, is the major impetus of land use changes. More people means greater demand for homes and more homes means greater demand for urban land. Population growth in Hawaii, historically, is one of the fastest in the nation. Oahu's population growth had led the way, until recently.

Starting from 1940 census to 1980, the changes in population are meaningful. The decades of the 1960's and 1970's are most relevant because they are the years of the Land Use Law and district boundaries were in effect. In 1940, there were 422,770 people living in the State, with 257,696 or 61% of them living on Oahu. The year 1950 showed 499,794 people in Hawaii with 71% or 353,006 of them living on Oahu. A migration from rural to urban areas had occurred in the 1940's and 1950's. The population of the outer islands--Maui, Kauai and Hawaii--had declined. Only Oahu showed an increase. In the decade following, the same phenomena continued. Population of the State increased to 632,772 with 500,394 of the people or 79% residing on Oahu. The population of the outer islands again declined. This decade, 1960's, showed remarkable growth. In 1970, for the first time in 30 years population of all the islands increased. Now, 82% of the total population living on Oahu. During the 1970's, growth on Oahu slowed considerably. The figures indicate that the rest of Hawaii is growing faster than Oahu. Now only 79% of the population resides on Oahu; this is the first drop in percentage in 60 years. Kauai, Maui and Hawaii experienced tremendous growth. From 1970 until now, 1980, Oahu has grown by 21%, Kauai by 31%, Hawaii by 52%, and Maui (county) by 54%.

Population densities (per square mile) in the State has been increasing steadily over the years. In 1980, it was 150.4 persons per square mile, up from 120.0 in 1970, and 98.6 in 1960. The neighbor island densities have been relatively stable over the years. Kauai averages about 55.0, Maui about 59.0, and Hawaii about 16. Not surprisingly, the 1980 census showed a big jump in neighbor island densities. Kauai was up to 71.0, Maui to 84.1 and Hawaii to 22.9.

People apparently are tending to move away from the urban center, Oahu, and back to the rural areas. This may be a manifestation of the back to nature movement that was prevalent during the 1970's, or, the congestion on Oahu may have reached a critical level for some people, thus, prompting the exodus. A more obvious reason, especially for Maui and parts of the Big Island, is the fact that development has intensified. This has provided more job opportunities, i.e. in construction and tourism, enticing more people to relocate or to remain. Development is also occurring on Kauai and is attracting more and more residents to that island.

However, Oahu continues to be the major population center in Hawaii. But, the neighbor island population growth is increasing at a faster rate. If this trend continues, the result may be a more balanced population mix in terms of population dispersion. If not, continued concentration of the population and economy on Oahu may soon cause resource shortages for Oahu and possibly unemployment for the neighbor islands if the construction sector slows down (see Table VIII).

Annual Changes

As far as the yearly changes are concerned, the total defacto population in Hawaii since 1962 (including visitors present) has increased from 693,000 to 984,700 in 1978, a 41.9% increase. Fastest growth occurred in the early 1970's, at almost a 4% rate yearly. Much of this was accounted for by a dramatic increase in tourists.

Total resident population in the State increased from 683,500 in 1962 to 896,000 in 1978, a 31% increase over 18 years. Resident population includes armed forces personnel stationed in Hawaii and their dependents (see Table IX).

TABLE VIII

TOTAL POPULATION BY ISLANDS
1920-1980

	OAHU	%	KAUAI	MAUI	HAWAII	STATE
1920	123,496	48	29,247	36,080	64,895	255,881
1940	257,696	61	35,636	46,919	73,276	422,770
1950	353,006	71	29,683	40,103	68,350	499,794
1960	500,394	79	27,922	35,717	61,332	632,772
1970	630,497	82	29,524	38,691	63,468	769,913
1980	761,960	79	39,117	61,191*	92,206	964,624

POPULATION DENSITY BY ISLANDS
1920-1980

	OAHU	%	KAUAI	MAUI	HAWAII	STATE
1920	207.5		53.1	49.6	16.1	39.9
1940	433.1		64.7	64.4	18.2	65.9
1950	593.3		53.9	55.1	17.0	77.9
1960	841.0		50.7	49.1	15.2	98.6
1970	1,059.7		53.6	53.1	15.6	120.0
1980	1,277.2		71.0	84.1	22.9	150.4

Per Square Mile

* Approximate
Source: Atlas of Hawaii

TABLE IX

ESTIMATED POPULATION, BY RESIDENCE AND MILITARY STATUS: 1962 TO 1978

YEAR[a]	RESIDENT POPULATION[b]					VISITORS PRESENT (ANNUAL AVERAGE)	RESIDENTS ABSENT (ANNUAL AVERAGE)	DE FACTO POPULATION[c]	PERCENT CHANGE
			Civilian Population						
	Total	Armed Forces[d]	Total	Military Dependents[e]	Non-Military Dependents				
1962	683,500	79,000	604,500	63,200	541,300	13,100	3,000	693,600	
1963	682,200	59,600	622,700	61,500	561,200	15,300	3,100	694,500	0.129
1964	699,900	73,200	626,700	69,100	557,600	16,000	4,700	711,200	2.4
1965	703,800	53,400	650,400	65,800	584,600	17,300	5,700	715,400	0.59
1966	710,300	54,100	656,300	62,500	593,600	21,000	6,800	724,600	1.29
1967	722,500	56,000	666,500	61,300	605,200	27,700	7,600	742,600	2.49
1968	734,500	57,000	677,400	59,100	618,300	32,500	8,100	758,800	2.18
1969	750,200	48,500	701,800	59,700	642,100	37,400	8,800	778,800	2.64
1970									2.38
April 1	769,913	55,142	714,771	61,858	652,913	37,600	10,300	797,300	
July 1	775,800	53,200	722,600	57,800	664,800	37,600	10,000	803,400	0.44

TABLE IX (Continued)

YEAR[a]	RESIDENT POPULATION[b] Total	Armed Forces[d]	Civilian Population Total	Military Dependents[e]	Non-Military Dependents	VISITORS PRESENT (ANNUAL AVERAGE)	RESIDENTS ABSENT (ANNUAL AVERAGE)	DE FACTO POPULATION[c]	PERCENT CHANGE
1971	800,900	50,800	750,000	62,200	687,900	41,900	9,400	833,300	3.72
1972	823,800	52,000	771,300	66,200	705,100	51,300	8,600	865,900	3.91
1973	844,100	58,100	785,900	70,300	715,600	61,600	9,800	895,900	3.46
1974	855,400	57,500	797,900	68,300	729,600	66,000	7,800	913,600	1.98
1975	867,900	58,900	809,000	63,700	745,300	68,800	9,000	927,700	1.54
1976	883,500	57,800	825,700	67,000	758,800	78,500	9,400	952,700	2.69
1977	891,400	56,500	834,900	65,000	769,900	86,800	9,000	969,200	1.73
1978	896,600	56,500	840,100	61,100	779,000	96,000	7,900	984,700	1.6

[a] July 1 unless otherwise specified.
[b] Includes residents temporarily absent; excludes visitors present.
[c] Excludes residents temporarily absent; includes visitors present.
[d] De facto basis, 1962-69; stationed or homeported in Hawaii, 1970 forward.
[e] Dependents living in Hawaii, regardless of location of family head.

Source: Hawaii State Department of Planning and Economic Development, The Population of Hawaii, 1978 (Statistical Report 131, April 2, 1979), Table 1.

APPENDIX D

GENERAL PATTERN OF BOUNDARY CHANGES AND ESTIMATED ACREAGE OF STATE LAND USE DISTRICTS: 1962-1980

TABLE X

GENERAL PATTERN OF LAND USE DISTRICT BOUNDARY CHANGES: 1962-1980

SUMMARY

	1962	1980	Change	%
CONSERVATION DISTRICT				
Oahu	151,400.0	154,896.4	3,496.4	+2.3
Maui	172,741.0	193,667.7	20,397.7	+12.1
Hawaii	1,240,000.0	1,309,461.8	69,461.8	+5.6
Kauai	173,100.0	198,758.0	25,658.0	+14.8
State	1,863,630.0	1,975,865.1	112,235.1	+6.0
AGRICULTURAL DISTRICT				
Oahu	159,652.0	143,736.1	-15,915.9	-9.9
Maui	277,526.0	252,807.8	-24,718.7	-8.9
Hawaii	1,311,992.0	1,228,844.7	-83,147.3	-6.3
Kauai	172,500.0	144,023.7	-28,476.3	-16.5
State	2,126,014.5	1,974,195.5	-151,819.0	-7.1
RURAL DISTRICT				
Oahu	–	–	–	–
Maui	3,700.0	3,780.0	80.0	+2.2
Hawaii	1,100.0	612.0	-488.0	-44.4
Kauai	1,100.0	1,233.3	+133.3	+12.1
State	6,700.0	9,240.3	2,540.3	+3.8
URBAN DISTRICT				
Oahu	74,248.0	86,667.5	12,419.5	+16.7
Maui	11,843.5	15,533.5	3,690.0	+31.1
Hawaii	19,908.0	34,481.5	14,573.5	+73.2
Kauai	7,300.0	9,885.1	2,585.1	+35.4
State	115,155.5	152,199.2	37,043.7	+32.0

Source: Land Use Commission Records

TABLE XI

ESTIMATED ACREAGE OF STATE LAND USE DISTRICTS
1962-1980

OAHU TOTALS

Date	Total	Urban	Conservation	Agriculture	Rural
1962	385,300.0	74,248.0	151,400.0	159,652.0	–
1963	385,300.0	74,523.0	515,400.0	159,377.0	–
1964	385,300.0	75,700.0	151,400.0	158,200.0	–
1965	385,300.0	75,790.0	151,377.0	158,133.0	–
1966	385,300.0	77,280.1	151,361.9	156,658.0	–
1967	385,300.0	77,322.7	151,375.8	156,601.5	–
1968	385,300.0	77,872.8	151,375.1	156,552.1	–
1969	385,300.0	82,592.9	156,801.0	145,906.1	–
1970	385,300.0	82,595.6	156,798.3	145,906.1	–
1971	385,300.0	82,817.0	156,956.0	145,527.0	–
1972	385,300.0	82,751.3	156,991.4	145,425.9	–
1973	385,300.0	83,617.7	156,991.4	144,559.5	–
1974	385,300.0	84,093.4	156,920.9	144,205.7	–
1975	385,300.0	85,186.5	154,907.6	145,205.9	–
1976	385,300.0	85,259.1	154,907.6	145,133.3	–
1977	385,300.0	85,259.1	154,907.6	145,133.3	–
1978	385,300.0	86,489.2	154,907.6	143,903.2	–
1979	385,300.0	86,492.2	154,904.8	143,903.2	–
1980	385,300.0	86,667.5	154,896.4	143,736.1	–

TABLE XII

ESTIMATED ACREAGE IN STATE LAND USE DISTRICTS
1962-1980

MAUI TOTALS (EXCLUDING MOLOKAI AND LANAI)

Date	Total	Urban	Conservation	Agriculture	Rural
1962	465,800.0	11,843.5	172,741.0	277,526.5	3,700.0
1963	465,800.0	12,787.5	171,700.0	277,612.5	3,700.0
1964	465,800.0	12,800.0	171,700.0	277,600.0	3,700.0
1965	465,800.0	13,063.0	171,615.0	277,422.0	3,700.0
1966	465,800.0	13,075.0	171,615.0	277,009.0	4,101.0
1967	465,800.0	13,124.8	171,612.7	276,954.3	4,108.2
1968	465,800.0	13,236.1	171,612.7	276,785.0	4,166.2
1969	465,800.0	13,406.6	193,336.7	255,321.5	3,375.2
1970	465,800.0	13,744.4	193,336.7	254,983.7	3,735.2
1971	465,800.0	13,765.7	193,336.7	254,962.4	3,735.2
1972	465,800.0	13,826.2	193,336.7	254,897.1	3,740.2
1973	465,800.0	13,938.5	193,336.7	254,776.1	3,748.1
1974	465,800.0	14,725.5	193,336.7	254,225.7	3,512.1
1975	465,800.0	15,376.4	193,678.7	253,221.3	3,523.6
1976	465,800.0	15,441.8	193,678.7	253,129.2	3,550.3
1977	465,800.0	15,441.8	193,678.7	253,129.2	3,550.3
1978	465,800.0	15,442.8	193,678.7	252,887.7	3,790.8
1979	465,800.0	15,464.7	193,678.7	252,882.2	3,774.4
1980	465,800.0	15,533.5	193,678.7	252,807.8	3,780.0

TABLE XIII

ESTIMATED ACREAGE OF STATE LAND USE DISTRICTS
1962-1980

HAWAII TOTALS

Date	Total	Urban	Conservation	Agriculture	Rural
1962	2,573,400.0	19,908.0	1,240,400.0	1,311,922.0	1,100.0
1963	2,573,400.0	19,997.5	1,240,400.0	1,311,902.5	1,100.0
1964	2,573,400.0	20,000.0	1,240,400.0	1,311,900.0	1,100.0
1965	2,573,400.0	20,477.3	1,240,400.0	1,311,422.7	1,100.0
1966	2,573,400.0	20,897.6	1,240,368.5	1,311,033.9	1,000.0
1967	2,573,400.0	21,020.5	1,240,368.5	1,310,911.0	1,100.0
1968	2,573,400.0	25,419.9	1,239,653.5	1,307,226.6	1,100.0
1969	2,573,400.0	19,489.8	1,322,965.0	1,220,352.2	593.0
1970	2,573,400.0	19,591.0	1,322,872.0	1,220,344.0	593.0
1971	2,573,400.0	30,487.0	1,322,787.9	1,219,514.6	610.5
1972	2,573,400.0	31,177.6	1,322,786.7	1,218,826.6	611.9
1973	2,573,400.0	31,314.5	1,322,786.7	1,218,009.8	611.9
1974	2,573,400.0	32,249.6	1,322,528.6	1,228,779.3	612.0
1975	2,573,400.0	33,435.7	1,310,573.0	1,228,586.5	612.0
1976	2,573,400.0	33,628.5	1,310,573.0	1,228,586.5	612.0
1977	2,573,400.0	33,628.5	1,310,573.0	1,228,637.5	612.0
1978	2,573,400.0	33,643.3	1,310,516.2	1,228,637.5	612.0
1979	2,573,400.0	34,457.0	1,309,693.5	1,228,637.5	612.0
1980	2,573,400.0	34,481.5	1,309,461.8	1,228,844.7	612.0

TABLE XIV

ESTIMATED ACREAGE OF STATE LAND USE DISTRICTS
1962-1980

KAUAI TOTALS

Date	Total	Urban	Conservation	Agriculture	Rural
1962	353,900.0	7,300.0	173,100.0	172,500.0	1,100.0
1963	353,900.0	7,300.0	173,100.0	172,500.0	1,100.0
1964	353,900.0	7,300.0	173,100.0	172,500.0	1,000.0
1965	353,900.0	7,353.6	172,250.0	173,278.1	1,018.3
1966	353,900.0	7,411.8	172,250.0	173,146.9	1,091.3
1967	353,900.0	7,418.3	172,250.0	173,130.4	1,101.3
1968	353,900.0	7,504.8	172,250.0	173,031.0	1,114.2
1969	353,900.0	9,121.0	197,654.0	145,983.1	1,141.2
1970	353,900.0	9,174.5	197,607.7	145,984.8	1,135.4
1971	353,900.0	9,065.9	197,681.7	146,017.9	1,186.9
1972	353,900.0	9,073.6	197,681.7	146,010.2	1,136.9
1973	353,900.0	9,065.5	197,681.7	146,018.3	1,136.9
1974	353,900.0	1,115.5	197,681.7	145,965.9	1,136.9
1975	353,900.0	1,248.7	198,758.7	144,705.7	1,136.9
1976	353,900.0	9,472.2	198,758.7	144,488.9	1,180.2
1977	353,900.0	9,309.4	198,758.7	144,695.0	1,136.9
1978	353,900.0	9,814.6	198,758.7	144,127.9	1,198.9
1979	353,900.0	9,884.4	198,758.7	144,023.7	1,233.3
1980	353,900.0	9,885.1	198,758.0	144,023.7	1,233.3

APPENDIX E

THE LUC APPROACH TO LAND EVALUATION AND PLANNING DECISIONS

The LUC Approach to Land Evaluation and Planning Decisions

The Land Use Commission decisions to rezone land is based upon the suitability of that land to that use. A person wishing to rezone land, petitions the Land Use Commission with the request. Specific instructions for providing relevant information and procedural matters are mandated.

General requirements are that the specific property must be identified and described. This includes, but is not limited to, tax map key number. The exact names and proprietory interests of the petitioners must be disclosed. The type of reclassification sought must also be noted.

For petitions requesting an urban classification, special requirements must be adhered to. Additional information must be provided. The list includes (1) type of urban development, i.e., single family, residential, resort, etc., (2) preliminary data such as lot size, number, lots, selling prices, (3) petitioner financial statements, (4) significant effects, if any, upon the environment, agriculture, recreational, historic or other resources <u>of the area</u>, (5) preliminary report of the physical condition of property, i.e., soil, topography, demography, (6) availability of public services, (7) location of proposed development in relation to adjacent urban districts, and (8) relationship to employment centers and any unique development factors. All statements made to support a petitioner's contention that the proposed amendment is consistent with the land use law and regulation shall be supported by appropriate documents that will provide a field record and will aid the Commission in lending a sound decision.

The Commission shall not approve a reclassification unless the evidence shows that the proposed boundary change is reasonable and not in violation of the law. The Commission shall observe and comply with the interim Statewide Land Use Guidance policies. These are (1) land use amendments shall be approved only as reasonably necessary to accommodate growth and development provided there are no significant adverse effects upon agricultural, natural, environmental, recreational, scenic, historic or other resources of the area, (2) lands reclassified as urban shall have adequate public services and facilities or can be provided by the petitioner at reasonable cost, (3) maximum use shall be made of existing services, (4) urban districts shall be continuous to an existing urban district or be self contained, (5) preference shall be given to petitioner which will provide permanent employment or housing for all economic and social groups, (6) consideration shall be given to the general plan of the county, (7) as far as practicable, conservation lands shall not be reclassified as urban, and (8) urban lands may be reclassified if not developed in a timely manner.

The Approach to Land Evaluation as Related to the State

For the most part, the State concern is the impact of land use changes on the immediate area. Most of the regulations are stated in terms of significant effects upon "the area" with no mention of the repercussions upon the State. Consequently, most petitions received by the LUC lean primarily toward examining the effect of land use changes upon the economy in that particular locale. Demographic, economic and social conditions of the subject area are described in detail along with the projected changes.

However, as far as impacts upon the State are concerned, the implicit assumption seems to be: If it's good for the area, it's good for the State. This is not an unacceptable or unrealistic assumption to make. For if each site or parcel of land could be utilized in its best possible way, it is not improbable that, in total, the State would be utilizing its land in the best possible way. Perhaps and perhaps not. The State does not, at the moment, have a systematized method for determining or even discussing how cumulative changes in land use affects State welfare. The five year Boundary Review that were mandated by the Land Use Law have been repealed and are no longer required. The Hawaii State Plan enacted in 1978 is the beginnings of recognition that land use impacts upon the State. Hopefully, a methodology may be empiricized and applied to the State to determine such impacts. But, for now, making sure that the use is suited to the land is a major part of land use planning.

APPENDIX F

AGRICULTURAL LANDS OF IMPORTANCE TO THE STATE OF HAWAII

For the State of Hawaii, a project to designate the Agricultural Lands of Importance to the State of Hawaii (ALISH) got under way in 1975 as part of the United States Department of Agricultural, Soil Conservation Service program to inventory important farmlands in the nation. They classified important agricultural lands into three groups: (1) prime, (2) unique, and (3) other important agricultural land (Baker).

Prime agricultural land is land best suited for the production of food, feed, forage and fiber crops. This class of land has the soil quality, growing season and moisture supply needed to produce sustained high yields with the lowest inputs of energy or money with the least damage to the environment.

Unique land is land other than prime that is currently used for the production of specific high value food crops. This land has special combinations of soil quality, growing season, temperature, humidity, sunlight, air drainage, elevation, moisture supply that favors the production of a special crop. Examples of such specialty crops in Hawaii are coffee, taro, and watercress.

Other important agricultural land is land of statewide or local importance for the production of food, feed, fiber and forage and are not prime or unique lands. These lands can be farmed satisfactorily by applying greater inputs of fertilizer or other soil amendments.

In the State of Hawaii, in 1978, only 24% of the total land area could be considered as important agricultural (prime, unique or other) land. This roughly corresponds to 49.5% of the total land zoned agricultural by the LUC. For Oahu, 24% of the island was classified as important agricultural land. This translates to 65.7% of the land zoned agricultural. This implies that there are sufficient quantities of non-prime agricultural lands available for urban and other uses. However, since 1974, the start of the ALISH program, 80% of the total area converted from agricultural to urban has been important agricultural land; 56.1% of which was prime, 5.8% unique, and 18.4% other. Out of the 3,060.5 acres converted, 2,458.5 were important (see Table VII).

BIBLIOGRAPHY

Nature of Research

Gordon, R.A., "Rigor and Relevance in an Institutional Setting", in AER, March 1976, vol. 66(1), pp. 1-14.

Klein, "Economics, Allocation or Valuation", in Journal of Economic Issues, vol. 8(4), Dec. 1974, pp. 785-811.

Mini, Pierre, "Some Observations in Methodological Studies", in Philosophy and Economics, 1974, pp. 1-13.

Randall, Alan, "Information, Power and Academic Responsibility", in AJAE, vol. 56, May 1974, pp. 227-234.

Agricultural Land (Supply, Importance)

Beek, K.J. and Bennema, J., Land Evaluation for Agricultural Land Use Planning, An Ecological Methodology, Dept. of Soil Science and Geo., Agric. University, Wagenigen, 1972.

Food and Agricultural Organization of the United Nations, A Framework for Land Evaluation, Soil Resources Development and Conservation Service, Land and Water Development Division, Soils Bulletin 32, Rome, 1976.

Fliegee, Frederick G., Van Es. J.C., Burdge, Raber J., and Schweitzer, Harvey J., Farming in an Urban Environment, Agriculture in Illinois, Alternating Futures for the 1980's, Sept. 1979, AERR 167.

Frey, H. Thomas, Otte, Robert C., Cropland for Today and Tomorrow, Economic Research Service, USDA, AER-291, 1975, p. 9.

Frey, H. Thomas, Major Uses of Land in the United States, 1974, USDA, ESCS, Ag Economics Report no. 440.

Gustafon, R.L., "Carryover Levels for Grains", USDA Technical Bulletin 1178, 1958.

Leopold, L.B., Quantitative Comparison of Some Aesthetic Factors Among Rivers, Circular 620, U.S. Geological Survey, 1969.

Raup, Philip M., "Urban Threats to Rural Lands, Backgrounds and Beginnings", Journal of the American Institute of Planners, vol. 41(6), Nov. 1975, pp. 371-379.

Schmude, Keith O., "A Perspective on Prime Farmland", Journal of Soil and Water Conservation, XXXII, Sept.-Oct., 1977, pp. 240-242.

Schneider, Roger E., Fettig, Lyle P., Changes in the Farmland Base, Agriculture in Illinois, Alternative Futures for the 1980's, Sept. 1979, AERR 168.

Vink, A.P.A., Land Use in Advancing Agriculture, Springer, Berlin, Heidelberg, New York, 1975.

United States Department of Agriculture, "Who Owns the Land? A Preliminary Report of a U.S. Land Ownership Survey", USDA, ESCS, no. 70, Sept. 1978.

_____, "Changes in Farm Production and Efficiency, 1978", USDA, ESCS, Statistical Bulletin no. 628, Washington, D.C., Jan. 1980.

Wunderlich, Gene, "Facts About U.S. Land Ownership", USDA, ESCS, Ag. Information Bulletin 422.

Hawaii

Baker, Harold L., "Agricultural Lands of Importance to the State of Hawaii", CES, CTAHR, University of Hawaii, Circular 496.

Bank of Hawaii, "Year in Review", Annual Economic Report of the State of Hawaii, 1962-79.

Chinen, Jon J., The Great Mahele, Hawaii's Land Division of 1848, University of Hawaii Press, Honolulu, HI, 1958.

City and County of Honolulu, Planning for Oahu, Land Use Model, Technical Report no. 7, Dept. of General Planning, City and County of Honolulu, March 1974.

_____, Comprehensive Zoning Code, 1969, Ordinance no. 3234, Effective date January 2, 1967.

Co, Howard, "History and Provisions of the Agricultural Dedication Law in Hawaii, August 1974, unpublished draft manuscript cited with permission of author.

Dept. of Buildings, Summary of Building Permits, Hawaii, Kauai, Maui County Dept. of Public Works Records, in the City and County of Honolulu files.

Creighton, Thomas H., The Lands of Hawaii, Their Use and Misuse, University Press of Hawaii, Honolulu, HI, 1978.

Eckbo, Dean, Austin and Williams, State of Hawaii Land Use Districts and Regulations Review, First Five Year Review, prepared for the State of Hawaii Land Use Commission, June 1970.

First Hawaiian Bank, "Honolulu Construct Cost Indexes, Revised", in Economic Indicators, Dec. 1974.

Fisher, Tad, Hawaii: Growing Pains in Paradise, Population Bulletin, A publication of the Population Reference Bureau, Inc., vol. 29, no. 3, 1973.

Fuchs, Lawrence H., Hawaii Pono, New York, Harcourt, Brace and World, Inc., 1961.

Hahn, Rory H., Executive Director of the Land Use Research Foundation of Hawaii, and member of People for Sensible Growth.

Hawaii Visitors Bureau, -Annual Research Reports 1952 to 1975
-Revised Visitor Statistics 1964-70 (July 1971)

Land Use Commission, Mr. Dan Yasue and Joseph Chu, Planners personal interviews.

Lowry, Kem, et al., Analysis of Alernative Land Management Techniques for Hawaii, in Growth Management Issues in Hawaii, Hawaii State Department of Budget and Finance, Honolulu, HI, 1977.

Lowry, Gordon K., Jr., Control and Consequences: Impacts of Hawaii's Land Use Law, dissertation, University of Hawaii, Honolulu, HI, 1976.

Lum, David, T.E., Camp, Samuel G., Gertel, Karl, Hawaii's Experience in Zoning, pamphlet, Hawaii Agricultural Experiment Station, College of Tropical Agriculture, University of Hawaii, Research Report no. 172, June 1969.

Mandelker, Daniel R., Environmental and Land Control Legislation, Chapter VII: Progress in Paradise, The Hawaii Land Use Law, The Bobbs-Merrill Co., Inc., publishers, Indianpolis, New York, 1976.

Myers, Phyllis, Zoning Hawaii, An Analysis of the Passage and Implementation of Hawaii's Land Use Law, the Conservation Foundation, Washington, D.C., 1976.

Nunns, Frederick K., "Reasons and Methods for Protecting Farmlands on Oahu", Public Affairs Series no. 2, Cooperative Extension Service, University of Hawaii, 1960.

Overview Corporation, From the Mountains to the Sea, State of Hawaii Open Space Plan, Prepared for the State of Hawaii Department of Economic Development, Honolulu, 1972.

Pacific Urban Studies and Planning Program, University of Hawaii, "Environment and Urbanization in Central Oahu: Planning Study

Resource Base Component", Nov. 1971.

Pukui, Mary Kawena, Elbert, Samuel H., Hawaiian Dictionary: Hawaiian-English, English-Hawaiian, University of Hawaii Press, Honolulu, HI, 1971.

Schwind, Paul, "The Evaluation of Land Use Alternatives: A Case Study of the Metropolitan Fringe of Honolulu, Hawaii", in Land Economics, vol. 53, no. 4, Nov. 1977.

Session Laws of Hawaii (Hawaii Revised Statutes)
1961 State of Hawaii Act 187: Land Use Law
1963 State of Hawaii Act 205: Added Rural District
1965 State of Hawaii Acts 32: 201, 277, 296: on tax assessments
1973 State of Hawaii Act 175: Revised Tax Laws
1974 State of Hawaii Act 246: Hawaii Environmental Protection Act.

State of Hawaii, Department of Planning and Economic Development, The State of Hawaii: Data Book, 1979, A Statistical Abstract.

_____, Report to the People, Second Five Year District Boundaries and Regulation Review, Technical Reports nos. 1 and 2, State Land Use Commission, Feb. 1975.

_____, Statistical Report #98, Land Use and Ownership Trends in Hawaii, Dept. of Planning and Economic Development, Dec. 28, 1974.

_____, Preservation of Agriculture and Agricultural Lands in Hawaii, Dept. of Planning and Economic Development, Sept. 8, 1971.

_____, "A Temporary Commission on Statewide Environmental Planning", A Plan for Hawaii's Environment, Honolulu, 1973.

_____, State Agriculture Plan, "A Functional Prepared in Accordance with Chapter 226, Hawaii Revised Statutes," Department of Agriculture, January 1980.

_____, Statistics of Hawaiian Agriculture, Dept. of Agriculture, annually and records.

_____, Housing and Community Development Research, Dept. of Regulatory Agencies, Bank Examination Division and Insurance Division, Records, Honolulu, Dept. of Housing and Community Development, no. 36, July 1976, p. 21.

_____, "Labor Force Estimates (Annual)", Dept. of Labor and Industrial Relations.

_____, "Act 187, Session Laws of 1961, Rules of Practice and Procedures, Interim Regulation, Temporary District Boundaries, effective date July 11, 1961, Land Use Commission", Dept. of Planning and Research.

_____, "Hawaii's Income and Expenditure Accounts: 1958-76, vol. I, Accounts (Data)", Department of Planning and Economic Development, June 1978.

_____, Land and Water Resource Management in Hawaii, Hawaii State Department of Budget and Finance, Hawaii Institute for Management and Analysis of Government, Honolulu, HI, January 1979.

_____, "Rules of Practice and Procedure, and District Regulations", effective date Dec. 21, 1975, State of Hawaii Land Use Commission.

University of Hawaii Conference, "The Public Costs of Private Development", University of Hawaii 1973, Summary of Proceedings, Jan. 11-12, 1973.

Tax Foundation of Hawaii, Government in Hawaii, A Handbook of Financial Statistics, 23rd edition, Honolulu, HI, 1976.

Young, Steven C., Land Use Forecast for Oahu, 1975-1985, prepared by S.C. Young in association with Alan M. Voorhees Associates, Inc., 1978.

The Mathematics of Control Theory

Anonymous, "Optimal Control: A Mathematical Supertool", in Business Week, May 19, 1973, no. 2280, pp. 74-76.

Aoki, Masanao, Optimal Control and Systems Theory in Dynamic Economic Analysis, North-Holland Publishing Co., New York, 1976.

Athans, M. and Falb, P.L., Optimal Control, McGraw-Hill Book Co., Inc., New York, 1966.

Bellman, R., Dynamic Programming, Princeton University Press, Princeton, NJ, 1957.

Bellman, R., ed., Mathematical Optimization Techniques, University of California Press, Berkeley and Los Angeles, CA, 1963.

Bellman, R. and Dreyfus, S., Applied Dynamic Programming, Princeton University Press, Princeton, NJ, 1962.

Blackwell, D., "Discrete Dynamic Programming", in Annals of Mathematical Statistics, 33(1962), pp. 719-726.

Clark, Willian C., "Witches, Floods and Wonder Drugs: Historical Perspectives in Risk Management", from Institute of Resource Ecology, January 1980, University of British Columbia.

Dreyfus, S., Dynamic Programming and the Calculus of Variations, New York, Academia Press, Inc., 1965.

Feldbaum, A.A., Optimal Control Systems, Translated from Russian by A. Kraiman, Academic Press Inc., New York, 1965.

Hadley, G., Non-linear and Dynamic Programming, Addison-Wesley Publishing Co., Inc., Reading, MA, 1964.

Hestenes, M., Calculus of Variation and Optimal Control Theory, John Wiley & Sons, New York, 1966.

Howe, Charles W., Natural Resource Economics: Issues, Analysis and Policy, John Wiley & Sons, New York, 1979.

Intrilligator, M.D., Mathematical Optimization and Economic Theory, Prentice-Hall, Englewood Cliffs, NJ, 1971.

Kaufmann, A. and Cruan, R., Dynamic Programming, translated from French by H.C. Sneyd, Academic Press, New York, 1967.

Lasalle, J.P., "Time Optimal Control Systems", in Proceedings National Academy of Sciences, USA, 45(1959): pp. 573-577.

Lee, E.B. and Markus, L., Foundations of Optimal Control Theory, John Wiley & Sons, New York, 1968.

Leitmann, G., An Introduction to Optimal Control, McGraw-Hill Book Co., Inc., New York, 1966.

Newhauser, G., An Introduction to Dynamic Programming, John Wiley & Sons, New York, 1966.

Pontryagin, L.S., et al., The Mathematical Theory of Optimal Processes, New York, Interscience, 1962.

Economic Applications of Control Theory

Ando, Albert and Palash, Carl, "Some Stabilization Problems of 1971-75, with an Application of Optimal Control Algorithms", from Papers and Proceedings of the American Economic Association, May 1976, vol. 66, no. 2, pp. 346-348.

Arrow, K.J., "Applications of Control Theory to Economic Growth", Lectures in Applied Mathematics, vol. 12, Mathematics of the Decision Sciences-Part 2, (Providence, RI American Mathematical Society).

Beek, K.J.; Reis, Luis; Thiadens, Reiner, "Data Analysis in Land Evaluation: Some Experiences in a Land Reclamation Project in Portugal", discussion paper prepared at the request of FAO for the Expert Consultation on "Guidelines for Land Evaluation for Rainfed Agriculture", Rome, December 12-14, 1979, International Institute for Land Reclamation and Improvement, Netherlands.

Chow, Gregory C., Analysis and Control of Dynamic and Economic Systems, John Wiley & Sons, New York, 1975.

Chow, Gregory C., "Control Methods for Macroeconomic Policy Analysis", from papers and proceedings of the American Economic Association, May 1976, vol. 66, no. 2, pp. 340-345.

Dorfman, Robert, "An Economic Interpretation of Optimal Control Theory", in American Economic Review, vol. LIX, no. 5, 1967.

Harberger, A.C., "Three Basic Postulates for Applied Welfare Economics", in Journal of Economic Literature, vol. 9, no. 3, 1971.

L'Esperance, Wilfred, "Optimal Stab.lization Policy at the Regional Level", in Regional Science and Urban Economics, vol. 7, no. 1/2, March 1977, pp. 25-48.

L'Esperance, Wilfred, "An Optimal Control of a State Econometric Model", in Growth and Change: A Journal of Regional Development, vol. 10, no. 2, April 1979, pp. 30-39.

L'Esperance, Wilfred; Nestel, G. and Fromm, D., "Gross State Product and an Econometric Model of a State", in Journal of the American Statistical Association, vol. 64, no. 327, Sept. 1966, pp. 787-807.

Pindyck, Robert S., Optimal Planning for Economic Stabilization: the application of control theory to stabilization policy, North-Holland Publising Co., 1973.

Pitchford, John D.; Turnovsky, S.J., Application of Control Theory to Economic Analysis, North-Holland Publishing Co., 1977.

Rausser, Gordon C., "Active Learning, Control Theory and Agricultural Policy", in AJAE, vol. 60, no. 3, Aug. 1978, pp. 476-490.

Wallich, Henry C., et al., "Application of Optimal Control, Discussion", from Papers and proceedings of the American Economic Association, vol. 66, no. 2, May 1976, pp. 356-360.

Environmental Concerns (Preservation, Valuation)

Arrow, K.J. and Fisher, A.C., "Environmental Preservation, Uncertainty and Irreversibility", in Quarterly Journal of Economics, vol. LXXXVIII, no. 2, 1974.

Cichetti, C.; Fisher, A. and Smith, V., "An Economic and Econometric Model for the Valuation of Environmental Resources", a paper presented at the Econometric Society Meeting in Toronto, 1972.

Ciriacy-Wantrup, S.V., "Benefit-Cost Analysis and Public Resource Development", in Economics and Public Policy in Water Resource

Development, Smith and Castle, ed.

Coomber, N.H. and Biswas, A.K., Evaluation of Environmental Intangibles: Review of Techniques, Environment Canada, Ottawa and Genera Press, P.O. Box 336, Bronxville, New York, 1972.

Council on Environmental Quality, The Seventh Annual Report, Government Printing Office, Washington, D.C., 1976, pp. 67-76.

Environmental Protection Agency, The Quality of Life Concept: A potential tool for decision makers, Office of Research and Monitoring, Environmental Studies Division, March 1973.

Fisher, A.C.; Krutilla, J.V. and Cichetti, "The Economics of Environmental Preservation", in American Economic Review, vol. LXII, no. 4, 1972.

Fisher, A.C.; Krutilla, J.V. and Cichetti, C.J., Alternative Uses of Natural Environments: The Economics of Environmental Modification, in Natural Environments, Krutilla, editor, The John Hopkins University Press, Baltimore, 1972, pp. 18-53.

Krutilla, J.V., "Conservation Reconsidered", in American Economic Review, vol. 57, Sept. 1967, pp. 777-786.

McInerney, John P., "The Simple Analytics of Natural Resource Economics", in Journal of Agricultural Economics (U.K.), vol. 27, no. 1, pp. 31-51, Jan. 1976.

Rausser and Howitt, "Stochastic Control of Environmental Externalities", Annual: Economic and Social Measures, vol. 4, 1975, pp. 271-279.

Smith, V.K., "Uncertainty and Allocation Decisions Involving Unique Natural Environments", Washington, D.C., Quality of the Environment Division, Resources for the Future, Disc. Paper no. D-21, 1978.

Viscusi, W.K. and Zeckhauser, R., "Environmental Policy Choice Under Uncertainty", in Journal of Environmental Economics and Management, vol. 3, 1976, pp. 97-112.

Walters, Carl J. and Hilborn, Ray, "Ecological Optimization and Adaptive Management", in Annual Review of Ecological Systems, vol. 9, 1978, pp. 157-180.

Walters, Carl J., "Optimum Escapements in the Face of Alternative Recruitment Hypothesis", Canadian Journal of Fish, 1980.

Untaxing Open Space: An Evaluation of the Effectiveness of Differential Assessments of Farms and Open Space, Prepared for the Council of Environmental Quality, April 1976, Stock #041-011-00031-9.

Investment (Optimal Decision Rules)

Arrow, K.J., "Optimal Capital Policy with Irreversible Investment", in Value, Capital and Growth, J.N. Wolfe, ed., Chicago, Aldine Atherton Publishers, 1968.

Arrow, K.J., "Optimal Capital Policy, The Cost of Capital and Myopic Decision Rules", in Annals of the Institute of Statistical Mathematics, vol. 16, 1964.

Arrow, K.J. and Kurz, M., "Optimal Growth with Irreversible Investment in a Ramsey Model", in Econometrica, vol. 38, March 1970, pp. 331-344.

Clark, Colin W., "Optimal Control Theory and Renewable Resource Management", Optimal Control Theory and its Application--lecture notes in Economics and Mathematical Systems, Part II, Springer-Verlag, Berlin, 1973, Proceedings of the 14th Biennial Seminar of the Canadian Mathematical Congress.

Goldman, S.M., "Optimal Growth and Continual Planning Revision", in Review of Economic Studies, vol. 35, 1968, pp. 145-154.

Judge, G.G., Day, R.; Johnson, S.R.; Rausser, G.C.; and Martin, L., Survey of Agricultural Economics: Quantitative Methods, vol. 2, Minneapolis, University of Minnesota Press, 1977.

Kalchbrenner, J.H. and Tinsley, P.A., "On the Use of Feedback Control in the Design of Aggregate Monetary Policy", from Papers and proceedings of the American Economic Association, vol. 66, no. 2, May 1976, pp. 349-355.

Kendrick, D., "Control Theory with Applications to Economics", in Handbook of Mathematical Economics, Arrow & Intrilligatorm, eds., Amsterdam: North-Holland Publishing Co., 1978.

Prescott, E.C., "Multi-Period Control Problem Under Uncertainty", Econometrica, vol. 40, 1972, pp. 1043-1058.

Rausser, G.C., and Hochman, E., Dynamic Agricultural Systems: Economic Prediction and Control, Amsterdam: Elsevier-North Holland Publishing Co. (Dynamic Economic Series), 1978.

Shell, Karl, Application of Pontryagin's Maximum Principle to Economics, H.W. Kuhn and G.P. Szego, eds., (Berlin: Springer-Verlag).

Stoleru, L.G., "An Optimal Policy for Economic Growth", in Econometrica, vol. 33, no. 2, April 1965.

Discount Rate

Myers, Norman, "Discounting and Depletion: The Case of Tropical Forests", in FUTURES, The Journal of Forecasting and Planning, vol. 9, no. 6, Dec. 1977, pp. 502-509.

Price, Colin, "To the Future: With Indifference or Concern,--The Social Discount Rate and Its Implications for Land Use", in Journal of Agricgltural Economics, vol. XXIV, no. 2, May 1973, pp. 393-397.

Hogg, H.Ċ.; Lau, L.; Garrod, P.V. and Vieth, G., "Selected Methods of Financial Analysis for Agricultural Investments", HAES, CTA, University of Hawaii, Departmental Paper 34.

Simulation (Modelling)

Fisher, A. and Krutilla, J., "Determination of Optimal Capacity of Resource Based Recreation Capacity", in Natural Resources Journal, vol. 12, no. 3, 1972, pp. 417-444.

Kendrick, D. and Taylor, L., "A Dynamic Non-Linear Model for Korea", in I. Adelman, Practical Approaches to Development Planning, John Hopkins Press, Baltimore.

Kendrick, D. and Taylor, L., "Numerical Solution of Non-Linear Planning Models", in Econometrica, May 1970.

Schecter, Mordecai, "On the Use of Computer Simulation for Research", in Simulation and Games, vol. 2, no. 1, 1971, pp. 73-88.

Smith, V.K.; Webster, D. and Heck, N., "Analyzing the Use of Wilderness", in Simulation Today, vol. 24, 1974, pp. 93-96.

South Eastern Wisconsin Regional Planning Commission, Technical Report:
Volume 1-A Land Use Plan Design Model. Model Development. Jan. 1968.
Volume 2-A Land Use Plan Design Model. Model Test. Oct. 1969.

Miscellaneous

Barlowe, Raleigh, Land Resource Economics, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1972.

Misham, E.J., Cost-Benefit Analysis, New and Expanded Ed.tion, Praeger Publishers, New York, a Division of Holt, Rhinehart and Winston, 1976.

Johnston, J., Econometric Methods, 2nd edition, McGraw-Hill Publishing Co., NY, 1972.

Hotelling, Harold, "The Economics of Exhaustible Resources," Journal of Political Economy, April, 1931, XXXIX, pp. 137-75.