AN ABSTRACT OF THE THESIS OF

Seong-Hoon Cho for the degree of Master of Science in Agricultural and Resource Economics presented on August 9, 1996.

Title: Opportunity Cost to Agriculture of Meeting Environmental Restrictions on Upper Klamath Lake, Oregon.

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Abstract Approved: ___

Richard M. Adams

The Klamath Basin in South Central Oregon has experienced several severe drought seasons in the past decade. Upper Klamath Lake is the principal water source of the basin. There are four competing users of water from Upper Klamath Lake; endangered species habitat in the lake, irrigation, instream flows (downstream of the lake) for fisheries, and wildlife habitat for migratory birds on the Lower Klamath and Tule Lake Wildlife Refuges.

The Bureau of Reclamation manages the storage and distribution of water in the lake. Below-normal precipitation during the last decade (particularly 1992 and 1994) in the Klamath River Basin and increased demand for water forced the Bureau to impose a strict program of balanced water distribution. Moreover, the endangered status of the Lost River and shortnose sucker in Upper Klamath Lake requires lake level management based on biological decisions by the U.S. Fish and Wildlife Service. The Operations Plan (OP) of the Bureau of Reclamation's Klamath Project for 1995 developed a water use guide to meet the U.S. Fish and Wildlife Service's 1992 Long

Term Biological Opinion (LTBO) which recommends minimum water levels in Upper Klamath Lake to protect the endangered sucker species. The LTBO mandates certain seasonal lake levels to preserve the ecosystem health of the lake.

The objective of this thesis is to assess the opportunity cost of the various lake level restrictions arising from the LTBO to agriculture, by comparing the effects of lake levels recommended by the LTBO with alternative lake levels. Another aspect of this assessment is to determine the most efficient agricultural use of available water, in terms of irrigation techniques, deficit irrigation and crop mixture.

The procedure relies on GAMS (General Algebraic Modeling System) to calculate the most efficient use of water for a series of representative farm models. Specifically, four representative farm models are designed to categorize and reflect the variations (soil, topography, and mixture of crops) among the farms of the Project. The amount of water available to the representative farm models is determined by a hydrological model based on the surface levels of the lake. Water availability is simulated with the model over a 73 year period. The representative farm models are cast as the linear programming (LP) models, whose objective function is to maximize the profit for each farm model, given different water supplies. The GAMS-LP models suggest efficient irrigation types and deficit irrigation levels, and predicts the profits of farm models.

The results of these farm models show first that the production (crop mix and acreage) of the representative farm models agrees with the actual farm activities of the basin. The optimal solution of the farm models suggests that an efficient allocation of water requires both alternative irrigation techniques and deficit irrigation. The results also indicate that maintaining lake levels suggested by the LTBO over the average of 73 water years, reduces profits to agriculture within the Project by about $ 2 million, annually. The steeply increasing marginal cost curve shows an increasingly heavier economic burden to agriculture as water use restrictions rise.

Opportunity Cost to Agriculture of Meeting Environmental Restrictions on Upper Klamath Lake, Oregon

by

Seong-Hoon Cho

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APPROVED:

Redacted for Privacy

Major professor, representing Agricultural and Resource Economics

Redacted for Privacy

Chair of Department of Agricultural and Resource Economics

Redacted for Privacy

Dean of Graduate School

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Seong-Hoon Cho, Author

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CHAPTER 1: INTRODUCTION

Upper Klamath Lake is the largest lake in the state of Oregon in terms of surface area. The Klamath Basin in which the lake lies is prone to periodic droughts. In spite of its size, the lake is susceptible to drought seasons because it is relatively shallow. The primary use of Klamath Lake water has been irrigated agriculture within the Klamath Project. Over 220,000 acres are irrigated in the Project. Extension of the Endangered Species Act (ESA) to the Lost River and shortnose sucker in the lake and a recent drought cycle have focused attention on the water allocation alternative of the basin. Specifically, contractual obligations to Project irrigation water users and the ESA ruling have confronted each other during the recent drought cycle.

Irrigation management decisions concerning alternative irrigation systems, use of deficit irrigation, and crop mix selection are of economic importance, even in the absence of ESA restrictions. For example, farmers may choose to plant less acreage and switch to high-efficiency irrigation types when water supplies are reduced.

The experience of the worst recent drought years, 1992 and 1994, indicates that neither the obligation to Project water users nor the absolute protection of endangered fish could be achieved without a compromise. The expected cost of the ESA lake restrictions to agriculture is one piece of the information needed to understand the potential for compromise. Information on the expected opportunity cost may allow authorities to make better decisions regarding water allocation in the basin.

1.1 Problem Statement

Disputes over scarce water supplies are becoming increasingly common in arid regions of the west. Within the Klamath Basin, there are at least four potential uses of water of Upper Klamath Lake and the Klamath River. For example, irrigators, Indian tribes, endangered species, and wildlife refuges all compete for the use of this water. The Klamath Project, operated by the Bureau of Reclamation, must first meet its needs for all the Klamath Project irrigators. However, recent drought cycles and the Endangered Species Act disrupted contractual obligations and created a crisis within the agricultural community. For example, about a third of the farmers in the Klamath Project got only half of their normal water supply from Upper Klamath Lake. Losses to agriculture and the community were estimated to be as high as $75 million in 1992, the worst drought year.

In 1988, the Endangered Species Act (ESA) extended its protection to two endangered fish; the Lost River sucker and the shortnose sucker in Upper Klamath Lake (Oregonian, 1991). In 1992 and 1994, the U.S. Fish and Wildlife Service required a reduction in irrigation water for the first time in the Project's 87 years. In addition to ESA concerns on the lake, the stock of salmon in the Klamath River and coastal streams has sharply declined in part due to recent drought cycles. The cost of this reduction to the fishing industry and local coastal economies is estimated at $100 million (Oregonian, 1993). The fall Chinook run of 1992 in the Klamath River was the smallest since record keeping began.

Upper Klamath Lake is the major source of water for six wildlife refuges. Migratory birds that winter in these refuges suffered from a lack of water, which caused an increase in avian diseases during the drought seasons. In 1994, water allocated from Upper Klamath Lake to National Wildlife Refuges was at its lowest level since 1930s. Only ten percent of which was needed to flood the refuge wetlands, was supplied.

Poor water quality of Upper Klamath Lake during periods of low lake levels is well documented (U.S. Army Corps of Engineers 1982; Kann and Smith 1993). Dissolved oxygen has increased the pH of the lake water to lethal levels. The improvement of pH is essential in order to protect fisheries. The volume and elevation of the lake has a direct effect on water quality in the lake. A reduction of the volume of the lake worsens water quality during the drought seasons. The lake level during the summer months of 1992 was the lowest recorded level of all time. Available habitat for fisheries is reduced as the lake level is lowered, particularly through reduction in shoreline rearing habitat of larval and juvenile endangered sucker species (Dunsman 1993; Buttner 1995).

Under increasing pressures for competing uses of water from the lake, it is important to understand and to determine the trade offs between lake levels for protection of endangered fish and the costs to agriculture. This requires an understanding of farm level water management responses to reduced water supply levels.

1.2 Objectives

The general objectives of this study are to measure the opportunity cost to agriculture for maintaining lake levels for the benefit of the endangered sucker fish and to identify alternative farm techniques to mitigate these costs under various water supply conditions. The specific objectives are to

1. Develop economic decision models of representative farms of the Klamath Project that reflect current crop and irrigation alternatives;
2. Estimate the hypothetical amount of water that would be supplied to the farm models over the last 73 years, under a range of lake level restrictions, including those recommended by the LTBO;
3. Estimate the expected opportunity cost to agriculture of the Klamath Project using the economic models of the representative farms under various water constraints, provided by the hydrological model.

For objective 1, four representative farm models are created, embodying suitable soil and crop mixtures. They are developed to capture the variations formed among farms in the basin. For objective 2, historical lake elevations and water inflows of the last 73 years are used to determine the water available to the representative farms of the basin, given different lake levels. For objective 3, the profits of the farms without water restriction are compared with average of historical profits under water restriction conditions associated with alternative lake levels. Agricultural losses for both individual farms and the entire Project due to restricted water supplies are calculated to measure the expected opportunity cost to agriculture.

1.3 Study Area and Scope

The study area of this thesis includes Upper Klamath Lake and the Klamath Project which relies on water from Upper Klamath Lake. Figure 1-1 shows the location of the Klamath Project. The Klamath Project is located on the Oregon California border in Oregon's Klamath County and California's Siskiyou and Modoc Counties.

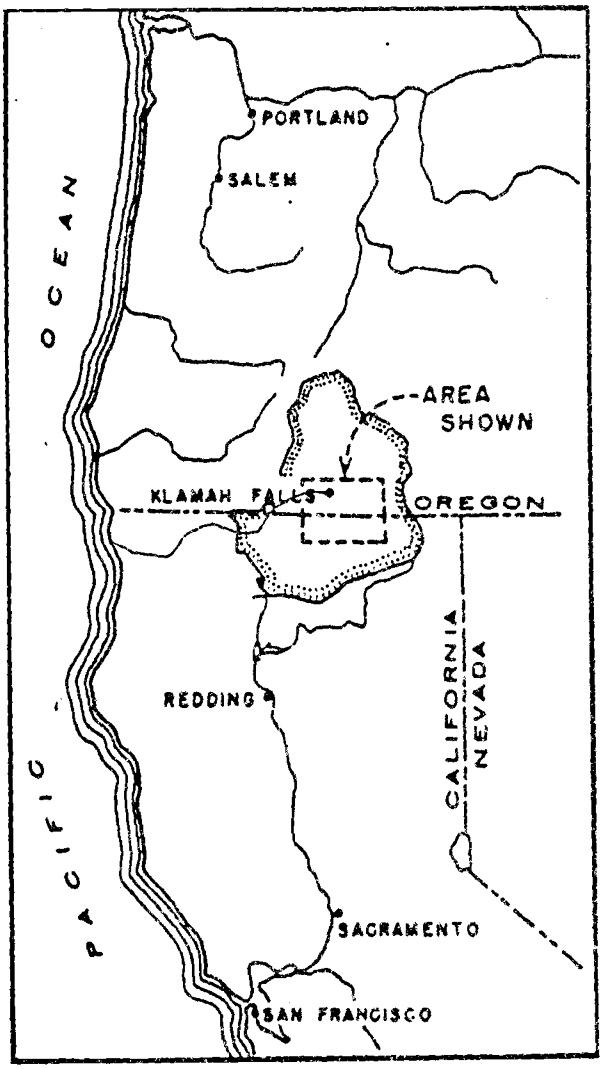


Figure 1.1 Location of the Klamath Project
(Source: U.S. Bureau of Reclamation, 1993)

Figure 1-2 shows the complex water drainage system of the Project. Two main sources supply the water for the Project. One consists of Upper Klamath Lake and the Klamath River, and the other consists of Clear Lake Reservoir, and Lost River, which are located in a closed basin.

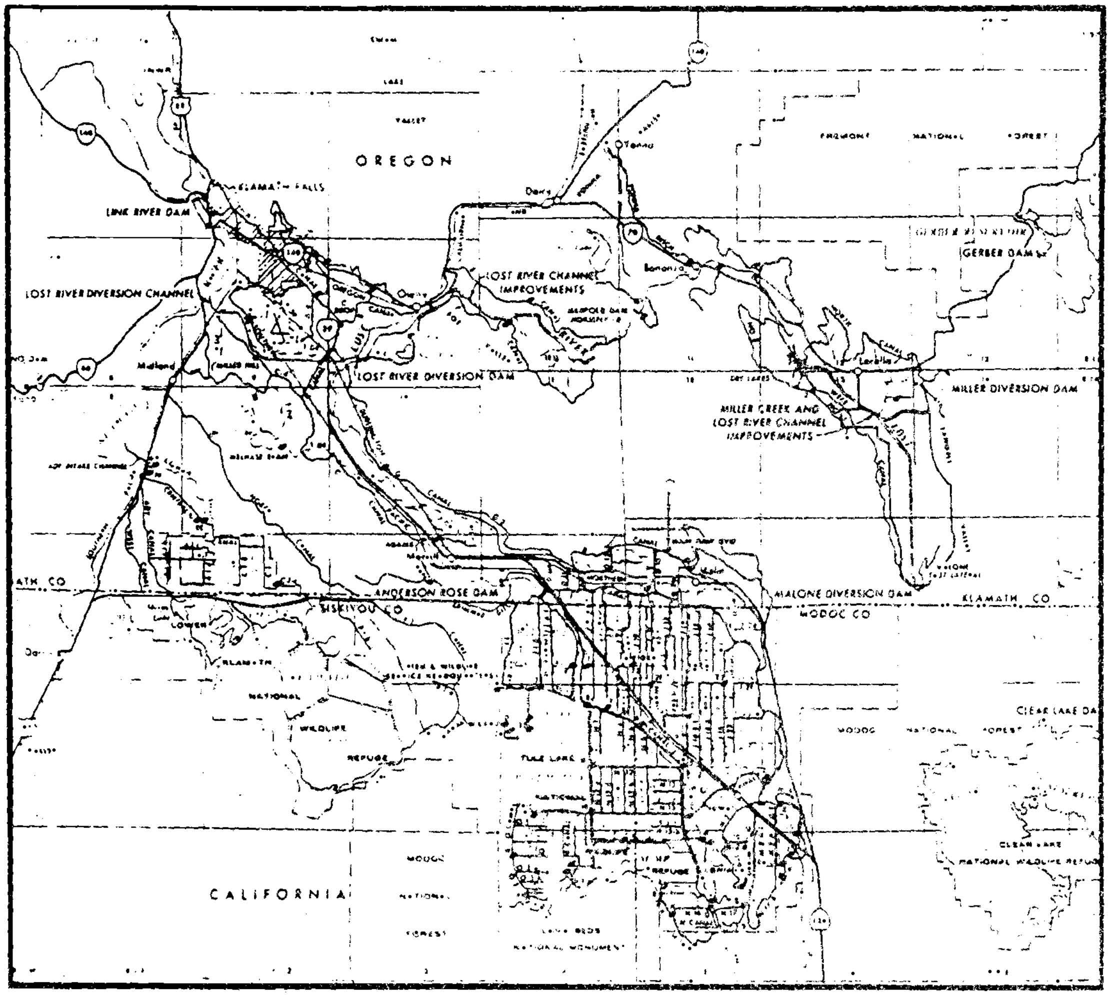


Figure 1.2 Klamath Project
(Source: U.S. Bureau of Reclamation, 1993)

The terrain varies from rugged, heavily timbered mountain slopes to rolling sagebrush benches and broad flat valleys. Most of the valleys of the Klamath Basin are high and comparatively flat (U.S. Bureau of Reclamation, 1993).

This analysis focuses on the way in which maintaining lake levels for the endangered fish affects agriculture within the basin. The effects of maintaining lake levels under the ESA on other users of lake water, such as downstream salmon production and the wildlife refuges, are not considered. Although the effects of reduced instream flows and water supplies on salmon runs and waterfowl are substantial, the focus here is only on direct effects of farm income. The volume and elevation of the lake ties the income of irrigators to the survival of endangered fish species within the lake.

Irrigation management decisions are a central part of this study. Alternative irrigation systems and deficit irrigation are included in the farm model to demonstrate the potential for water conservation and to mitigate against losses in profit. Analysis of irrigation system and deficit irrigation are stressed in this thesis because expected losses to irrigators, caused by higher lake level restrictions, can be reduced by optimal irrigation systems.

1.4 Thesis Organization

This thesis contains six chapters. Chapter two contains a discussion of the complex interrelationship between agriculture and the environment, including its physical, institutional, and technical dimensions. Chapter three deals with the economic assessment framework, including the representative farm models and their LP characterizations.

Chapter four is a description of the procedures of this research including solution procedures and sources of data. Chapter five contains the results and analysis of the simulations. The final chapter contains a summary and conclusions and points out the limitations of this thesis and the need for further study.

CHAPTER 2. PHYSICAL, INSTITUTIONAL, AND TECHNICAL DIMENSIONS

The focus of this research is agricultural production activity within the Klamath River Basin in Southern Oregon and Northern California. The region is characterized by cold, moderately wet winters and hot, dry summers. Elevations range from 4000 and 9000 feet, with precipitation rising with elevation (U.S. Bureau of Reclamation, 1993). Because of the high elevations, snowfall during the winter months is the main form of precipitation in the region. Snow melt from high elevation snowpacks maintains streamflows and is used for agricultural irrigation during the dry summer period.

Due to the hot and dry summers, there was very little agriculture in the basin prior to irrigation development. Large-scale agricultural development commenced with the Water Right Contract in 1905, which established the Klamath Project. There are four watersheds in the Project area: Klamath River, Clear Lake, Malone, and Gerber watersheds. The Klamath River watershed is the largest of the four watersheds and is the most important in terms of irrigation (U.S. Bureau of Reclamation, 1993). Within the Klamath Basin, the area below Upper Klamath Lake contains the bulk of the irrigated agricultural land and is the focus of this thesis.

2.1 Klamath River Watershed Characteristics

This watershed is the principal source of water of the Klamath Basin. It has a relatively complex water supply system with a number of competing uses for the water, including Indian Water Rights, hydropower, irrigation, fish and wildlife and recreation. The Pacific Power & Light Co. constructed Link River Dam on Upper Klamath Lake and it is regulated by the Bureau of Reclamation. "Contract No. 14-06-200-5075 allows Pacific Power to operate the dam in such a manner as to control the elevation of Upper Klamath Lake within defined limits, namely between elevation 4,137.0 and 4,143.3. Pacific Power also operates Iron Gate Dam on the mainstream Klamath River, approximately 50 miles downstream from Upper Klamath Lake. The Federal Energy Regulatory Commission (FERC) permit requires that the Power Co. maintain certain minimum flows below Iron Gate Dam into the Klamath River." (U.S. Bureau of Reclamation, 1993). In times of drought, the Bureau allows lower FERC flows. This has happened in 1968, 1979, 1981, 1988, 1991, 1992, and 1994.

2.1.1 Soils

Soil characteristics are a primary determinant of crop yield. Sixty-three soil series are found in Klamath county and sixty- five soil series are found in Siskiyou and Modoc counties: There are twenty-one soil associations (grouping of soil series) on which the majority of cultivated crops are grown within the Klamath Basin (USDA Soil Conservation Service. 1985;1994). In this study, these twenty-one associations are further grouped into four general soil classifications according to their crop potential. These four general soil classes in the basin are the basis for the representative farm models discussed below. Four farm types are constructed to represent the dominant crops, soil classes, and territorial subregions within the Klamath Basin. The four farm models are also designed to represent the best management of the soils of the basin. The first class of soil is characterized by moderately deep or very deep, moderately well drained to very poorly drained soils on bottom land, terraces, and flood plains. The second is characterized by moderately deep or very deep, somewhat poorly drained and poorly drained soils that formed in alluvial and lacustrine sediment. The third class is characterized by shallow to very deep, excessively drained and well drained soils on benches, terraces, and low hills, and the fourth is characterized by very deep to shallow and excessively drained to very poorly drained loamy or sandy soils. Each soil class encompasses several soil associations. The following represents the characteristics of the soil associations in each farm model.

Soil Classification (Farm Model) I: This soil classification consists of Heneley-Poe-Laki, Tulana-Algoma-Teeters, and Fordny-Calimus. The Heneley-Poe-Laki soils are located in Modoc Point and on low terraces along Lost and Klamath Rivers. Slopes range from 0 to 2 percent. These soil associations are used mostly for irrigated pasture and alkali tolerant crops such as barley, alfalfa, and hay. Irish potatoes are grown in some cultivated areas of Poe and Laki soils. The Tulana-Algoma-Teeters soils are on the drained bottom of Lower Klamath Lake land bordering the flood plain of the Klamath River. Slopes are 0 to 1 percent. These soils are mostly cultivated for irrigated pasture, barely, oats, and cereal hay. Irish potatoes are cultivated on these soil types. Finally, the

Fordney-Calimus soils are in the Modoc Point region and on terraces drained by the Lost and Klamath Rivers. Slopes are 0 to 35 percent. These soils are used mainly for Irish potatoes. Alfalfa hay, wheat, oats, barley, pasture, and cereal hay are also grown.

Soil Classification (Farm Model) II: The classification consists of one soil association, Malin-Scherrard-Pit. Malin-Scherrard-Pit soils are on flood plains and low terraces along Lost River. Slopes are 0 to 1 percent. These soils are used mostly for irrigated pasture and cereal hay.

Soil Classification (Farm Model) III: The third classification involves agricultural production in the Modoc-Harriman-Dodes association. Modoc-Harriman-Dodes soils are primarily on terraces in the Klamath Valley. Slopes are 0 to 15 percent. These soils are mainly used for alfalfa, hay, cereal hay, wheat, oats, barley, and pasture. Irish potatoes are grown on some soils where slopes are less then 5 percent.

Soil Classification (Farm Model) IV: This soil classification consists of soils in the Capjac-Tulebasin-Lamath, Poman-Fordney, and Laki-Lalos associations. Capjac-Tulebasin-Lamath soils are dominant in the Lower Klamath and Tule Lake Basins. Slopes are 0 to 1 percent. All areas are protected from flooding by dikes. Poman-Fordney soils are located at elevations range from 4,050 to 4,500 feet. These soils are used mainly for alfalfa, wheat, barley, sugarbeets, potatoes, and onions. Finally, Laki-Lalos soils are on the eastern side of the Lower Klamath Basin and Oregon-California border line, northeast of the Tulelake.

2.1.2 Crops

The three counties of the Klamath Project include 220,000 acres of irrigated land. No single crop dominates irrigated acreage within the basin. For the 1985 - 1994 period, 31% of the land were allocated to barley, 24% to irrigated pasture, 19% to alfalfa, 11% to potatoes, 8% to other hay, 4% to wheat, 2% to sugarbeets, and 1% to onion (U.S. Bureau of Reclamation,1994). Onions are grown only in the Tule Lake Irrigation District, which is on the California side of the basin. The distribution of crops is a function of soil and climatic conditions.

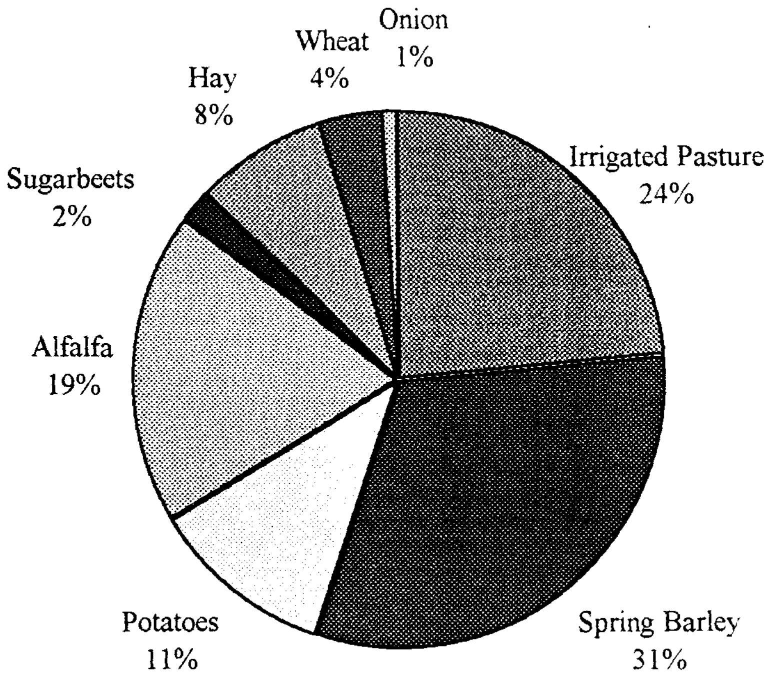
Table 2.1 Crop Acreage and Gross Crop Value (Average of 1985-1994)

Crop	*Acre*	*Value ($1,000)*
Irrigated Pasture	44,000	1,950
Spring Barley	59,000	12,400
Potatoes	20,500	47,300
Alfalfa	35,000	15,800
Sugarbeets	3,400	5,100
Hay	15,000	1,970
Winter Wheat	7,500	2,300
Onions	1,500	2,500
Total	185,900	89,320

Table 2.1 shows the average acreage and values of major crops in the basin for the period of 1985-1994. An average of 44,000 acres of irrigated pasture has been harvested in the basin over the last 10 years. Pasture can be grown on any of the agricultural soil types. Pasture represents commercial pastures for cattle ranches, dairy farms, small farms, and homesteads. Only irrigated pasture is considered here. While pasture is assumed to

have a productive seven-year life, including the establishment year, a well-maintained pasture can often be kept in production longer than seven years (Taylor, 1992). Barley is the largest crop by acreage in the basin and averages 59,000 acres over the last 10 years. Potatoes are a high value crop grown on an average of 20,500 acres in the basin over the 10 year period. Potatoes are usually grown in rotation with sugarbeets and alfalfa. Alfalfa acreage average has about 35,000 acres over the last 10 years. Like hay, alfalfa is a perennial crop. Typically, alfalfa has a four-year productive life, in addition to an establishment year. Sugarbeets are another high-value crop of localized importance. Average acreage has been 3,400 acres. The other crops in the basin are hay (15,000 acres) and winter wheat (7,500acres). Hay is a mixture of native grass and planted grass. The yield is typically one cutting per year. Grass hay is usually a mixed-seeded grass (not alfalfa) that may be cut and dried or pastured, or may be in rotation with grains and/or row crops. Winter wheat is grown on well-drained soils. It is either cropped by itself or grown in rotation with oats (Turner, 1995c). Onions are a high-value crop grown primarily in the Tule Lake Irrigation District. Acreage harvested has been approximately 1,500 acres. Figure 2.1 shows the average crop allocations of the last 10 years in the basin.

Figure 2.1 Distribution of Acreage by Crop



Livestock production , mostly beef cattle, is an important component of the agricultural economy within the Klamath Basin. In 1992, livestock products accounted for approximately 40 percent of total agricultural value in the three counties of the Klamath Basin. In this analysis, cattle or other livestock productions are not included in the farm models. Hay and pasture, which are frequently fed on-farm to cattle as part of integrated crop- livestock enterprises, are instead valued at market prices (as per ton or per AUM). These crops would have greater value in an integrated livestock operation. As a result, total agriculture value is underestimated in this study.

2.1.3 Hydrological Characteristics: Water Quality and Quantity

Upper Klamath Lake is the primary water source of the Klamath Basin. Transfers of water from Upper Klamath Lake provide water for the irrigation for most crops within the Klamath Basin. Water from the lake is also delivered to the Tule Lake and Lower Klamath Lake National Wildlife Refuges for wildlife habitat. Releases from the lake are the source of Klamath River instream flows from Link River to Iron Gate Dam.

There are two outlets from the Upper Klamath Lake: flows into the Klamath River and flows into the A Canal. Link River Dam controls releases from the lake. Pacific Power owns and operates facilities that regulate flows of the Klamath River below the Link River Dam. The flows in the Klamath River below Iron Gate Dam (about 50 miles below the lake) are dependent on release from Link River Dam, since the Upper Klamath Lake is the only major water source above Iron Gate Dam. Releases into the A Canal are also controlled by the Bureau of Reclamation. Water from the A Canal is delivered to Klamath Irrigation District. Some districts within the Project utilize return flows from the Klamath Irrigation District. The rest of the irrigation districts receive water from the Klamath River and Lost River (U.S. Bureau of Reclamation, 1993).

The volume and elevation of Upper Klamath Lake has a direct effect on the physical and chemical status of water in the lake. Available habitat for fisheries is reduced as the lake level is lowered, particularly through reduction in shoreline rearing habitat of larval and juvenile endangered sucker species (Dunsmoor 1993; U.S. Bureau of Reclamation 1995d). In addition, a reduction of elevation and volume of the lake worsen water quality. For example, the volume and depth of the lake affects temperature, which is a critical parameter for the survival of most fish species. Shallow lakes show more rapid heating and cooling than deep lakes. Also, algal bloom initiation is linked to temperature increases. Algal blooms are associated with poor water quality. Lake temperature also affects algal growth rates and oxygen consumption rates (respiration). Phosphorus is also a water quality concern, since phosphorus determines algal productivity and biomass, which influences water quality and fisheries. Phosphorus in shallow lakes tends to elevate pH (Welch 1992; Sondergaard 1988; Jacoby et al.1982). Elevated pH can increase phosphorus flux. These physical, chemical, and biological processes increase the probability that fisheries in the lake experience stresses or death due to inadequate amounts of dissolved oxygen, as lake levels decrease (Kann, 1993).

2.2 Technical Dimensions: Irrigation and Water Management Issues

2.2.1 Irrigation System

Irrigation management decisions are based on technical feasibility and economic consideration. Each farmer chooses the most appropriate irrigation techniques based on the available resources, such as soil, climate, water topography, labor, capital, and management skills . Each irrigation system employs diversified sequences of labor, capital, water, energy, and other resources. Recent irrigation system studies have emphasized the notions of irrigation scheduling, peak load irrigating, and deficit irrigation (Berbardo and Whittlesey; Dudek and Horner; Harris and Mapp; and Taylor, et al.). In this thesis, alternative irrigation systems and deficit irrigation are included in the representative farm models to capture the range of potential irrigation techniques in the Klamath Project. These systems are described below.

Flood irrigation is a common irrigation method in some parts of the basin. Water may be supplied continuously or intermittently, usually from a ditch, siphon tubes or gated pipes. Relatively low-value crops such as barley, alfalfa, hay, wheat, and pasture, use this method. Flood irrigation has the lowest field efficiency of available irrigation techniques. However, runoff from one field or district is usually used by lower field or districts. Flood irrigation requires no energy and little capital, hence it is viewed as a relatively low-cost irrigation method.

Wheel-line irrigation is one of the sprinkler irrigation methods. The sprinkler devices give uniform application of water over the field and hence provide higher efficiency than flood irrigation. The lateral line is mounted on wheels with a pipe forming the axle. The wheel height is determined by height of the crop. Nearly all crops can be irrigated within the design parameters of a wheel-line system. The method requires less labor but a higher skill level and higher cost than flood.

Center-pivot irrigation is the other sprinkler irrigation method. It consists of a single sprinkler lateral supported by a series of towers or bridge-type trusses. These systems are suitable for irrigating most field crops but have a higher cost than flood or wheel line system. Higher profit crops, such as sugarbeets, potatoes, and onions, typically use center-pivot system. These systems have low operating costs but, once installed, require skilled labor. Deficit irrigation schemes may utilize any irrigation techniques of water application (Bernardo and Whittlesey; Taylor, et al.). Irrigation water is supplied to the crops at amounts less than needed by the crops to produce maximum yields. Thus, limited water application schemes yield less output by consuming less water. If water or energy costs are very high, net economic profits may be increased with deficit irrigation (Blair, 1990).

2.2.2 Alternative Irrigation Techniques

To investigate the economics of water conserving irrigation systems, alternative irrigation practices were added to the models. The alternative irrigation practices were chosen based on the availability of previous irrigation system efficiency research and water conservation potential. Also, only those systems that were technologically feasible for the Klamath Basin were included. Specifically, in addition to wheel line and center-pivot systems for the major high value crops (sugarbeets, potatoes, and onions), three other primary irrigation technologies were considered. The primary water-conserving irrigation alternatives included surge-furrow, surge-furrow-pumpback, and drip systems. The use of theses alternatives reduces water application required to meet crop needs by reducing deep percolation and run off.

Surge furrow is a recent development for furrow irrigation. The cost and water efficiency of the system are lower than centerpivot system. The unique feature of surge furrow is its repeated cycling of water from first one set to another and then back. This process lowers the water infiltration rate, especially on the first irrigation (by the process of wetting and recession) reduces percolation depth, and produces a more uniform distribution of water over the entire furrow length. Surge furrow is capable of high uniformities. Uniformities of 90% are not uncommon. The potential of benefit varies significantly with soil type.

The addition of a pumpback system to each furrow technology is another variation. Enough water must be applied with any furrow system such that the bottom end of furrows receive adequate water. The efficiency of a furrow system can be increased by collecting this runoff and redistributing the water. Additional cost is required to set up the pumpback system to the surge furrow. A ditch constructed along the bottom of the field collects the runoff and accumulates it in a pond. The water can be pumped from the pond and reapplied to crops.

Drip irrigation is the slow application of water through small emitter openings to the soil surface. Rates of discharge for wide spaced individual applicators are generally less than 15 lph (3 gph). Lateral types are usually classed as individual emission point or line source laterals. Individual emission point laterals are primarily used in widely spaced crops. However, with equipment to retrieve, store and reinstall laterals and closer emitter spacing, this type lateral is gaining acceptance in closely spaced crops. The system costs substantially more than other irrigation systems, although the water efficiency is the highest.

2.2.3 Water Management

The Bureau of Reclamation administers the Klamath Project according to authority granted by the Reclamation Act of 1902. Any development of water in the Klamath Basin must also operate under the laws of the states of Oregon or California. All senior water rights, trust obligations to the Tribes, protection of species listed under the Endangered Species Act, contractual obligations to water users within the Project, and obligations under the Migratory Bird Treaty Act and other federal laws that control the protection of wildlife area in the basin must be satisfied prior to developing any new uses of water. There are four leading legislative or regulatory principles that guide water management in the Klamath Basin.

(1) Endangered Species Act: The Lost River and shortnose suckers are listed as endangered species in the Upper Klamath Lake and the Klamath River. Steelhead in the Klamath River have been proposed to be listed as a threatened species. Therefore, management of the Upper Klamath Lake to meet specific lake levels and management of Klamath River flows must be considered for the endangered and threatened species. (U.S. Bureau of Reclamation ,1995b)

(2) Fulfilling Federal Trust Responsibility to Tribes within the Klamath River Basin: This includes the responsibilities to protect and manage Tribal natural resources. Fishery resources in the Klamath River as well as management of the Upper Klamath Lake are all a part of these resource management responsibilities. Water management includes specified flow regimes, water quality, and lake levels.

(3) Providing Deliveries of Project Water: The Bureau of Reclamation provides water to meet its contractual obligations to Project water users, including A, B, and C

contractors. Approximately 220,000 acres of agricultural lands are served by the Klamath Project. Water management includes efficient delivery and allocation of water for the benefit of agricultural production within the Project.

(4) Conserving Wetland and Wildlife Values: To provide sufficient habitat for migratory birds of several wildlife refuges within the Upper Klamath River Basin, water is supplied by the Bureau of Reclamation and the states under the Migratory Bird Treaty Act. The water requirements are specified under the Kuchel Act, and federal reserved water rights.

2.2.4 Water Disputes

About 1,200 farmers make their living off the 220,000 acres of irrigated land of the Klamath Basin and ultimately depend on water from the Upper Klamath Lake for their livelihood. They produce potatoes, onions, sugarbeets, grain, and hay with a gross revenue of $94 million. Water from Upper Klamath Lake also serves 40,000 acres on the Tule Lake and Lower Klamath National Wildlife refuges, which provide habitat to waterfowl migrating on the Pacific Flyway. During the winter months, the refuges feature the largest concentration of bald eagles in the continental United States (Oregonian, 1992b). Upper Klamath Lake is also a source of the water for Klamath River, which is Northern California's most important commercial Chinook salmon stream. Ocean fishermen in towns between Florence, Oregon and Monterey, California fish for salmon stocks which spawn in Klamath River tributaries. Hoopa and Yurok Indian tribes, who have fishing rights in the Lower Klamath River, depend on the water from the Upper

Klamath Lake to maintain salmon and steelhead runs (Oregonian, 1993). The Klamath Basin is similar to many areas of the west; there is increasing competition for available water supplies in the Klamath Basin: this includes irrigators, Indians and fishermen who depends on salmon produced by the Klamath River, migrating waterfowl that use the Lower Klamath and Tule Lake Wildlife Refuges and finally endangered species such as , Lost River and shortnose suckers of Upper Klamath Lake.

2.2.4.1 Endangered Species

The nation's most powerful environmental law, the Endangered Species Act (ESA), extended its protection to two endangered fish: the Lost River sucker and the shortnose sucker in the Upper Klamath Lake in 1988. The ESA of 1973 provides a means for conserving various species of fish, wildlife, and plants that are threatened with extinction. Actions that might jeopardize listed species include direct and indirect effects, as well as cumulative effects of other actions. Under the rule of ESA, the U.S. Fish and Wildlife Service had to cut back irrigation water of the Klamath Basin to protect two endangered fish in 1992 and 1994. The Bureau of Reclamation, which manages the storage of water in the lake and other reservoirs for distribution to farmers in the Klamath Basin, withheld water from farmers to maintain minimum flows for salmon and to protect spawning areas for endangered sucker fish in the Upper Klamath Lake.

2.2.4.2 Irrigators

Farmers of the basin hold priority water rights. Beginning in 1902, the Klamath Project converted the lakes, land, marshes, and rivers within the Project into a highly regulated system of canals and reservoirs. Today, about 500,000 acre-feet of water per year are diverted from the Upper Klamath Lake for irrigation. Congress adopted the bi-state compact, the Klamath Compact Commission, in 1957 (Oregonian, 1993). By the rules of the Klamath Project, the bureau must first meet its obligations to all Klamath Project irrigators. Recent drought cycles have focused attention on the competition for Upper Klamath Lake water. The worst drought year of the recent period (1992) disrupted contractual irrigation withdrawals and created a crisis within the basin. Specifically, about a third of the farmers in the Klamath Basin got only half of their normal water from the Upper Klamath Lake. Approximately 80,000 acres were fallowed with some estimates of losses exceeding $30 million.

The magnitude of the drought effects varied by water class within the Project. For example, the U.S. Bureau of Reclamation did not supply a full allotment of water to the 106,000 acres of Class A farmland in the basin for the first time in the Project's 87 years. In addition, water for 61,000 acres of Class B farmland was reduced by 50 percent to keep endangered fish alive in the Upper Klamath Lake (Oregonian, 1992a). As a result of the drought and the U.S. Fish and Wildlife Service's decision to maintain levels of the Upper Klamath Lake, irrigators of the Klamath Basin suffered economic damage due to reduced crops. These losses focused attention on future drought incidents. According to one study, the worst case scenario of a complete cut-off of Upper Klamath Lake water for agriculture use would result in agricultural losses of $105 million and 3,116 jobs in the Klamath Basin (Oregonian, 1992c).

As a consequence of the recent ESA / drought effects, two Oregon ranchers and two state irrigation districts sued the government for "over-enforcing" the ESA in 1992. In 1993, a federal judge threw out the suit, ruling that the ranchers lacked legal standing to sue under the environmental law. That decision was upheld in August, 1995 by the 9th U.S. Circuit Court of Appeals. In March 1996, the U.S. Supreme Court decided to hear arguments in an Oregon case over whether people with an economic stake can use the ESA to accuse the federal government of overprotecting a species (Oregonian, 1996).

2.2.4.3 Salmon Resources

Since the recent droguth cycle, the Pacific Fishery Management Council has sharply reduced salmon fishing in the ocean as well as in the Klamath River and coastal streams. The cost of this reduction to the fishing industry and local coastal economies is estimated at $100 million (Oregonian, 1993). The 1992 fall Chinook run in the Klamath River was the smallest since the California Department of Fish and Game began keeping records. Congress acknowledged the precarious situation of anadromous fish in 1986 when it passed the Klamath Act, creating the Klamath River Basin Fisheries Task Force and gave it $21 million to develop a 20 year plan for salmon restoration. The task force reviewed the circumstances of the salmon runs of the Klamath River and concluded that no restoration plan would be effective unless it included the problems in the Upper Klamath Basin, source of the mainstream flow. "No matter what we do, we don't restore salmon in the Klamath River until we do something about the quality of the water coming out of the Upper Klamath Lake," said fisheries consultant, Kier (Oregonian, 1993). There remains some hope of saving the fish without destroying the economy of the Klamath Basin by developing more efficient irrigation methods, increasing water storage in the Upper Klamath Lake, and fencing cattle out of streams.

2.2.4.4 Wildlife Habitat of the Lower Klamath Lake and Tule Lake National Wildlife Refuges

The National Wildlife Refuges in the basin get water from Upper Klamath Lake. During the drought years, the Bureau of Reclamation was forced to make tough decisions regarding the balancing of water supplies between farmers, fish and wildlife. Far less lake water was allocated to the refuges than they actually needed. In 1994, water allocated from the Upper Klamath Lake to the refuges, which was at its lowest level since the 1930s, was 6,000 acre feet. This is only 10 percent of the amount needed to flood refuge wetlands (Oregonian, 1994). The U.S. Fish and Wildlife Service, the agency responsible for running the six Klamath Basin waterfowl refuges, has almost no authority over refuge water. The Bureau of Reclamation has primary authority over how much water reaches the refuge.

2.2.5 Water Rights

Water rights in the basin are of two types: the rights of Klamath Indians and those of landowners outside the Klamath Indian Reservation. The rights of the Klamath

Indians for use of water on the Klamath Indian Reservation lands have a priority dating from October 14, 1864, the date of the Treaty establishing the Reservation. These rights are prior to any others in the Upper Klamath River Basin (U.S. Bureau of Reclamation, 1995a). In 1905, the state of Oregon initiated water rights for the operation of the Klamath Project. Any project after 1905 is considered of lower priority according to the contract. Two types of contract were used on the Project: a Repayment contract and a Warren Act contract. The Main and Tule Lake Division used a Repayment contract and the secondary right used the Warren Act. The Project included three classes of irrigators mainly according to their dates of contract. First Priority of Use (Class A) were those lands under the Repayment Contract of 1902. The Van Brimmer Irrigation District contracted with the United States to supply water to replace the district's supply from Lower Klamath Lake. It has a pre-1905 priority. The Klamath Irrigation District contract was signed in 1905 and has the highest priority of record after that of the Van Brimmer District. Tule Lake Irrigation District has a contract dated September, 1956 but has the same contractual right as the Act of 1902. The Class A water rights are contracted for the beneficial use without any specific contractual amount.

Table 2.2 Class A Water Rights

Name of Agency or District	*Source of Water*	*Year of Contract*	*Total contract Acres*
Van Brimmer Irrigation District	Lost River	1902	3,622

Table 2.2 (Continued)

Klamath Irrigation District	A Canal, Diversion Canal	1905	38,982
Tule Lake Irrigation District	J Canal, Klamath Irrigation District return flows	1956	41,570

The second Priority of Use (Class B) are those lands under the Warren Act of 1911. The Warren Act clearly cited the priority of the Class A Project. Article 1 of the Act states that "---, preserving a first right to lands and entry under the project." The Enterprise Irrigation District receives water from the A Canal, contracted October, 1920. The Klamath Drainage District receives water from the Klamath River below the Link River Dam, contracted August, 1921. The Maline Irrigation District receives water from the D-Canal, contracted September, 1922. The Shasta View Irrigation District receives water from the Van Brimmer Canal, contracted in October, 1922. The Sunnyside Irrigation District receives water from the Van Brimmer Canal, contracted October, 1922. The Pine Grove Irrigation District receives water from A-Canal, contracted June, 1936. The Colonial Realty Company-Westside Improvement District receives water from Tulelake Sump and J-1 lateral, contracted October, 1936. The Plevna District Improvement Company receives water from the Klamath River below the Link River Dam, contracted April, 1940. The Emmitt District Improvement Company receives water from the Klamath River below the Link River Dam, contracted December, 1947. The Midland District Improvement Company receives water from the Klamath River below the Link River Dam, contracted February, 1952.

The Poe Valley Improvement Company receives water from the Lost River below Harpold Dam, contracted July, 1953. The Ady District Improvement Company receives water from the Klamath River below the Link River Dam, contracted August, 1954. The Klamath Basin Improvement District receives water from the Klamath Irrigation District system, contracted April, 1962

Table 2.3 Class B Water Rights

Name of Agency or District	*Source of Water*	*Year of Contract*	*Contractual Amount (ac ft)*	*Total Contract Acres*
Enterprise Irrigation District	A Canal, Klamath Irrigation District	1920	3.0	2,981
Klamath Drainage District	Klamath River	1921	1.3	19,229
Maline Irrigation District	D Canal	1922	2.5	3,507
Shasta View Irrigation District	Van Brimmer Canal	1922	3.0	4,141
Sunnyside Irrigation District	Van Brimmer Canal	1922	2.5	595
Pine Grove Irrigation District	A Canal	1936	2.5	927
Colonial Reality	Tulelake Sump and J-1 lateral	1936	2.5	1,190
Plevna District Improvement Company	Klamath River	1940	3.0	523
Emmitt District Improvement Company	Klamath River	1947	3.0	424

Table 2.3 (Continued)

Midland District Improvement	Klamath River	1952	3.0	581
	Lost River	1953	2.5	2,636
Ady District Improvement Company	Klamath River	1954	Beneficial Use	435
Klamath Basin Improvement District	Klamath Irrigation District	1962	3.0	10,342

The third Priority of Use (Class C) receives water from the P-Canal and the Lost River areas, according to contracts granting temporary water rental to individual farmers. During the recent drought cycle, class C deliveries were eliminated.

CHAPTER 3. ECONOMIC ASSESSMENT FRAMEWORK

The cornerstone of the economic assessment performed here are the representative farm models. These are decision models, designed to capture the key aspects of the economic and technical problems facing irrigators in the Project. The representative farm models are built on the assumption that irrigators maximize profit, subject to the availability of water and other fixed resources of the Klamath Basin. Although the economic assumptions used in such models may not perfectly match the goals and information needs of the "average" farmer, the models constitute a benchmark against which to judge present irrigation management strategies for agriculture.

In this chapter, the profit maximization goal is first reviewed in terms of its importance for production behavior. Next, the linear programming method, used to optimize the representative farm models, is discussed Together, the economic models and their linear programming representation constitute the economic assessment framework.

3.1 Economic Optimization

The entrepreneur is usually free to vary the levels of both cost and output, and his ultimate aim is the maximization of profit rather than the solution of constrained-maximum and -minimum problems. The total revenue of an entrepreneur who sells his output in a perfectly competitive market is given by the number of units he sells multiplied by the fixed unit price (P) he receives. His profit (Π) is the difference between his total revenue and his total cost: $\Pi = PQ - C$ (Henderson and Quandt, 1980). A firm's decisions are constrained by available technology as embedded in a production function with 's' outputs and 'm' inputs. The production function is usually expressed as:

$$F(Q_1 \ldots\ldots\ldots Q_s, X_1, \ldots, \ldots, X_m) = 0 \qquad (1)$$

where Qs are outputs and Xs are inputs.

The assumptions are:

1) Continuous first and second-order partial derivations are non-zero,

2) 'F' is an increasing function of the Q's and a decreasing function of the X's, and

3) The function is strictly convex over a relevant domain.

Profit is the difference between total revenue and the expenditure on all inputs. It is written as:

$$\Pi = \sum_{i=1}^{s} p_i q_i - \sum_{j=1}^{n} r_j x_j \qquad (2)$$

where Π is the profit,
r_j is cost of x_j,
q_i are outputs,
x_i are inputs, and
p_i is price of q_i

The maximization of profit, subject to technical constraints given by the production function, is written as:

$$J = \sum_{i-1}^{s} p_i q_i - \sum_{j=1}^{n} r_i x_i + \lambda F(q_1, \ldots, x_n) \qquad (3)$$

where J is maximum profit with constraints and
λ is a Lagrange Multiplier

The partial derivatives are equal to zero to meet the sufficient conditions of profit maximization:

$$\frac{\partial J}{\partial Qi} = Pi + \lambda\, Fi = 0 \qquad i=1, \ldots, s \qquad (4)$$

$$\frac{\partial J}{\partial Xi} = -Rj + \lambda Fs{+}j = 0 \qquad j=1, \ldots, n \qquad (5)$$

$$\frac{\partial J}{\partial \lambda} = F(Q1, \ldots, Xn)=0 \qquad (6)$$

where Fi (i=1, . . . , s+n=m) is the partial derivative of equation (1) with respect to its argument. Manipulation of equation (4) results in

$$\frac{P_j}{P_k} = \frac{F_j}{F_k} = -\frac{\partial q_k}{\partial q_j} \qquad j, k = 1, \ldots, s \qquad (7)$$

The RPT for every pair of outputs must equal the ratio of their prices, that is

$$\frac{r_j}{r_k} = \frac{F_{s+j}}{F_k} = \frac{\partial q_k}{\partial X_j} \text{ or } r_j = p_k \frac{\partial q_k}{\partial X_j} \qquad k=1, \ldots, s \qquad j=1, \ldots, n \quad (8)$$

The value of the marginal product of each input is equated to the input price. The first-order conditions become

$$\frac{r_j}{r_k} = -\frac{\partial X_k}{\partial X_j} \qquad j, k = 1, \ldots, n$$

The second-order conditions for the maximization of profit are that

$$\begin{vmatrix} \lambda F_{11} & \lambda F_{12} & F_1 \\ \lambda F_{21} & \lambda F_{22} & F_2 \\ F_1 & F_2 & 0 \end{vmatrix} > 0, \ldots, (-1)^m \begin{vmatrix} \lambda F_{11} & .. & \lambda F_{1m} & F_1 \\ .. & .. & .. & .. \\ \lambda F_{m1} & .. & \lambda F_{mm} & F_m \\ F_1 & .. & F_m & 0 \end{vmatrix} > 0$$

since $\lambda < 0$ from equation (4), the second order conditions require that

$$\begin{vmatrix} F_{11} F_{12} F_1 \\ F_{21} F_{22} F_2 \\ F_1 \; F_2 \; 0 \end{vmatrix} < 0, \ldots, \begin{vmatrix} F_{11} .. F_{1m} F_1 \\ .. \; .. \; .. \; .. \\ F_{m1} .. F_{mm} F_m \\ F_1 .. F_m \; 0 \end{vmatrix} < 0$$

These conditions are satisfied by the assumption that the production function is strictly quasi-convex.

3.2 Linear Programming

Linear programming has been widely used in evaluating the economic efficiency of agricultural decisions for more than 30 years. Hazell and Norton noted that linear programming (LP) is a method of determining a profit maximizing combination of farm enterprises that is feasible with respect to a set of fixed farm constraints. The first application of linear programming in the field of agricultural economics was done by Hildreth in 1948 (Hildreth and Stanely). Its application has spread rapidly in the 1960s and 1970s. There have been a number of methodological advances in LP as well. The improvements have been in the direction of incorporating more economic theory and more reality into the models.

Larson and Supalla (1978) used an LP model to analyze policy options directed at controlling water in agriculture. Yaron and Dinar (1982) used an LP model to evaluate changes in a farm's income by generating new irrigation scheduling activities. Baker and McCarl (1982) used an LP model to explore the consequences of alternative degrees of time aggregation within a Corn Belt farm. Cory, Evans, Leones, and Wade used an LP model of irrigated farmers in Arizona to analyze changes in groundwater use and net returns to agriculture over a 36 year period, 1990 to 2025. Eckert and Wang (1993) used an LP decision model to determine the response of farmers in Conejos county, Colorado to changes in water supply levels.

Farmers must make decisions concerning what combinations of crops to produce by what kinds of methods, subject to their resource constraints. Traditionally, farmers depended on their experience and input and output price information to make their decisions. Formal optimization techniques such as linear programming are being applied by extension economists to help farm-level decision making. The primary use of LP based economic evaluation continues to be in policy research where interest is on hypothetical changes in resources or other parameters.

In this analysis, LP is used to solve a series of representative farm models. The specification requirements for each representative farm are 1) the alternative farm activities, units of measurement , resource requirements, and any variable constraints, 2) fixed resource constraints, and 3) net returns of variable costs. Mathematically, these specification requirements are written as:

$$\text{Max } Z = \sum_{j=1}^{n} C_j X_j$$

$$\text{such that } \sum_{j=1}^{n} a_{ij} X_j \leq b_i \text{ all } i = 1 \text{ to } m$$

$$\text{and } X_j \geq 0, \text{ all } j = 1 \text{ to } n,$$

where X_j = acreage of crops grown
C_j = forecast gross margin of unit
a_{ij} = quantity of i th resource to produce one unit of j th activity
bi = amount of the i th resource available

The model is solved to find the level of X_j that maximizes Z (proft), subject to resource constraints. Fundamental assumptions of an LP model are 1) an objective function is to be maximized or minimized, 2) there is at least one nonzero constraint, 3) a finite number of activities are considered 4) all resource endowments, resource constraints, objective function coefficients are known, 5) resources used and activities produced are in fractional units, 6) units of same resources are identical 7) there are no interaction effects between activities, and 8) the gross margin and resource requirements are constant.

3.3 Solving Linear Programming Problem

In the case of a representative farm decision model, solution of a linear programming problem determines the optimal activity of the farm. Mathematically, it is solved by finding the optimal level from an infinite number of farm plans that satisfy the resource constraints. The solution of the LP model can be easily represented in geometric terms. Consider the following LP model.

$$\begin{array}{lll} \max Z = 5X_1 + 6X_2 & & \\ \text{such that} \;\; 2X_1 + 3X_2 \leq 12 & \text{resource } b_1 \\ \text{and} \qquad\quad 6X_1 + 5X_2 \leq 30 & \text{resources } b_2 \\ \qquad\qquad\quad X_1, X_2 \geq 0 & \end{array}$$

The linear constraints of the problem are illustrated as in Figure 3.1. Each constraint, being linear, is represented by a straight line which intersects the axes at the maximum possible level of each activity with the assumed supply of the associated resource. The area under the intersection of the constraints in Figure 3.1 defines the feasible region of production. The production possibility frontier (the surface of the feasible regions) defines the highest levels of production obtainable under the combinations of available resources.

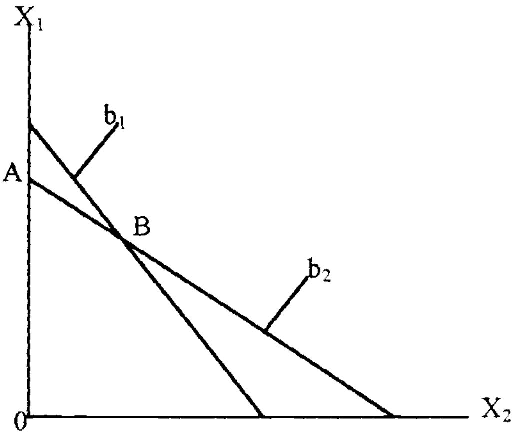


Figure 3.1 Linear Constraints

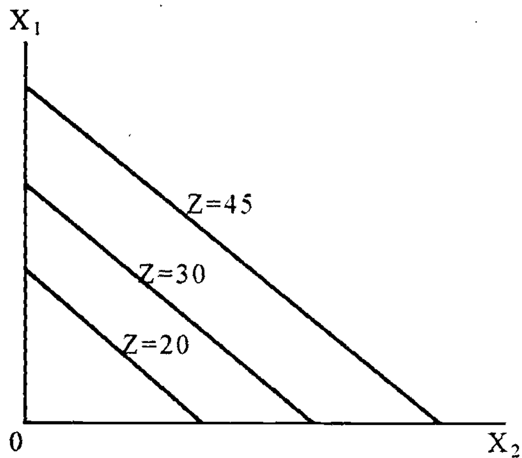


Figure 3.2 Isorevenue Lines

The objective function is also linear and can be characterized by a family of isorevenue lines.In Figure 3.2, a family of isorevenue lines corresponding to Z=20, Z=30, and Z=45 is presented. The isorevenue lines are always parallel, with those corresponding to larger values lying above and to the right of the ones of lower values. Maximization of

Z subject to the constraints of X_1, X_2 can be obtained when both graphs are superimposed as in a Figure 3.3.

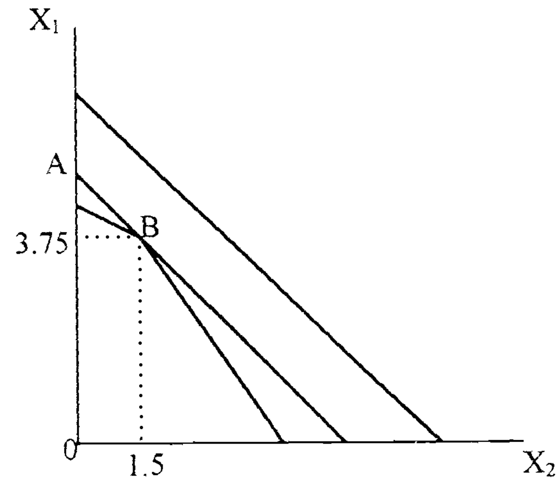


Figure 3.3 Optimal Solution of LP

The highest isorevenue line touches the production possibility frontier at B. Therefore, point B is the optimal solution to this linear programming problem. For this example, its solution is 3.75 units of X_1 and 1.5 units of X_2 and yields a total gross margin of 22.75 (Hazell and Norton).

3.4 Principles of the Simplex Method

GAMS solves linear programs using a reliable implementation of the primal simplex method. The simplex method, as developed by G. B. Dantzig, is an iterative procedure for solving linear programming problems expressed in standard form. In addition to the standard form, the simplex method requires that the constraint equations be expressed as a canonical system from which a basic feasible solution can be readily obtained. The general steps of the simplex method are as follows.

1. Start with an initial feasible solution in canonical form.

2. Improve the initial solution if possible by finding another basic feasible solution with a better objective function value. At this step the simplex method implicitly eliminates from consideration all those basic feasible solutions whose objective function values are worse than the present one.

3. Continue to find better basic feasible solutions improving the objective function values. When a particular basic feasible solution cannot be improved further, it becomes an optimal solution and the simplex method terminates.

3.5 Representative Farm Models

Agricultural lands within the Klamath Basin are composed of various types of soil, topography, drainage and other edaphic features. Accordingly, the mixture of crops may differ across them. The four farm models are designed to categorize the variations among the farms of the basin. Farm model I represents fairly productive soil groups along the Lost and Klamath Rivers within the basin. In this region, soils such as Poe-Laki and Fordney-Calimus are suitable for potatoes, which are a highly profitable crop. Farm model II is characterized by less productive soils and is cultivated mainly for pasture and hay. This farm model also characterizes relatively small and less profitable farms. Areas of this model represent the flood plains and low terraces along the Lost River. Farm model III represents the areas of Klamath Valley. Some areas of the valley feature fairly steep slopes ranges and water is used for less water intense crops. The quality of the lands in this model lie between that of models I and II. Some limited lands of this type are suitable for potatoes but are not included as a crop alternative in this model. Farm model IV is intended to represent almost all cultivable lands of the Tule Lake Basin and the Lower Klamath Lake area. This type is characterized by relatively large farms on fertile soils. Highly profitable crops, such as potatoes, sugarbeets, and onions are grown here. The model includes the only farms in the basin where onions are grown. Below are listed the main agronomic and edaphic criteria by which the representative farm models have been defined:

Model I

ACREAGE	400 acres; represents 57,000 acres in the Project
MAIN CROPS	Potatoes, Sugarbeets, Barley, Alfalfa, Other Hay, and Wheat
LOCATION	Along Lost, Klamath River, and Lower Klamath Lake
SOILS	Poe-Laki, Tualana-Algoma, and Fordney-Calimus

Model II

ACREAGE	300 acres; represents 62,000 acres in the Project
MAIN CROPS	Irrigated Pasture and Other Hay
LOCATION	Along Lost River
SOILS	Malin-Scherrard-Pit, Heneley, and Teeters

Model III

ACREAGE	500 acres; represents 36,000 acres in the Project
MAIN CROPS	Alfalfa, Other Hay, Wheat, Barley, and Irrigated Pasture
LOCATION	Klamath Valley
SOILS	Modoc-Harriman-Dodes

Model IV

ACREAGE	600 acres; represents 37,000 acres in the Project
MAIN CROPS	Alfalfa, Wheat, Barley, Potatoes, Onion, and Sugarbeets
LOCATION	Lower Klamath and Tule Lake Basin
SOILS	Capjac-Tulebasin-Lamath, Poman-Fordney, and Laki-Lalos

The LP versions of these representative farms were built using GAMS (General Algebraic Modeling System). Specifically, GAMS is used to solve each model for the efficient use of water, given the amount of water available at various lake levels. The objective for the program is profit maximization of each farm model. By using equations and variables coded in blocks, GAMS creates LP models that are rationally consistent and relatively easy to debug. The parameters can be easily and quickly adjusted. The GAMS-LP model embodies the input / output and cost variables of the farm. The farm models are also characterized by water constraints, land-size constraints for each crop, alternative irrigation types, and deficient irrigation techniques. Water constraints for each farm model are linked to the elevation of Upper Klamath Lake in the hydrological model.

3.6 Linear Programming Version of the Representative Farms

The four representative farms are cast and solved as linear programming problems. In each model, the objective is to maximize total revenue minus total cost subject to constraints. The revenue of each acre is computed by multiplying maximum yield, price, and a yield by percentage term. The yield percentage term is a function of irrigation level (degrees of deficit irrigation) determined by the water supply and water yield function. The constraints of the models are water availability, aggregated land use, available acres for each crop, and irrigation techniques. The GAMS program solves the objective function, which is the maximization of net profit subject to all constraints. The profit maximizing function is written as follows.

$$\text{Max } \Pi = \sum_{i=1}^{4}\sum_{j=1}^{8}\sum_{a=1}^{8}(YIELD_j * PY_{ija} * PRICE_j - COST_{ija}) * ACRES_{ija}$$

where Π = annual net profit
i = irrigation types i = flood, wheel-line, center-pivot, and fallow
j = different crops j = barley, wheat, alfalfa, other hay, pasture, sugarbeets, potatoes, and onion
a = deficit irrigation a = .65, .70, .75, .80, .85, .90, .95, 1
$YIELD_j$ = crop yield per acre
PY_{ija} = percent of potential yield
$PRICE_j$ = price of crop for each unit
$COST_{ija}$ = cost of crop by irrigation types and deficit irrigation
$ACRES_{ija}$ = irrigated acres by crops, irrigation types, and deficit irrigation

The GAMS program simply finds the combination of acres of crops, irrigation types and deficit irrigation options that maximizes the objective function, or net profit. Constraints, such as available water, available acreage for each crop, and farm size, are determined exogenously.

Fallow acreage was used as one of the irrigation options, where no yield with fixed cost is involved. The fallow acreage is expected to be chosen when the water supply is so low that farmers are better off fallowing some acreage to "free up" water for more profitable crops. The available total acreage of each crop in each model varies, based on actual acreage of irrigated lands in the basin during the last 10 years. The maximum irrigated acreage for each crop over the last 10 years is used as the acreage constraint for that crop. The production of high value crops, such as sugarbeets, potatoes, and onions are frequently constrained by contracts between irrigators and processors, which tends to stabilize those crops. The constraints allow the cropped acreage to be fallowed up to the level of the acreage of each crop during drought years. The common constraints of the model are written as:

$$\sum_{i=1}^{4}\sum_{j=1}^{8}\sum_{a=1}^{8} ACRES_{ija} \leq \text{LUSE}$$

$$\sum_{i=1}^{4}\sum_{j=1}^{8}\sum_{a=1}^{8} W_{ija} * CWR_j * ACRES_{ija} \leq \text{WUSE}$$

where W_{ija} = multiple of crop evapotransporation applied to crops
CWRj = crop water requirement
$ACRES_{ija}$ = irrigated acres by crops, irrigation types, and deficit irrigation
LUSE = size of a representative farm
WUSE = water supply

The acreage constraints of each crops for each model are written as

Model I

$$\sum_{i=1}^{4}\sum_{a=1}^{8} ACRES_{alfalfa,i,a} \leq .28*\text{LUSE}$$

$$0 \leq \sum_{i=1}^{4}\sum_{a=1}^{8} ACRES_{hay,i,a} \leq .21 * \text{LUSE}$$

$$0 \leq \sum_{i=1}^{4}\sum_{a=1}^{8} ACRES_{barley,i,a} \leq .39 * \text{LUSE}$$

$$0 \leq \sum_{i=1}^{4}\sum_{a=1}^{8} ACRES_{potaoes,i,a} \leq .13 * \text{LUSE}$$

$$0 \leq \sum_{i=1}^{4}\sum_{a=1}^{8} ACRES_{sugarbeets,i,a} \leq .08 *\text{LUSE}$$

Model II

$$0 \leq \sum_{i=1}^{4}\sum_{a=1}^{8} ACRES_{hay,i,a} \leq .94* \text{LUSE}$$

$$0 \leq \sum_{i=1}^{4}\sum_{a=1}^{8} ACRES_{pasture,i,a} \leq .26 * \text{LUSE}$$

Model III

$$\sum_{i=1}^{4}\sum_{a=1}^{8} ACRES_{alfalfa,i,a} \leq .16 * \text{LUSE}$$

$$0 \leq \sum_{i=1}^{4}\sum_{a=1}^{8} ACRES_{hay,i,a} \leq .46 * \text{LUSE}$$

$$0 \leq \sum_{i=1}^{4}\sum_{a=1}^{8} ACRES_{barley,i,a} \leq .10 * \text{LUSE}$$

$$0 \leq \sum_{i=1}^{4}\sum_{a=1}^{8} ACRES_{pasture,i,a} \leq .40 * \text{LUSE}$$

$$0 \leq \sum_{i=1}^{4}\sum_{a=1}^{8} ACRES_{wheat,i,a} \leq .06 * \text{LUSE}$$

Model IV

$$\sum_{i=1}^{4}\sum_{a=1}^{8} ACRES_{alfalfa,i,a} \leq .18 * \text{LUSE}$$

$$0 \leq \sum_{i=1}^{4}\sum_{a=1}^{8} ACRES_{barley,i,a} \leq .51 * \text{LUSE}$$

$$0 \leq \sum_{i=1}^{4}\sum_{a=1}^{8} ACRES_{wheat,i,a} \leq .10 * \text{LUSE}$$

$$0 \leq \sum_{i=1}^{4}\sum_{a=1}^{8} ACRES_{sugarbeets,i,a} \leq .11 * \text{LUSE}$$

$$0 \leq \sum_{i=1}^{4}\sum_{a=1}^{8} ACRES_{potatoes,i,a} \leq .22 * \text{LUSE}$$

$$0 \leq \sum_{i=1}^{4}\sum_{a=1}^{8} ACRES_{onions,i,a} \leq .12 * \text{LUSE}$$

As shown by the constraints above, alfalfa does not include a fallow acreage activity in any of the models, because alfalfa is a perennial with a four productive year life. The GAMS-LP models allocate water and acreage efficiently, generate optimal profits with the given resources, and also choose the most efficient irrigation types and deficit irrigation levels. The models thus assume a level of information that may not duplicate the activities of real farms in the Klamath Basin. Within the models, irrigators are assumed to be able to switch to the water saving irrigation types and to choose deficit irrigation levels when they face a lack of water. They are also assumed to be able to switch to the lower cost irrigation type and lower (or no) deficit irrigation levels when they have a relatively high water supply. These changes are assumed to take place instantly and without transaction costs.

CHAPTER 4. PROCEDURES AND DATA

This chapter summarizes the procedures used to implement the representative farm models and to estimate the cost of maintaining lake levels recommended by the long term biological opinion (LTBO) to agriculture, as well as alternative lake levels. A brief description of general background and procedures is presented first. It is followed by the derivation of crop yields for use in the representative farm models. The following section illustrates hypothetical water supplies that would have been delivered to farms during the last 73 years if lake levels had been maintained according to LTBO recommendations. The next segment outlines how the expected cost to agriculture of alternative lake levels can be derived from the outputs of the representative farm models. It also reveals expected opportunity cost to the agriculture of the basin for different options of lake levels. The marginal cost curve is established by using various levels of expected opportunity cost for different lake levels, including levels recommended by the LTBO. Finally, alternative irrigation techniques are added to the farm model to investigate the substituting of model outcomes to the type of technology used in irrigation. This analysis would also test the potential economies of water conserving irrigation systems.

4.1 General Procedures

The research in this thesis can be characterized as a general three-part simulation: (1) economic farm modeling of the Klamath Basin to represent four distinct farm types found in the basin, (2) hydrological modeling and estimation of the hypothetical water supply of the last 73 years under alternative lake levels, including that level recommended by the LTBO, and (3) estimation of expected opportunity cost to agriculture using the models from (1) and the outputs from (2) under various water constraints of the farm models. Specifically, the procedure can be broken down into the following steps:

1) establishing a classification of soils and crops for the Klamath Basin;
2) creating representative farms embodying suitable soil and crop mixtures;
3) constructing profit maximizing farm models in GAMS;
4) estimating the amounts of water supplied to the farm models over the last 73 years while meeting lake levels recommended by the LTBO;
5) solving farm models with variable water amounts;
6) assessing the opportunity cost of different lake levels;
7) developing a marginal cost curve representing costs to agriculture.
8) investigating the economies of water conserving irrigation system by adding alternative irrigation practices.

The representative farm models are based on different soil types which are suitable for different crop mixtures. The identification of comparable soil associations is important to the assembly of representative farm models. Crops compatible with the group of soil associations represent the crop alternatives for each of the models. The farm models are also based on actual farming practices and technology of the basin in recent years. The models are built on the assumption that the farmers in the basin have sufficient knowledge of efficient farm practices and are putting this knowledge into practice. The farm models attempted to show the most efficient resource allocation while closely reflecting the actual practice of farm activity in the basin. The different elevations of the lake are converted to different water supply levels for the farm models. The actual lake elevations of the last 73 years, together with the output from the farm models under the water supplies associated with each lake level, indicate the expected opportunity cost to agriculture of the different lake levels. By running the farm models with different lake level options, a marginal cost curve is established. By examining a range of lake levels, the models will indicate how the opportunity cost is increased by increasing the level of the lake.

4.2 Sources of Data

Agricultural production data for Klamath Basin crops were obtained from enterprise budgets (by O.S.U. Extension Service) of south central Oregon. The enterprise budgets estimate the typical economic costs and returns of producing crops in a particular region. The variable costs (inputs, machinery fuel, and lube) and fixed costs (depreciation, interest, land, and insurance) which are collected from enterprise budgets, are used for each representative farm model. The data for production and cost used here represent 1994 and 1995 costs. The different irrigation techniques which were available for each crop in the region are included as alternative irrigation systems in each farm model. Flood and wheel-line irrigation types were commonly used for crops such as barley, wheat, alfalfa, other hay, and pasture. The wheel-line and center-pivot irrigation types were used for crops such as sugarbeets, potatoes, and onion. When a range of water supply options was given, the most profitable irrigation types were chosen. Cost data available in the enterprise budgets were limited to the irrigation technique most commonly practiced. The cost of alternative irrigation techniques had to be calculated based on cost information associated with that irrigation type as well as an alternative crop.

Crop price data were collected from the Crop Report, Klamath Project (U.S. Bureau of Reclamation, 1994). The average price of the last 3 years was used. Yield data were collected from the Soil Survey of Klamath, Siskiyou, and Modoc Counties, and keyed to different soil types. Yield data were corroborated with data from the budgets. The collected yield data were assumed to be the yield level attained with 100% of the water supply needed for each crop. The water-yield function was used to establish yield levels at varying water application levels. The actual acreage of irrigable soil classes of the basin was obtained with the help from Marcia Brett, professor in the department of Crop and Soil Sciences at Oregon State University. She used the GIS (Geographical Information System) method to identify the soil components and to measure the acreage for each soil class. Only the acreage for irrigable soil classes was used in this thesis. The irrigable soil classes were identified through a soil survey which was done by the Soil Conservation Service.

4.3 Crop Yield and Water Supply Modeling

An important aspect of this analysis is modeling the effects on yields of alternative irrigation techniques and application levels. To include this yield effect requires a water-yield function for each crop. The yield per acre for each crop using different irrigation techniques was adopted from the water-yield function developed by Connor, in his Ph.D dissertation. Specifically, a water-yield function was created to estimate the relationship between water supply and yield for different irrigation techniques. The GAMS program was used to generate the relationship. The water-yield function was used to estimate the effect of irrigation system efficiency, such as deep percolation, on crop yield. By using different application levels of water, the program estimates the percent of a crop's potential yield level. The maximum yield was available when water was not limited. The percent of a crop's potential yield was used to determine the water-yield relationship of different irrigation alternatives using regression techniques. The model generated the deficit irrigation technique available by calculating the percent of potential yield depending on the amount of water application. The output from Connor's model, the percentage of potential yield by multiple of crop [1]evapotranspiration to crop, was used for the regression of the quadratic function. The NLP model was used for the quadratic function.

$$PY_{ija} = \beta_{0i} + \beta_{1i}W_{ija} + \beta_{2i}W_{ija}^2$$

where PY_{ija} = percent of potential yield
W_{ija} = multiple of crop evapotranspiration applied to crops
β_{0i} = regression intercept
β_{1i} = change in PY given W_{ija}
β_{2i} = change in PY given W_{ija}^2
i = irrigation types *i* = flood, wheel-line, center-pivot, and fallow
j = different crops *j* = barley, wheat, alfalfa, other hay, pasture, sugarbeets, potatoes, and onion
a = level of deficit irrigation *a* = .65, .70, .75, .80, .85, .90, .95, 1

[1] Evapotranspiration is one of the primary elements of the hydrologic cycle. It represents the primary use of water by a growing crop or vegetation, and is strongly influenced by the nature and amount of canopy, water content of the root zone and local weather conditions. Evaporative demand is characterized by both atmospheric variables and the aerodynamic and radiative properties of the particular plant and soil environments. The loss of water through plants is mainly by transpiration through stomates, although evaporative demand also results in some direct evaporation of moisture from leaf and soil surfaces. The relationship between transpiration and evaporative demand is dynamic and complex. Basically, when the soil-water content reaches approximately 50 % of the available water holding capacity in the root zone, then the available water begins to govern evapotranspiration rather than atmospheric demand (U.S. Bureau of Reclamation, 1995c).

The W_{ija} is obtained by

$$W_{ija} = 1/ EF_{ij} * a$$

where EF_{ij} = water use efficiency of crops using different irrigation types.

Eight different deficit irrigation levels were used, with 5 percent intervals. The five percent interval was chosen because it offered a better representation of the water-yield function than other intervals, as shown in several trials. Lower levels than 65 % were ignored because there is no incentive to farm with the low yields, associated with such a high level of deficit irrigation and because the accuracy of Conner's function, decreases at those levels.

4.4 Hydrological Model[2]

The Upper Klamath Lake is the major source of irrigation water in the Klamath Basin. While there are other, minor sources of irrigation water in the basin, the Upper Klamath Lake was assumed to be the only source of irrigation water in this analysis. The LTBO determined a specific acceptable lake level for each month, which was intended to protect the endangered fish. The maintenance of these monthly lake levels, especially during certain critical months (June, July, and August) ensures the greatest probability of adequate dissolved oxygen levels for fish. These months also correspond to the period of greatest irrigation demands.

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[2] The hydrological model was developed by assistance of Paul Montagne from Department of Civil Engineering in Oregon State University.

Historically (prior to the LTBO), there were no restrictions on the lake level. The historical average water supply for irrigators during the critical months is compared with the restricted water supply for the maintenance of the lake level by the LTBO. The target lake levels by the LTBO are 4142.4 feet through June, 4141.25 feet through July, 4140.17 feet through August, and the targeted average of three months is 4141.3 feet. Historical data on lake levels are available for the period 1922 to 1994. The lake levels of those 3 months for the last 73 years were compared with the lake levels for those months under the LTBO. The historical records show that water levels during the critical months have been both higher and lower than the LTBO target levels. For the month of June, 45 out of 73 years revealed lower lake levels than the LTBO lake level. For the months of July and August, 40 out of 73 years had lower lake levels than the LTBO lake level. If the LTBO lake level had been enforced during these years of low lake levels, irrigators would have faced a reduction in water supplies. The estimated loss to agriculture due to a lower water supply is calculated using the economic farm models. The average of the profit losses suffered during those years is interpreted as the opportunity cost of the LTBO.

Knowing how much water has been available to irrigators of the Klamath Basin because of changes in the elevation of the Upper Klamath Lake is essential to this research. The estimation of the water supply for the basin is done by using the relationship between the elevation of the Upper Klamath Lake and the amount of the water made available to agriculture. First, historical data of the elevation of Upper Klamath Lake of last 73 years for the critical months were collected. The target lake levels by the LTBO for the critical months were drawn from the report, 1995 Operations Plan of the Klamath Project

(U.S. Bureau of Reclamation, 1995b). These target lake levels are established based on the analysis of water quality data presented by the Klamath Tribes. Second, the water storage capacity of the lake was approximated using the elevation of the lake. Specifically, the Bureau of Reclamation provides data linking lake elevation to the amount of water storage in the lake. The estimate of water storage capacity according to the elevation of the lake was established by Bureau of Reclamation employing many factors influencing the water storage level of the lake. Simple linear regression analysis was performed here to compute the relationship between storage capacity of the lake (as the dependent variable) and elevation of the lake (as the independent variable). The computed equation is written as:

$$\text{Storage of the lake (acres feet)} = -300771198 + 72715 * \text{Elevation of the lake (feet)}$$

Elevations during the critical months of the last 73 years were converted to the storage of the lake for each month by the above equation. By plugging the LTBO lake levels into this equation, the water storage capacity under LTBO restrictions is computed. The computed storage of the LTBO lake level for each critical month minus the computed storage of the lake for each critical month of the last 73 years gives us the difference in water storage between the LTBO lake level for each month and the lake level for each critical month of the last 73 years. A positive value from the calculation indicates that the lake level for a particular month was lower than the LTBO lake level and that more water was used than would have been allowed under LTBO restrictions. The phrase "inadequate water supply" is used here, referring to those years in which amount of the water available to agriculture violates the LTBO. Negative values from the calculation indicates that maintaining the LTBO lake level would have been feasible without reducing the water supply to irrigators in the basin, in those years. The water amount of the negative number is called "adequate water supply". For the month of June, the lake provided an inadequate water supply in 45 out of 73 years and for the months of July and August, the water supply was inadequate in 40 out of 73 years.

Water flows from the Upper Klamath Lake through two channels: the A Canal and the Link River Dam release. The water through A Canal supplies irrigation water for the Klamath Basin. The water through the Link River Dam goes to Klamath River. The inadequate water supply is also assumed to flow from the Upper Klamath Lake through these two separate channels. Since the water through the A Canal supplies irrigation water to the Klamath Basin, the inadequate water supply for the irrigation of the Klamath Basin is the proportion of inadequate water supply that goes through the A Canal. The proportion of water flow through the A Canal and the Link River Dam release has been fairly stable over time. The inadequate water supply use through A Canal for each critical month of the year is calculated by multiplying the proportion of the A Canal water and the amount of inadequate water supply for each critical month of the year. The percentage of inadequate water supply by the irrigators of the Klamath Basin for each critical month of the year can be calculated by multiplying the average proportion of the outflow for each critical month and the amount of inadequate water supply through the A Canal by the irrigators of the Klamath Basin, divided by the average amount of water by flowing through the A Canal release. Hence, the percentage of inadequate water supply to the average A Canal release for the critical month of the year is calculated as

$$\text{Percentage of inadequate water supply to the average A Canal release} = \frac{\text{Inadequate water supply of A Canal} * \text{Proportion of the outflow for each critical month}}{\text{Average A Canal release for each critical month}}$$

The hypothetical levels of water supply for each farm model (under conditions of the LTBO) are calculated using the historical data of the percentage of inadequate water supply to the average A Canal release for the critical months of the year. For this calculation, the average of the percentages for the critical 3 months were used. They are calculated as

Water supply of the year for each farm while maintaining LTBO lake level =
(1 - Average of 3 months for the proportion of inadequate water supply to average A Canal release) * Water supply of the base case of each representative farm model

The "base case" is defined as the situation where irrigation districts receive their contractual water supply without exceeding the LTBO supply level; i.e. in years when water is plentiful, and LTBO target levels can be maintained without restrictions. The water supply of the base case of each representative farm is determined by the average of the water duty contracted between the Bureau of Reclamation and irrigation districts of the basin. There are 3 classes of water rights in the basin as mentioned in the background section; class A, B, and C. The average water use restriction for class B contracts is used because it is the only class with a specific contractual amount of water. Class A is defined as "beneficial use" and class C is entitled to use the rest of the water after class A and B. The average contractual amount of class B users by irrigation districts is 2.69 acre feet. The 2.69 acre feet is the base case water supply. The water supply of the base case for each representative farm is calculated by multiplying 2.69 acre feet by the size of the farm.

The water supply of the base case is 1076 acre feet of water for model I, 807 acre feet of water for Model II, 1345 acre feet of water for model III, and 1614 acre feet of water for model IV.

4.5 Assessment of Opportunity Cost

The hypothetical water supply for the average of most critical months is established for the last 73 years for each model. By plugging these different levels of water supply into the water constraint factor in the representative farm models developed earlier, the model solves for the most efficient irrigation techniques and also computes the profit attainable by practicing these optimal irrigation techniques. The loop command was used to run each model with many different levels of water supply constraints

The historical profits for each farm, based on the hypothetical water constraints by the LTBO, are calculated. The average of the historical profits for each farm, based on water constraints by the LTBO is obtained and is assumed to be the average profit of each farm operating under LTBO restrictions. The average profit of each farm under the hypothetical water supply is compared with the profit of each farm with the water supply of the base case. The profit of each farm with the base case is greater then the historical average profit under the LTBO, since the supply of water with the LTBO is smaller then the supply of water with the base case. The difference of the two profits for each model is the opportunity cost to each farm, when the supply of water is restricted by the lake elevations targeted by the LTBO. The opportunity cost for each farm is used to predict the opportunity cost of all irrigated lands in the Klamath Project. Aggregate opportunity cost is estimated by multiplying the opportunity cost per acre for each representative farm model by the number of acres of the actual farm types within the Klamath Basin Project.

The same computations of the opportunity cost were undertaken for lake levels both lower and higher than those recommended by the LTBO. The average of LTBO lake levels for the critical three months (June, July, and August) were 4141.3 ft. The opportunity costs of maintaining elevations lower than 4141.3 ft (at 4140.9 ft, 4140.3ft, 4139.9ft, and 4139.3 ft) were calculated as was the opportunity cost at lake levels higher than 4141.3 ft (at 4141.9 ft and 4142.3 ft). The higher lake levels can suggest the shape of the marginal cost curve.

CHAPTER 5: RESULTS AND IMPLICATIONS

The main objectives of this thesis are 1) to identify optimal irrigation techniques for agriculture in the Klamath Basin under alternative water supply conditions and 2) to assess the opportunity cost to agriculture of maintaining Upper Klamath Lake levels for the benefit of the endangered sucker fish and other fish and wildlife species which utilize the lake. Chapters three and four presented the framework for performing this assessment. The results and their implications for water management are presented in this chapter.

This chapter is divided into six sections. The first section contains a summary of GAMS model results for the four representative farm models under an "unrestricted" water supply schedule. This set of results constitute the "base case" solutions against which the effects of alternative water supply levels will be judged. Specifically, the base farm models provide information regarding the most efficient irrigation technique, optimal crop mixtures, and expected profits under historical water allocation. The second section presents outputs of the hydrological model. These outputs provide a series of water supply levels or schedules for each representative farm during the critical summer irrigation months (June, July, and August) over the last 73 years. This set of water supply levels correspond to a range of alternative lake levels, including the level recommended by the long term biological opinion (LTBO), as well as several alternative levels above and below the LTBO levels. The third section presents the results from the four representative farm models, under the range of alternative water supply levels predicted by the hydrological model. Like the base case, these model outputs includes optimal technology, crop mixture, and profit of each representative farm, under conditions of restricted (average of last 73 years) water supply. The fourth section presents the potential opportunity cost curves to agriculture for the various water supply restrictions for Upper Klamath Lake, i.e. the opportunity costs of different targeted lake levels. The fifth section contains a summary of GAMS model results for the two representative farm models (Model I and IV) which have high value crops under an "unrestricted" water supply and opportunity costs with additional alternative irrigation techniques. The final section discusses the implications of these results in terms of the best management options for irrigation in response to the water supply restrictions within the Klamath Project.

5.1 Results of Representative Farm Models: Base Case (Unrestricted) Water Supply

Each representative farm model contains information about yields per acre (for each soil type for each crop for each irrigation technology), price of each crop, cost of each irrigation technique, including deficit irrigation for each crop, and size of farm. Historically, the water supply to agriculture has varied, depending on the elevation of the Upper Klamath Lake, which is determined by the previous winter snowpack and run off. However, in most years, irrigators have been allocated an amount of water for "beneficial" use. In the base case analysis, water is determined as the average of water rights of Class B irrigators in the Klamath Project; this is 2.7 acre feet per acre.

The base case model results assume "optimal" or profit-maximizing behavior on the part of irrigators. The models also include some irrigation techniques that may not be used by the average or typical farmer. Thus, the results are not expected to mirror historical cropping patterns. It is useful; however, to compare the predicted productive activities of the farm models with historical values. To perform such a comparison, total acreage of each crop for each farm model under "base case" water supplies is converted to an aggregate or total acreage value of each crop in the Project. The predicted acreage of each crop from the models can then be compared with the ranges of actual cropped acreage for the (1985 - 1994) period. These acreages are reported in Table 5.1. Except for onions and hay, the predicted acreage of each crop is fairly close to actual acreage. Specifically, the predicted total cropped acreage is within the range of the actual total cropped acreage over the last 10 years.

Table 5.1 Comparison of Modeled Acreage and Actual Acreages (1985 - 1994) for each Crop

Crop	*Predicted Acreage*	*Range of Actual Acreage*
Barley	44,160	71,055 - 50,581
Wheat	11,520	5,443 - 9,948
Alfalfa	28,800	30,136 - 39,314
Sugarbeets	5,760	906 - 8,204
Potatoes	17,280	16,012 - 23,983
Onions	5,760	578 - 1,570
Hay	46,080	13,314 - 18,054
Pasture	32,640	40,077 - 49,370
Total	192,000	177,520 - 201,024

Table 5.2, reports gross revenue for each crop from farm models for the "base case" water supplies and the actual gross revenue of the 10 years. The model gross revenue for onions and hay are much higher than actual revenue over the past 10 years, due to higher acreage of those crops of the farm models. Revenues for the rest of the

crops fall within the range of actual revenues. The comparison of acreage and gross revenue for each crop between the results of the farm models and actual production indicates that the representative farm models are plausible characterizations of actual farm activities of Project.

Table 5.2 Comparison of Modeled Revenues and Actual Revenues (1985 - 1994) for each Crop

Crop	*Predicted Revenue (million $)*	*Range of Actual Revenue (million $)*
Barley	15.9	6.1 -16.8
Wheat	4.5	1.4 - 3.0
Alfalfa	15.4	11.4 - 21.1
Sugarbeets	6.0	1.0 - 8.9
Potatoes	48.3	22.6 - 94.3
Onions	11.5	1.1 - 3.5
Hay	9.2	0.9 - 3.1
Pasture	5.9	1.3 - 4.4
Total	116.7	45.8 - 155.1

Tables 5.3, 5.4, 5.5, and 5.6 contain the farming practices (crop mix, irrigation technology) suggested by the farm models and the resulting profits for the base case water simulation. Given the optimizing nature of these model solutions, the crop mix and other values represent the best water management for each farm model (i.e., profit maximizing management).

Table 5.3 Farm Model I: Base Case Water Supply

Crop	*Acres*	*Irrigation Type*	*Deficit Level (%)*	*Profit (S)*
Barley	100	Flood	65	-2524
Wheat	10	Wheel Line	100	-2,661
	23	Fallow		
Alfalfa	112	Wheel Line	100	11,253
Hay	83	Flood	65	8,174
Sugarbeets	20	Wheel Line	95	2,595
Potatoes	52	Centerpivot	100	51,768
Total	400			68,605

Farm model I displays a range of crops and irrigation techniques and is representative of lands along Lost River. The farm reports a net profit (of $68,000), despite losses in barley and wheat. This farm model contains barley, wheat, alfalfa, hay, sugarbeets, and potatoes. A small percentage of land (approximately 23 acres) is fallowed. The low value crops (barley, alfalfa, and hay) are irrigated by flood and wheel-line irrigation. All potato acreage is irrigated by center-pivot. As expected, those crops which require more water and those that are irrigated by more expensive methods utilized a higher percentage of deficit irrigation.

Table 5.4 Farm Model II: Base Case Water Supply

Crop	*Acres*	*Irrigation Type*	*Deficit Level (%)*	*Profit (S)*
Hay	37	Flood	90	
	245	Flood	85	20,026
Pasture	18	Flood	70	-570
Total	300			19,456

Farm model II is devoted to lower value crops (hay and pasture) and all 300 acres of land are farmed. The pasture activity shows a slight loss (of $570) on 18 acres of farm land. The absence of livestock production in this farm undervalues hay prodution as mentioned earlier. However, even without livestock feeding, the farm model makes a profit due to the sale of hay. Both crops are flood irrigated. The model forces all the pasture land into production, despite the loss, because fallowing any of the pasture would lose even more money than deficit irrigation.

Farm model III produces small grains (barley, wheat), alfalfa, hay, and pasture. Wheat production shows a loss; however, barley, hay, pasture, and alfalfa make a sufficient profit to result in a positive return on the total acreage. The main source of profit is the relatively large hay acreage on this farm.

Table 5.5 Farm Model III: Base Case Water Supply

Crop	*Acres*	*Irrigation Type*	*Deficit Level (%)*	*Profit (S)*
Barley	50	Flood	70	646
Wheat	30	Wheel Line	100	-650
Alfalfa	80	Wheel Line	100	8,037
Hay	230	Flood	65	22,856
Pasture	110	Flood	65	1707
Total	500			32,596

Farm model IV is intended to represent the farming activity of most of the Tule Lake Basin on the California side of the Project. This farm model makes the largest profit of the four farm models. Highly profitable crops, such as sugarbeets, potatoes, and onions make up 45 percent of the irrigated lands in this farm model. No wheat is produced; instead this land is fallowed, which results in a slight loss on this acreage. All other crops make a profit. Sugarbeets, potatoes, and onions are irrigated at 100% of their full yield (no deficit) water level and by the most efficient irrigation type (center-pivot). Farm model IV is characterized by slope and soil conditions which are conducive to the production of high value crops. The availability of such high profit, high water consuming crops as potatoes and onions cause a shortage of water for the required acreage and leads to the idling of some lands.

Table 5.6 Farm Model IV: Base Case Water supply

Crop	*Acres*	*Irrigation Type*	*Deficit Level (%)*	*Profit ($)*
Barely	108	Flood	95	
	76	Fallow		-5580
Wheat	38	Fallow	100	-3,857
Alfalfa	108	Wheel Line	100	10,851
Sugarbeets	66	Wheel Line	100	21,507
Potatoes	132	Centerpivot	100	115, 560
Onion	72	Centerpivot	100	21,639
Total	600			160,120

5.2 Results of the Hydrological Model

The previous results are estimated assuming that farms receive their "average acreage" of approximately 2.7 acre feet per acre water entitlement. To measure the effects of changes in the lake levels or Project water supplies and ultimately to farm type requires input from the hydrological model. Specifically, the water supply levels for each farm model during the 3 critical summer irrigation months of the last 73 years are estimated by the hydrological model under the assumption of maintaining the lake level at 4141.3 feet (the LTBO levels for maintenance of the endangered fish species). The estimated average summer water supply indicates that irrigators of the basin would experience a reduction in water supply (from the 2.7 acre feet) in 40 out of the 73 years if this lake level must be met. The water supplies available to each farm type under alternative lake levels (both above and below the LTBO) are estimated as well. The actual lake levels and the estimated water supplies for each farm model under conditions of the LTBO recommendations are given in the Table 5.7.

Table 5.7 Average Lake Levels and Water Supplies for June, July, and August (1922-1994)

Year	Lake Level (ft)	Water Supply Model I (ac ft)	Water Supply Model II (ac ft)	Water Supply Model III (ac ft)	Water Supply Model IV (ac ft)
1994	4139.12	689	516	861	1033
1993	4141.53	1076	807	1345	1614
1992	4138.65	613	460	767	920
1991	4140.26	893	670	1116	1340
1990	4140.96	1019	764	1273	1528
1989	4141.02	1029	772	1287	1544
1988	4140.95	1015	761	1269	1523
1987	4140.90	1011	759	1264	1517
1986	4141.49	1076	807	1345	1614
1985	4141.40	1076	807	1345	1614
1984	4142.36	1076	807	1345	1614
1983	4142.63	1076	807	1345	1614
1982	4142.44	1076	807	1345	1614
1981	4140.02	829	621	1036	1243
1980	4141.33	1076	807	1345	1614
1979	4140.09	843	632	1054	1264
1978	4141.51	1076	807	1345	1614
1977	4140.91	994	745	1242	1490
1976	4141.82	1076	807	1345	1614
1975	4142.61	1076	807	1345	1614
1974	4142.42	1076	807	1345	1614
1973	4140.17	829	621	1036	1243
1972	4142.25	1076	807	1345	1614
1971	4142.57	1076	807	1345	1614
1970	4141.62	1076	807	1345	1614
1969	4142.14	1076	807	1345	1614
1968	4139.45	681	511	852	1022
1967	4141.97	1076	807	1345	1614
1966	4141.09	1033	775	1291	1549
1965	4142.57	1076	807	1345	1614
1964	4141.96	1076	807	1345	1614
1963	4141.48	1076	807	1345	1614
1962	4140.96	1008	756	1260	1512
1961	4140.58	947	710	1184	1420
1960	4140.24	872	654	1089	1307
1959	4140.21	886	664	1107	1329
1958	4142.52	1076	807	1345	1614
1957	4141.27	1076	807	1345	1614
1956	4142.32	1076	807	1345	1614
1955	4140.79	983	737	1228	1474
1954	4141.40	1076	807	1345	1614
1953	4141.88	1076	807	1345	1614
1952	4142.15	1076	807	1345	1614
1951	4140.80	990	742	1237	1485

Table 5.7 (Continued)

1950	4141.57	1076	807	1345	1614
1949	4141.30	1080	810	1345	1619
1948	4141.49	1076	807	1345	1614
1947	4140.33	904	678	1130	1356
1946	4140.80	994	745	1242	1490
1945	4140.52	954	716	1193	1431
1944	4140.11	886	664	1107	1329
1943	4141.98	1076	807	1345	1614
1942	4141.14	1058	794	1323	1587
1941	4140.84	1004	753	1255	1506
1940	4139.94	861	646	1076	1291
1939	4139.65	796	597	995	1194
1938	4141.26	1072	804	1341	1609
1937	4141.31	1076	807	1345	1614
1936	4141.41	1076	807	1345	1614
1935	4141.09	1040	780	1300	1560
1934	4140.26	889	667	1112	1334
1933	4141.77	1076	807	1345	1614
1932	4141.26	1076	807	1345	1614
1931	4138.22	291	218	363	436
1930	4138.69	635	476	794	952
1929	4139.02	725	543	906	1087
1928	4140.03	915	686	1143	1372
1927	4140.58	986	740	1233	1480
1926	4138.52	653	490	816	979
1925	4140.79	1015	761	1269	1523
1924	4139.12	703	527	879	1054
1923	4140.92	1026	769	1282	1539
1922	4140.60	983	737	1228	1474

5.3 Results of Representative Farm Models with Restricted Water Supply

The representative farm models are used to determine the most efficient irrigation techniques and their expected profits, subject to the changing water supply levels. The water supply levels, corresponding to lake levels at or around the LTBO (of 4141.3 feet) are obtained from the hydrological model. Table 5.8 shows the average profit of each farm model associated with different water supply levels for different lake levels, including the LTBO recommendation. For perspective, results for the base case and a "worst case" analysis for each model are also presented. The "worst case" is intended to simulate the water conditions during the worst year of the recent drought (1992), when an average of only 1.69 acre feet were available (approximately one acre feet less than the base case).

Table 5.8 Average Profits by Farm Model, at Different Lake Levels

Lake Level (elevation in ft)	*Farm Model I ($)*	*Farm Model II ($)*	*Farm Model III ($)*	*Farm Model IV ($)*
Base Case	68,601	19,455	32,596	160,120
4139.3	68,278	19,167	32,298	160,073
4139.9	67,526	18,793	31,556	159,933
4140.3	66,884	18,265	30,464	159,532
4140.9	64,817	17,010	29,866	158,785
4141.3 (LTBO)	61,840	16,506	29,295	157,028
4141.9	59,528	13,469	22,932	151,206
4142.3	52,605	11,283	19,234	148,145
Worst Case (1992 Water Year)	27,739	6,605	10,578	75,298

The average profits of all four farm models show decreasing profits as lake levels increase, because the increase in lake levels results in a decrease in water supply for each farm model. For example, as the lake level increases from 4139.3 feet to 4139.9 feet, the profit of farm model I decreases by $752, farm model II decreases by $374, farm model III decreases by $742, and farm model IV decreases by $140. The decreased profit of each farm model indicates that farm model I experiences the greatest reduction in profit from the decreased water supply. For the worst case scenario, profit reductions are severe. For example, farm model I profit is reduced by $40,000, and farm model IV by nearly $85,000.

Analysis of different lake levels shows that farm model I consistently loses the most profit from the incremental reduction of the water supply. A comparison of the farm profits under the LTBO water supply level and the base case shows that farm models I, II, III, and IV experience profits reductions of $6,761, $2,949, $3,301, and $3,092, respectively.

5.4 Assessment of the Expected Opportunity Cost of Alternative Lake Levels

Each farm model is built to represent different types of irrigable soil classes within the Project. As a result, the profit of each representative farm model can be aggregated to represent the profit of each general land class represented by the farm models. To convert individual profits to aggregate amounts, the average profit per acre of each farm is multiplied by the acreage of each land type. For example, the average profit per acre for farm model I for lake level 4139.3 feet is calculated as the profit of the farm model ($68,278) divided by the size of farm model I (400 acre) which is the profit per acre ($171 per acre). The average profit per acre, times the total cropped acreage (in the Klamath Project) of that farm type, then gives the aggregated profit for each type of farm model.

Table 5.9 Profit per Acre for Base Case Water Level and at Restricted Lake Levels

Lake Level (elevation in ft)	*Farm Model I ($)*	*Farm Model II ($)*	*Farm Model III ($)*	*Farm Model IV ($)*
Base Case	172	65	65	267
4139.3	171	64	65	267
4139.9	169	63	63	267
4140.3	167	61	61	266
4140.9	162	57	60	265
4141.3 (LTBO)	155	55	59	262
4141.9	149	45	46	252
4142.3	132	38	38	247
Worst Case	69	22	21	125

Tables 5.9 and 5.10 report the per acre and aggregate profits. As expected, farm models I and IV which contain highly profitable crops like potatoes and onions, make much higher per acre and aggregate profits than farm models II and III.

Table 5.10 Aggregate Profit for Base Case and Restricted Water Supplies

Lake Level (elevation in ft)	*Farm Model I ($)*	*Farm Model II ($)*	*Farm Model III ($)*	*Farm Model IV ($)*
Base Case	9,775,643	4,020,700	2,346,912	9,874,067
4139.3	9,729,584	3,961,081	2,325,444	9,871,151
4139.9	9,622,428	3,883,966	2,272,042	9,862,540
4140.3	9,530,917	3,774,749	2,193,424	9,837,834
4140.9	9,236,493	3,515,429	2,150,378	9,791,726
4141.3 (LTBO)	8,812,252	3,411,183	2,109,258	9,683,368
4141.9	8,482,685	2,783,651	1,651,122	9,324,355
4142.3	7,496,156	2,331,848	1,384,881	9,135,588
Worst Case	3,952,808	1,365,033	761,616	4,643,377

The difference in aggregate profit between the base case water supply analysis and each restricted water supply level provides a measure of the expected opportunity cost to each farm model for each lake restriction. The summation of the expected opportunity costs for each farm model for each lake level, gives a measure of the opportunity cost for agriculture in the Project.

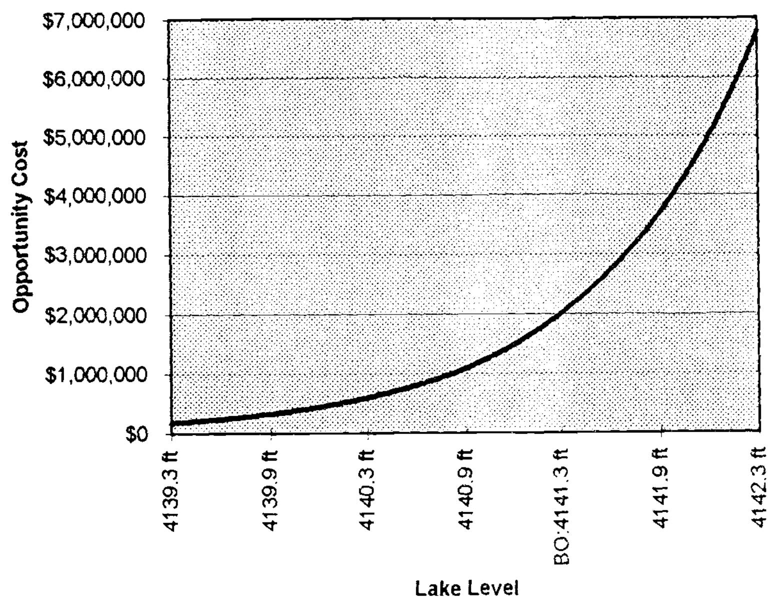
Meeting the LTBO imposes an annual cost in agriculture of \$2,001,261 as measured against the base case water allocation. The aggregate cost to agriculture during the worst drought year (1992), as measured against the base case water supply, is approximately \$15,300,000. As expected, increasing or decreasing the lake level relative to the LTBO or any other benchmark increases or decreases the opportunity costs to agriculture. For example, increasing the lake level restriction by six inches (from 4139.3 feet to 4139.9 feet) causes the expected opportunity cost to increase by \$246,285. Incremental increases of 6 inches cause opportunity costs to increase. Specifically, 'increasing marginal costs' means that the same change in water level results in an increased change in costs. For example, a 6 inch increase in the lake level from 4141.9 feet to 4142.3 feet, results in an expected opportunity cost of \$1,893,340 or over seven times the cost of going from 4139.3 to 4139.9 feet. This rapid increase in marginal costs to agriculture is due to the exhaustion of mitigating adjustments in the models, such as water saving techniques.

Table 5.11 Opportunity Cost by Farm Model and Total, for each Lake Level as Measured Against Base Case Project

Lake Level (elevation in ft)	*Model I ($)*	*Model II ($)*	*Model III ($)*	*Model IV ($)*	*Total Cost ($)*
4139.3	46,059	59,619	21,468	2,915	130,061
4139.9	153,215	136,734	74,870	11,527	376,346
4140.3	244,726	245,951	153,488	36,233	680,397
4140.9	539,150	505,271	196,534	82,341	1,323,296
4141.3 (LTBO)	963,390	609,517	237,654	190,699	2,001,261
4141.9	1,292,957	1,237,049	695,790	549,711	3,775,508
4142.3	2,279,486	1,688,852	962,031	738,479	5,668,848
Worst Case	5,822,836	2,655,667	1,585,296	5,230,690	15,294,489

The increasing marginal costs result from the exhaustion of mitigating activities, such as increased use of deficit irrigation and alternative irrigation techniques. This is reflected in an aggregated marginal cost curve in Figure 6.1 which shows a very steep marginal cost curve as the targeted lake level rises.

Figure 6.1 Lake Level vs Opportunity Cost



5.5 Sensitivity of Results to the Adoption of Alternative Irrigation Techniques

It is expected that technological advancements may soften or mitigate some of the adverse effects of reduced water supplies. To test this, the three irrigation techniques discussed earlier are added to the irrigation options in the models. Results are reported in Table 5.12 and 5.13. Farm model I with these three alternative irrigation techniques reports a net profit of $72,931. This net profit is $4,325 higher than the analysis without the alternative techniques. The increased profit is generated by switching irrigation techniques for sugarbeets and potatoes from wheel line and centerpivot to the surge furrow-pumpback system which is more water efficient and less expensive than the conventional systems

Table 5.12 Farm Model I: Base Case Water Supply with Alternative Irrigation Systems

Crop	*Acres*	*Irrigation Type*	*Deficit Level (%)*	*Profit ($)*
Barley	100	Flood	65	-2,524
Wheat	32	Wheel Line	100	-3,259
Alfalfa	112	Wheel Line	100	11,253
Hay	82	Flood	65	8,174
Sugarbeets	20	Surge Furrow Pumpback	95	3,248
Potatoes	54	Surge Furrow Pumpback	100	56,039
Total	400			72,931

Farm model IV with these alternative techniques also reports a higher profit than obtained earlier. The increased profits come from switching the existing irrigation techniques for sugarbeets, potatoes, and onions to the surge furrow-pumpback system. Surge furrow (without pumpback) and drip systems were not adapted in theses solutions because of their lower water efficiency and higher cost than conventional systems.

Table 5.13 Farm Model IV: Base Case Water supply with Alternative Irrigation Systems

Crop	*Acres*	*Irrigation Type*	*Deficit Level (%)*	*Profit ($)*
Barely	108	Flood	95	-5,580
	88	Fallow	100	
Wheat	38	Fallow	100	-3,857
Alfalfa	108	Wheel Line	100	10,851
Sugarbeets	66	Surge Furrow Pumpback	100	17,706
Potatoes	132	Surge Furrow Pumpback	100	124,430
Onion	72	Surge Furrow Pumpback	100	30,509

Table 5.13 (Continued)

Total	600	174,059

The availability and use of alternative irrigation techniques also affects the opportunity cost calculation (Table 5.14). The expected opportunity cost with alternative irrigation techniques is decreased through the use of a water conserving irrigation system (surge furrow-pumpback) for the high value crops in farm models I and IV. For example, the opportunity cost for the LTBO decreased by about $70,000 annually (from $2,001,261 to $1,938,618) and the opportunity cost for the worst drought year (1992) decreased by over $1.1 million (from $15,294,489 to $14,146,466).

Table 5.14 Opportunity Cost by Farm Model and Total, for each Lake Level as Measured Against Base Case Project, with Alternative Irrigation Systems

Lake Level (elevation in ft)	*Model I ($)*	*Model II ($)*	*Model III ($)*	*Model IV ($)*	*Total Cost ($)*
4139.3	30,876	59,619	21,468	2,921	114,884
4139.9	146,966	136,734	74,870	10,258	366,828
4140.3	234,426	245,951	153,488	30,903	664,768
4140.9	451,841	505,271	196,534	77,280	1,230,927
4141.3 (LTBO)	907,440	609,517	237,654	184,007	1,938,618
4141.9	1,364,159	1,237,049	695,790	359,767	3,656,765
4142.3	2,261,565	1,688,852	962,031	500,345	5,412,793
Worst Case	5,311,831	2,655,667	1,585,296	4,593,673	14,146,466

5.6 Implications

The results for the four representative farms provide quantitative evidence of the potential costs to irrigators of water reductions within the Klamath Project. These model results also have implications for both farm management and lake level management when the level of water supply is changed. Specifically, the restrictions of lake level affect farm profitability as measured by the opportunity cost curve. The model results suggest how changes in farm management can mitigate these costs.

The optimal solutions generated for each farm model indicates that the most efficient way for farmers to respond to water restriction indicates both the use of both alternative irrigation techniques and deficit irrigation. Specifically, a change in the water supply in the four representative farm models (from the base case level) results in a change in irrigation options. Farmers in the Klamath Basin can mitigate partly for the loss of water (due to lake restrictions or drought) by switching to more efficient irrigation methods and allocating available water to higher value crops. For example, if the base case water supply level (of 2.69 acre feet) is reduced (to 2 acre feet) in representative farm model I, barley is taken out of production and wheat switches to all fallow, whereas sugarbeets, alfalfa, and potatoes acreage stay the same (with wheel line and centerpivot irrigation, respectively).

The expected aggregate opportunity cost measured here indicates that across water years, maintaining the lake level at the LTBO reduces profits to agriculture by about \$2 million, annually. This annual opportunity cost of \$2 million is approximately 8% of estimated annual profit (\$26million) for the Klamath Project under the base case water supply. The annual opportunity cost of \$2 million could be reduced to \$1.9 million by switching to alternative irrigation techniques. The estimated opportunity cost of the LTBO under the worst drought year, 1992, could be reduced to about $14 million (from $15 million) with the alternative irrigation systems. The increasing marginal opportunity cost depicted in Figure 6.1 indicates that increasing the restriction of the lake level causes in the reduction of farm profits to increase at an increasing rate as mitigate options are exhausted.

CHAPTER 6. SUMMARY AND CONCLUSIONS

The results and implications discussed in Chapter five provide quantitative evidence regarding the agricultural impact of restrictions on Upper Klamath Lake water supplies for the benefit of endangered species. In this chapter, conclusions are drawn concerning the economic relationship between farming practices and water quantity of the Klamath Basin. The chapter is divided into three sections. The first section is a summary of the research problem and its physical, institutional and technical dimensions. Procedures are also summarized in this section. The next section deals with the limitations of this thesis and the need for future research. The final section contains lessons and applications of this thesis.

6.1 Summary

The Endangered Species Act extended its protection to the Lost River sucker and the shortnosed sucker in the Upper Klamath Lake in 1988. This action lead to development of strategies to protect habitat for the two endangered fish. A major feature of these strategies was the setting of minimum lake levels for Upper Klamath Lake (the level was specified by the U.S. Fish and Wildlife Service, "Long Term Biological Opinion"). These actions may have contributed to the survival of the species during the drought years, 1992 and 1994. However, some actions taken to protect the species, such as maintenance of the lake levels during the drought years, disrupted contractual irrigation withdrawals and created a crisis for the basin. For example, about a third of the farmers in the basin got only half of their normal water from the Upper Klamath Lake in 1992. The National Wildlife Refuges got only 10 percent of the water which was needed to flood the wetlands in 1994. It is therefore important to assess the economic costs of maintaining the lake level for these species. This information can be useful in determining the minimum cost (to agriculture) strategy of protecting the endangered species.

The objectives of this thesis were 1) to assess farm-level responses and then associated effects on profits under alternative water supply conditions and 2) to examine the expected opportunity cost to agriculture of maintaining the level of the Upper Klamath Lake for the sucker fish.

In chapter two, the physical, institutional, and technical dimensions of Klamath Basin water issues were explored. The geographical characteristics of the basin were described including climate, elevations, soil types, and hydrology. The agriculture of the basin was explained in terms of soil classes, crops, and irrigation techniques. Current water management, recent water disputes due to the ESA and a prolonged drought cycle, and water rights of the basin were also described. The current water management section listed the four "principles" that guide water management within the basin. The four principles are 1) Endangered Species Act; 2) federal trust responsibility to tribes; 3) contractual obligation to Project water users; and 4) conserving wetland and wildlife values. This section also summarized water disputes and the claims of different water users in the basin: Lost River and shortnose sucker, irrigators, chinook salmon, and migratory birds. The water rights section described the rights of the Klamath Indians and the rights of the Klamath Project. The three classes of irrigators in the Project were introduced.

The chapter of the economic assessment framework contained economic optimization, linear programming, and representative farm models. The profit maximization goal is first reviewed and linear programming method, used to optimize the representative farm models was discussed. The linear programming section reviewed applications of LP models in agricultural economics. Specific requirements and a number of assumptions underlying LP were summarized in this section. The section on representative farm models specified the four main criteria (acreage, main crops, location, and soil types) by which the representative farm models were defined. The linear programming formulas for the four representative farm models were given in this section as well.

Chapter four contained the framework and procedures used in developing the farm models and a hydrological model. The analysis used a general three-part simulation involving 1) constructing profit maximizing farm models, 2) estimating hypothetical water supply of the farm models over the last 73 years under restrictions, and 3) assessing the opportunity cost to agriculture of protecting these fish. The process was simulated in the LP representative farm models and the hydrological model using different lake levels. The crop budgets generated by farm-level data, farm activities, and constraints were used in the LP models.

The representative farm models were built based on different soil types and mixture of crops. The output of each of the representative farm models showed profit maximizing irrigation techniques, deficit irrigation levels, and fallowed lands when needed.

The empirical focus of this thesis was the Klamath Basin, the area below the Upper Klamath Lake. The Klamath Basin represents a complex water supply system involving many areas and interests: Indian rights, power, irrigators, fish and wildlife, and recreation uses. Important agricultural commodities of the basin include spring barley, irrigated pasture, alfalfa, potatoes, hay, wheat, sugarbeets, and onions. The region is characterized by cold, moderately wet winters and hot, dry summers. Snowfall during the winter months is the main form of precipitation. The four farm types were defined to represent dominant series of crops, soil classes, and geographical subregions within the basin. These include two representative farms along the Lost and Klamath Rivers, one representative farm within the Klamath Valley, and one representative farm within the Lower Klamath and Tule Lake Basin.

The hydrological model was designed to estimate the restricted water supply available to the farm models, subject to maintenance of the lake level for the protection of the endangered fish. A comparison between the profits of the farm models under base case water supply conditions and the conditions of restricted water supply as determined by the hydrological model provided a measure of the expected opportunity cost to agriculture of the lake level restrictions. The expected opportunity cost at the farm level was aggregated to represent costs to agriculture in the basin. The aggregation was based on the percentage of farm lands represented by each model.

The results from the simulations have implications for efficient irrigation techniques and efficient water allocation within the Klamath Basin under alternative water supplies.

(1) Restrictions on the level of Upper Klamath Lake result in a loss of water to agriculture and associated loss in profit.

(2) The use of alternative irrigation techniques, crop mixes and deficit irrigation help to soften or mitigate the effects of water reduction.

(3) The expected loss of profit (expected opportunity cost) to agriculture varies strongly with the level of restriction of the lake.

(4) Estimates of the expected opportunity cost to agriculture provide evidence with which to develop cost minimizing strategies to protect the lake.

(5) Investigate the economies of water conserving irrigation system by adding alternative irrigation practices.

6.2 Limitations and Research Needs

The modeling process of the representative farm models and the hydrological model used a number of simplifying assumptions. The area and scope of the study were confined to a well-defined portion of the basin due to data limitations. Peripheral areas that may be important to the entire hydrologic and agrnomic system of the basin were not considered. For example, four watersheds (Gerber, Clear Lake, Malone, and Upper Klamath River) in the Klamath Basin, only the Upper Klamath River Watershed was considered when determining potential water supplies. The irrigation water for farms below Upper Klamath Lake was assumed to be limited to the water from the Upper Klamath Lake. The water from the Lost River and Tule Lake was ignored in the hydrological model, as was conjunctive use of ground water.

Stochastic weather events were not considered in the hydrological model. The measure of the expected opportunity cost was calculated under the assumption of the 'base case' water supply which reflects the normal or long-term average precipitation in the region. Extreme events may influence crop yield variably and hence the risk of farming may increase. It is likely that the LTBO, if strictly enforced, will further increase the long term risk to farmers by reducing the capacity of the lake to serve as a buffer against drought "shocks". The expected opportunity cost to agriculture of the basin for maintaining lake levels under different weather conditions requires further study.

The representative farm models were built under the assumption of that farmers could adjust instantly to changes in water supplies by changing practices. Financial conditions of farmers influence both the selection of irrigation methods as well as the mixture of the crops. The financial flexibility of the farmers was not considered in the farm models.

The estimation of the expected opportunity cost may give some clues for lake management; however, it does not offer complete information on which to base lake management decisions. What is needed is an analysis of the actual benefits of higher lake levels to the sucker fish. Complete information on which to base lake management, both for the benefit of agriculture and of endangered species will not be available until further research regarding these sucker and other fish and wildlife species has been completed.

6.3 Conclusions

This thesis presents some insights concerning water management of the Upper Klamath Lake and agricultural production in the Klamath Basin. These insights include possible adjustments by agriculture to changes in water allocations to agriculture as well as an estimate of the expected opportunity cost (reduced profits) to agriculture associated with alternative lake levels for preservation of endangered species. For example, an analysis of the adoption of alternative irrigation techniques suggests that technical advancements of irrigation systems are one of the adjustments of agriculture to the change of the water allocations. More generally, this thesis quantify some of the trade offs between the water rights and allocations of irrigators and allocations for fish habitat and other environmental concerns, as mandated by the Endangered Species Act. Traditionally, farmers have had dominant or senior water rights in many parts of the western United States. Growing demands for other uses of water suggests that irrigators here and elsewhere will need to adopt to changing water supplies.

The marginal water value (shadow price) of the base case water supply for each representative farm varies depending on the profitability of the crops in the model. Water value is highest in Farm model IV which has higher value crops. Water allocation within the Project is not based on the marginal value of water, which means the water has not been allocated to maximize aggregate economic efficiency (maximizing the returns to society). The development of a water market to reallocate water among different crop irrigators is one alternative to help alleviate water allocation problems in water-short years. In such water markets, water would be supplied by irrigators at a minimum price not less than the value of their water when used for irrigation. Thus, markets have the potential to improve returns to individual irrigators and to society as well.

This research is only a start pointing in analyzing water supply issues in the basin. It does provide information on efficient water use potential at the farm level in the basin. The opportunity cost to agriculture for different lake levels (to meet fish habitat needs) reflects irrigation management options by agricultural producers. The expected annual cost to irrigators of meeting the LTBO is approximately $2.0 million. The marginal cost curve reveals the increasingly heavier economic burden assumed by agriculture as the restriction of the lake level increases. The analysis of the "worst case" scenario (mimicking the 1992 drought year) shows severe damages of over $15 million or over 50% of the estimated annual profit under the base case water supply to agriculture in the basin.

The view points of irrigators, Tribes, State and Federal agencies, and the general public are varied concerning the usage of Klamath Lake water. While there is disagreement about allocation, ultimately, water will be distributed, either through the political process or the courts. The most important lesson from this thesis is to reinforce the conventional economic wisdom that any allocation involves a mix of costs and benefits, and that the costs (in this case, to agriculture) at the margin are rising. Whatever allocation is selected, information of the type presented here can help decision makers understand the costs of various allocations.

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