AN ABSTRACT OF THE THESIS OF

Brent B. Boehlert for the degree of Master of Science in Agricultural and Resource Economics and Geography presented on November 13, 2006.
Title: Irrigated Agriculture, Energy, and Endangered Species in the Upper Klamath Basin: Evaluating Trade-Offs and Interconnections

Abstract approved: ______________________________________
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In 2001, an extreme drought tightened water supply in the Upper Klamath Basin (basin) while earlier increases in Endangered Species Act (ESA) water requirements for basin fish species that same year elevated demands. The Bureau of Reclamation (Reclamation), which manages irrigation water in parts of the basin located near the Oregon-California border, responded to ESA Section 7 obligations by severely curtailing water allocations to Reclamation Project irrigators for the 2001 growing season, costing irrigators an estimated $35 million in farm income. This event has directed attention to several important factors that may further undermine effective water management in the basin. These include higher ESA flow requirements due to a recent Ninth Circuit Court ruling and a ten-fold energy rate increase to irrigators resulting from a mid-2006 contract expiration with the regional energy provider.

The overall objective of this research is to assess the impact of changes in ESA flow requirements and energy prices on the Upper Klamath Basin farm economy given variable levels of water trading flexibility and groundwater availability. A mathematical programming and Geographic Information System (GIS) framework is used in which farm decisions are assumed to maximize net revenue subject to hydrological, institutional, economic, and agronomic constraints. The results suggest that greater development of basin groundwater resources and the institution of a flexible water bank may be sufficient to mitigate the majority of costs related to increased ESA flow requirements in future years.

Irrigated Agriculture, Energy, and Endangered Species in the Upper Klamath Basin: Evaluating Trade-Offs and Interconnections

by

Brent B. Boehlert

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements of the
degree of

Master of Science

Presented November 13, 2006
Commencement June 2007

Master of Science thesis of Brent B. Boehlert presented on November 13, 2006.

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Brent B. Boehlert, Author

ACKNOWLEDGEMENTS

I would like to thank several people who helped me complete this thesis. First, my committee: Bill Jaeger, my major advisor in Agricultural and Resource Economics, provided continual and invaluable feedback during our one and a half years working on this project together; Aaron Wolf, my Geography major advisor, helped to ensure that this work has institutional applicability through our discussions on Klamath water issues; Rich Adams, from the department of Agricultural and Resource Economics, provided insights from his extensive work in the Klamath basin and in the field of natural resource economics; Ron Doel, who is in both the Geography and History departments, provided an historical perspective in our discussions of the implications and conclusions of my results; Marshall Gannett, from the U.S. Geological Survey, contributed immeasurably to my understanding of the groundwater dynamics in the Klamath basin; and David Finch, my Graduate Council Representative from the Mathematics department, helped to ensure that my thesis defense went smoothly.

I would also like to thank my parents, George and Susan Boehlert, for their kindness, generosity, and love throughout the process; and my brother Brooks, for his service to our country during these uncertain times.

Finally, I wanted to extend my thanks to all of the wonderful friends that I met while in this dual degree program. In particular, I thank Kristel Fesler, Christiane Drangle, and Samantha Sheehy for providing me with friendship and support throughout my time in Corvallis.

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Irrigated Agriculture, Energy, and Endangered Species in the Upper Klamath Basin: Evaluating Trade-Offs and Interconnections

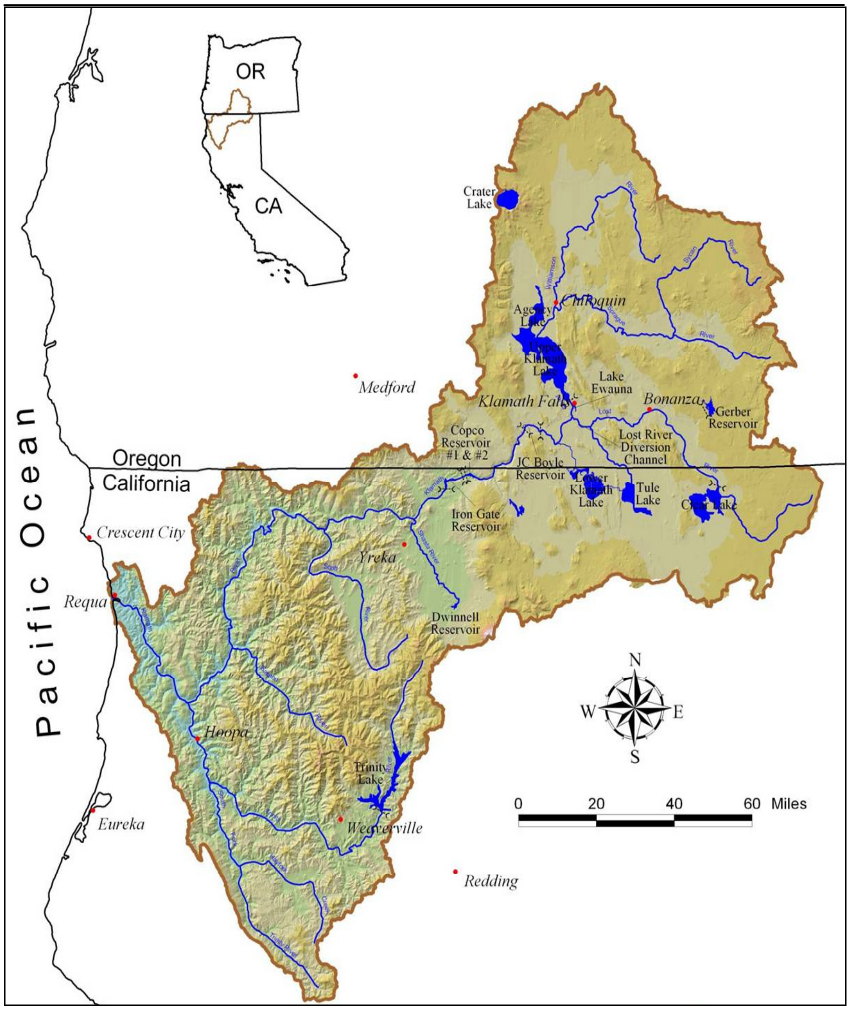
1 INTRODUCTION

> “The trouble with water – and there is trouble with water – is that they’re not making any more of it. They’re not making any less, mind, but no more either. There is the same amount of water on the planet now as there was in prehistoric times” (De Villiers 2000).

Conflicts over water resources have become more the rule than the exception in many arid regions of the west. Although the stakeholders in each region may differ, the issue is typically the same – demand for water is growing much faster than supply. In the Upper Klamath basin (the basin – see Figure 1), the most prominent demand for water over the past century has come from agriculture. Agriculture’s claim on this resource over the past few decades has remained relatively steady, in part because of the physical constraint on water availability given uncertain seasonal inflows. In the same period, other demands have increased in both magnitude and priority, introducing conflict during dry years. The causes of these increases include urban growth, the recognition of Indian rights to protect Tribal fishing harvests, growing interest in Klamath River recreation, the need for Klamath flow to promote salmon survival (and thus offshore fisheries), and legislative changes prioritizing the recovery of threatened and endangered species in the basin. The importance of these non-agricultural demands has become increasingly evident in recent years. During 2002, low flows caused a massive fish kill in the Lower Klamath basin that was linked partly to agricultural diversions in the Upper basin (CADFG 2003). This prompted a 2006 shutdown of the Pacific Chinook salmon fishery along 400 miles of Oregon and

California coastline, in response to the third consecutive year where populations of returning Klamath salmon fell below threshold levels outlined in their fishery management plan. This shutdown caused direct damages to the already strained fishing industry estimated at $16 million[1].

Map 1: Klamath Basin



Source: USGS

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[1] From an article on the webpage of U.S. Senator Dianne Feinstein titled "Commerce Secretary Gutierrez Declares Commercial Fishery Failure for Pacific Salmon Fisheries." Cited on October 24, 2006. Available at http://feinstein.senate.gov/06releases/r-fishery-fail.htm

Although each of these growing demands may independently constrain future supplies, this research focuses on the economic implications of water conflicts between environmental and agricultural uses in the basin. Nationwide, environmental demands to promote species recovery have been stimulated by broad changes in social values, reflected in the passage of the 1970 Endangered Species Act (ESA). In the 1980s and early 1990s, biologists recognized that populations of the Lost River and shortnose suckers in Upper Klamath Lake (UKL) and the anadromous coho salmon in the Lower Klamath basin were low and hence at risk due (presumably) to excessively low lake levels and river flows during irrigation months. The designation of the two sucker species as endangered in 1988 led to the first inflexible set of environmental demands in the basin; by 1997, biological opinions (BiOP) had been issued requiring minimum UKL water levels for the suckers and minimum instream flows at Iron Gate Dam (IGD) for the threatened coho salmon. These minimum environmental lake level and flow requirements took precedence during the infamous water conflict of 2001. That year, an extreme drought tightened supply while earlier 2001 increases in ESA water requirements for both the suckers and salmon elevated demands. The Bureau of Reclamation (Reclamation), which manages irrigation water in parts of the basin, was forced to severely curtail water allocations to Reclamation Project (project) irrigators for the 2001 growing season. Consequently, project irrigators lost approximately $35 million in farm income (an amount which exceeded net revenues in 2002). This conflict revealed that basin water resources were overallocated and that new approaches to water management needed to be developed. In response to this need, tens of millions of federal dollars have been spent on a wide range of physical and institutional approaches to augment supply or decrease demand[2]. The success of these solutions is unclear.

Several other challenges not present during 2001 have surfaced since. A recent Ninth Circuit Court ruling, mandating that flow requirements for the coho salmon be increased substantially, comes into effect at the same time energy rates will begin a dramatic series of annual increases due to the expiration of a long standing energy contract between irrigators and the regional energy provider (PacifiCorp).[3] During dry years, monthly flow requirements nearly doubled (starting in 2006) and energy prices will reach upwards of 10 times 2005 rates within five years (see Figure 1 and Table 1, below). It is clear that increased environmental flow requirements further constrain an overly taxed system, but it is uncertain how much farm profits will be impacted by these increased minimum flows. It is also clear that much higher energy costs will reduce farm profits (perhaps dramatically); however, the magnitude of the profit reduction, resultant shifts in irrigation technologies, the extent of land retirement, and corresponding increases in water availability are unknown.

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[2] Funded physical approaches include, for example, wetland restoration or switching irrigators to more efficient sprinkler irrigation systems. These programs have been funded through the Natural Resources Conservation Service (NRCS) at $50 million for the 2002 to 2007 period. An example of an institutional approach is the Reclamation “water bank”, which allowed temporary purchases of groundwater and surface water rights to provide an additional water buffer for environmental flows. The bank is currently funded at $7 million annually, but this funding is indirectly tied to the FWS BiOP.

[3] Pacific Coast Federation of Fishermen’s Associations; Institute for Fisheries Resources; Northcoast Environmental Center; Klamath Forest Alliance; Oregon Natural Resources Council; The Wilderness Society; Waterwatch of Oregon; Defenders of Wildlife; Headwaters and the Yurok and Hoopa Valley Tribes as Plaintiff Intervenors v. U.S. Bureau of Reclamation and National Marine Fisheries Service. 2005. United States Court of Appeals for the Ninth Circuit. The plaintiff argued that by the point that the final phase of flows has arrived, 3-5 generations of coho would have passed through system. NMFS was found to not have justified the first flow phases in any meaningful way.

The potential to relieve overallocation of surface water resources in the basin using water trading or groundwater supplies is unclear[4]. It is well understood that greater certainty at a lower cost results from increased geographic and institutional flexibility in transfers between water users (Vaux 1986); and although the potential benefits of flexible water trading in the basin during 2001 have been investigated (Jaeger 2004), its potential under a broader range of expected hydrological and institutional conditions has never been explored. In the case of groundwater, neither the quantity of water physically available for monthly pumping nor the sensitivity of the economic system to its provision is properly understood (McFarland, et al. 2005).

1.1 Objectives

The overall objective of this research is to assess how increased IGD flow requirements and energy prices in the presence of variable levels of water trading flexibility and groundwater availability impact the Upper Klamath basin farm economy. There are four specific objectives of this study: 1) evaluate the costs of an abrupt increase in ESA flow requirements given different levels of water trading flexibility; 2) evaluate the impact of anticipated energy cost increases on water availability and the resulting redistribution of irrigation technologies in the basin; 3) assess the sensitivity of farm profit reductions to changes in lake level and flow requirements; and 4) investigate the potential role of groundwater in future basin water

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[4] Other solutions have been proposed to ease the water supply issues of the Basin, but their consideration is beyond the scope of this study. These include developing additional surface water storage, decreasing agricultural use through increased efficiency, importation of water from adjacent basins, or adjusting ESA requirements.

supplies. These objectives are addressed using a mathematical optimization model and a Geographic Information System (GIS) of hydrologic, agronomic and economic data. The model reflects farmer behavior by maximizing net farm revenues in the context of institutional and physical constraints. Model parameters are adjusted to represent a range of future institutional and physical possibilities. Background to the objectives is provided below.

1.1.1 Increases in ESA Flow Requirements and the Role of Trading

The 2002 ESA flow requirements in the BiOP for coho salmon recovery allow for a decade-long ramp up of flows to the biologically necessary levels, allowing Reclamation time to acquire the needed water throughout the basin to meet their Section VII obligations under the ESA. Accordingly, current flows are significantly lower than the final flow requirements necessary for coho recovery. A 2005 9th circuit court ruling[5] concluded that these final flows will be required this year. These increases, in concert with existing lake level and refuge requirements, may further stretch the already overextended water supplies of the basin. Short-term (2005 and earlier) and long-term flow requirements for a year categorized as “dry” by NOAA are markedly different (Figure 1). Note the substantial differences between these “dry” year short- and long-term requirements during the irrigation months.

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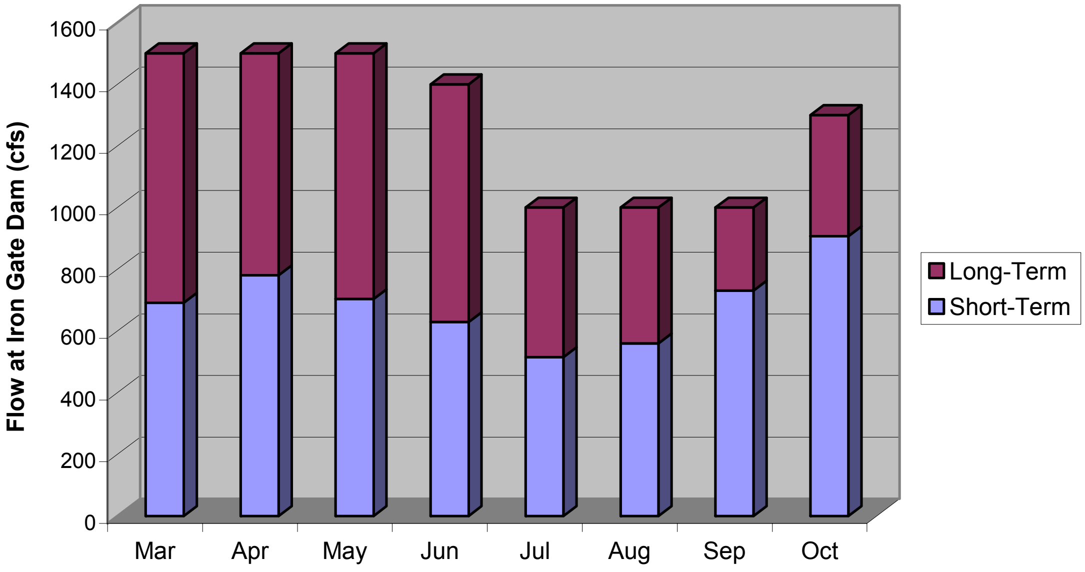
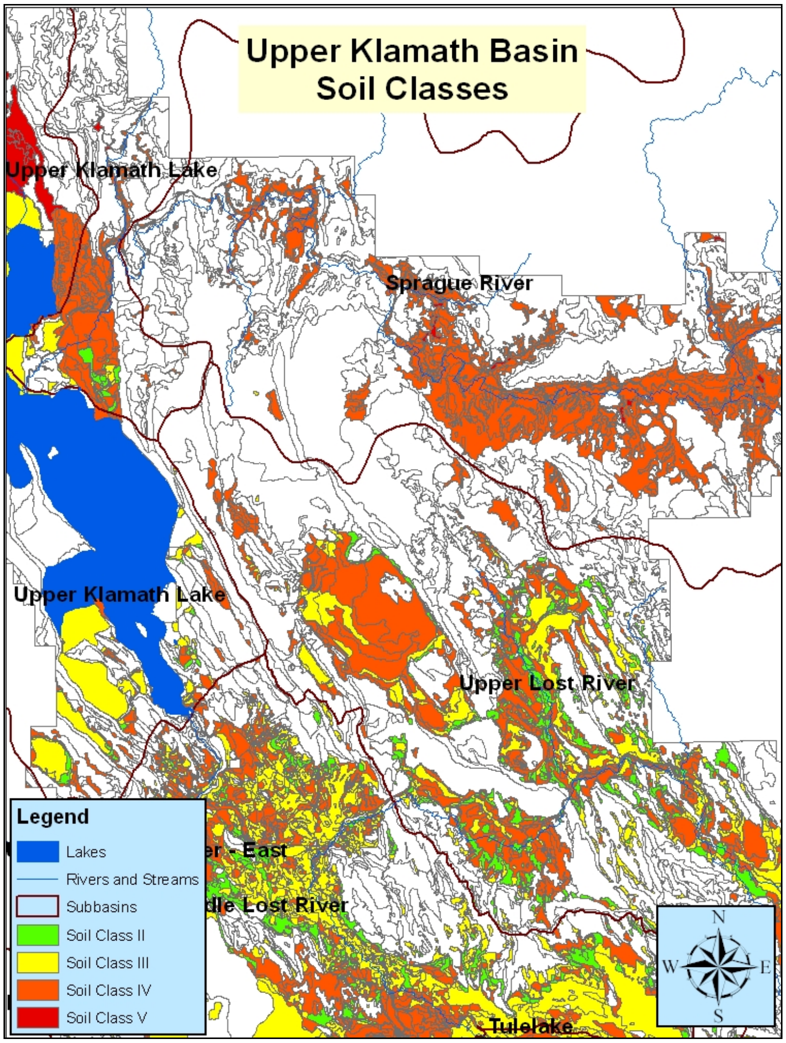
[5] Ibid.

Figure 1: Short-Term versus Long-Term NOAA "Dry" Monthly Flow Requirements



Research in economics has long demonstrated the efficiency benefits from water trading (i.e., Howe 1986; Easter, Dinar, and Rosegrant 1998; Ewers, Chermak, and Brookshire 2004). More recent research in the basin has shown that allowing more flexible trading could have alleviated much of the economic impact of the 2001 water shortage (Burke, Adams, and Wallender 2004; Jaeger 2004). As is true in a market for any good, the potential for a water market is greatly enhanced if wide differences exist between buyers' willingness to pay and sellers' willingness to accept compensation. In the Upper Klamath basin, the profitability of land varies widely, largely due to the wide ranges of climates and soil quality conditions. Both are captured in the soil classification system, which qualifies farmable soils from class I (high quality) to class V (poor quality). Map 2, below, shows the distribution of soil classes over irrigated agriculture in the vicinity of Upper Klamath Lake (UKL). Due to institutional requirements imposed by the ESA (discussed in more depth in chapter three), past and future curtailment of irrigation deliveries has focused in the Reclamation irrigation project to the area southeast of the lake. This area is primarily class II and III soils, as opposed to the less profitable class IV and V soils of the northern sub-basins. The economic impact of water shortages on agriculture could potentially be substantially decreased by allowing the redistribution of idled lands during droughts through water trading.

Map 2: Soil Classes in the Vicinity of Upper Klamath Lake



1.1.2 Energy Price Increases

In 1956, Klamath irrigators established a 50-year energy contract with PacifiCorp, fixing energy rates at between 0.6 and 0.75 cents per kilowatt-hour (kWh). The contract terminated this year, ostensibly allowing PacifiCorp to increase energy prices to the current regulated rates charged to other PacifiCorp farmers (6 to 6.9 cents per kwh). The transition to these new prices will significantly affect irrigators, particularly those who irrigate using sprinkler systems, which are far more energy intensive than flood irrigation systems. If costs exceed the revenues on these acres due to increased energy costs, sprinkler irrigators may have difficulty remaining in production. A schedule of projected energy prices and the associated costs to flood and sprinkler irrigators is provided in Table 1 below. Note that prices increase to 6 cents per kilowatt hour, which is within the range noted by Jaeger. Projected costs do not include increased water delivery charges to farms within irrigation districts[6].

Table 1: Upper Klamath Basin Irrigator Energy Price and Cost Schedule

Year	1956-2006	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12
Energy Price (per kWh)	$0.006	$0.009	$0.014	$0.020	$0.030	$0.046	$0.060
Flood (cost per acre)	$0.54	$0.81	$1.22	$1.82	$2.73	$4.10	$5.40
Sprinkler (cost per acre)	$4.14	$6.21	$9.32	$13.97	$20.96	$31.44	$41.40

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[6] Based on personal communication with Harry Carlson, Director, Intermountain Research and Extension Center (U.C. Davis) in Tulelake on July 27, 2006

1.1.3 More Flexible Lake and Flow Requirements

There is a strong connection between the 2001 ESA requirements and the level of farm profits (Burke 2003). Here the marginal impact on farm profits of changing lake levels and flow requirements, and how these constraints interact with one another, are investigated. Although Adams and Cho (1998) explored these costs attributable to ESA requirements, new institutional circumstances and a geographically broadened model warrant revisiting their analysis.

1.1.4 The Role of Groundwater

To address water needs after 2001, Reclamation established a federally-funded water bank (mandated in the 2002 NOAA BiOP) to provide greater supply certainty in the basin. The bank operates as a reverse auction, where Reclamation purchases enough water to meet their annual target (100,000 acre-feet) by purchasing the lowest cost groundwater and surface water bids proposed by water rights holders that season[7]. Since 2001, groundwater pumping has increased dramatically in the basin due to pumping contracts with irrigators formed in order to fulfill Reclamation's annual water bank requirements, which are in turn intended to fulfill ESA requirements. These increases have resulted in relatively substantial declines in regional groundwater levels over multiple-year periods. The extent to which groundwater can

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[7] Rights holders can be compensated for any of the following approaches: groundwater substitution, where groundwater is used to irrigate crops instead of surface water; groundwater pumping, where groundwater is pumped directly into irrigation canals; land idling, where land is fallowed for the season; or dryland farming (also known as forbearance), where crops are still harvested, but irrigation water is not applied.

be used as a major source of additional water to the basin is highly uncertain. The USGS is currently working on developing a finite difference groundwater flow model of the basin (workable in 2007) to better understand both the capacity of groundwater as a resource and the impact of pumping on surface water flows[8]. Groundwater in the basin is investigated in greater depth in chapters two, four, and five.

1.2 Overview

In the following chapters, a background on the study area is provided (chapter two); a description of some of the institutional, legal and economic issues facing the project (chapter three); the methodologies, data collected and model of the basin (chapter four); and an explanation and discussion of results (chapter five). A summary and conclusion follow in chapter six.

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[8] Based on personal communication with Marshall Gannett, Hydrologist with the U.S. Geological Survey in Portland, Oregon, March 15, 2006.

2 THE UPPER KLAMATH BASIN

The following sections provide an overview of the geography, history of conflict over water, economy, hydrology, agriculture and wildlife of the basin.

2.1 Geographic Setting

The Upper Klamath Basin sits on the Oregon-California border just east of the Cascades. It includes all of the area which drains into the Klamath River above Iron Gate Dam (IGD), which is located in California just south of the Oregon border. As defined, this area covers 5,155,000 acres, and is entirely contained within Klamath County in Oregon and Siskiyou and Modoc Counties in California. Elevations in the basin range from 4,000 to 9,000 feet above mean sea level. Lying beyond the rain shadow of the Cascades, the region is categorized by cold, moderately wet winters and hot, dry summers (Cho 1996).

The basin contains a national park, a national monument, two national forests and six wildlife refuges. Its wetlands rest at the juncture of the flyways comprising the Pacific Flyway, making it an essential stopping point for migratory waterfowl along the West Coast (Burke 2001). The basin contains the largest population of bald eagles in the U.S. outside of Alaska, and its hydrological contributions to Klamath River flows help to maintain populations of steelhead, and Chinook and coho salmon. The basin lakes also support two endangered species of fish: the Lost River and shortnose suckers.

2.2 A History of Water Conflict in the Upper Klamath Basin

In 1988, the U.S. Fish and Wildlife Service (FWS) listed the local Klamath populations of Lost River and shortnose suckers as endangered species, and subsequently produced a BiOP mandating minimum UKL levels in 1992. The coho salmon, whose local habitat extends from the Pacific Ocean to IGD (at the southern terminus of the study area), was listed in 1997 and a BiOP was submitted in 1999 requiring minimum monthly flows at IGD. In 2001, new BiOPs for the suckers and coho were issued, increasing both lake level and flow requirements in the basin (Hathaway and Welch, 2003). Under the provisions of the ESA (section 7), federal agencies operating projects that may affect an endangered or threatened species within its habitat must proactively work toward species recovery[9]. In the Klamath basin, this places a tremendous amount of pressure on Reclamation, which is solely responsible for meeting both monthly lake levels and flow requirements. A National Academy of Science (NAS) committee produced a report early in 2002 that indicated there was no "sound scientific basis" for the 2001 FWS Upper Klamath lake level requirements (NAS 2002), but failed to note that there was also no evidence that the requirements were wrong (McGarvey and Marshall 2005).

On May 31, 2002, both FWS and NOAA issued updated BiOPs requiring lake level and flow requirements that varied based upon expected basin inflows during the irrigation season. In September of that year, tens of thousands of Chinook and coho salmon were killed in the lower portion of the Klamath River due to parasite blooms

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[9] Endangered Species Act. 1973. 16 U.S.C.A. Section 1536: Interagency Cooperation.

triggered by excessively high water temperatures, which were caused by unusually low flows (CADFG 2003). Over the course of just two years, water shortfalls in the basin had caused $35 million in reduced farm profit and a devastating fish kill; this served to intensify the conflict between agricultural and environmental interests in the basin.

2.3 Agriculture

In response to increasing water demands to meet legal requirements for threatened and endangered species (hereafter referred to as ESA requirements), irrigated agriculture in the basin is at the center of a debate over how water should be supplied to meet competing needs. In the next three sections, the soil classes, crops, and irrigation technologies in the basin are examined. These descriptions are included primarily as background – data on basin soil classes, crop distribution, and irrigation technologies are presented in the methodologies chapter.

2.3.1 Soils

Soil class is an overall measure of the suitability of a given soil for agricultural production. It captures such characteristics of the soil as slope, elevation, organic content, drainage capacity and depth; each of these variables are important contributors to the productivity of a particular agricultural acre. The range of irrigable soil classes extends from class I to class V soils, where class I is the most productive and class V the least. Soil classes in the basin range from highly productive Class II soils to poorer Class V soils. The majority of class II soils are located in the agricultural areas south and east of UKL (the project area), whereas the majority of soils in the Williamson, Sprague and Wood sub-basins are class IV and V due to the high elevation and short growing season in those northern areas.

2.3.2 Crops

In addition to soil quality, the length of the growing season and susceptibility to frost are the primary determinants of cropping distribution throughout the basin. Depending on elevation and latitude, the growing season may vary from 50 to 120 days (Burke 2001). In the colder, higher elevation regions north of UKL, the primary crops include alfalfa, hay and pasture. In the eastern and western projects south of UKL, potatoes, mint, sugar beets, horseradish, onions and barley are also grown. Data on the farm-level economics and distribution of land values in the basin are included in chapter four.These crops have a wide range of water requirements: evapotranspiration varies from 20.9 inches (potatoes) to 33.5 inches (alfalfa hay) between April 1st and September 30th.

2.3.3 Irrigation Technology

Irrigation in the basin can be broadly categorized into flood and sprinkler technologies. Flood systems pour water from elevated irrigation canals directly onto agricultural fields (called flood basins), which must be leveled and sized based upon a range of soil and topographic characteristics. Sprinkler irrigation applies water directly to crops through pressurized piping and spray nozzles or sprinklers. Flood technologies include: earthen head ditch with siphon, concrete head ditch with siphon, gated pipe systems, surge flow gated pipe systems and cablegation gated pipe systems. Sprinkler systems include solid sets, hand lines, wheel lines and the self propelled linear and center pivot systems[10]. Each of the systems has different capital costs, variable costs, and irrigation efficiencies.

Irrigation efficiency (IE) is defined as the quantity of water evapotranspired by a crop divided by the quantity of water applied to the crop. The IE of sprinkler systems is generally higher than that of flood systems, although this need not be true if management and design of flood systems are appropriate[11]. Given the relatively low volume of water lost to deep percolation in most areas of the basin (due to hydrogeological separation of deep and shallow groundwater systems), the majority of excess water applied while irrigating tends to return to irrigation canals for reuse by other irrigators or ultimately to the Klamath River.

Each irrigation technology can be advantageous in different circumstances. Sprinkler systems may provide increased crop yields depending on the soil conditions, but this is not always the case[12]. Labor costs tend to be lower with sprinkler systems, but initial capital expenditures and subsequent energy costs are substantially higher. Sandy soil texture, high slopes or significant landscape undulation sometimes make flood irrigation impractical, and sprinkler irrigation is the only alternative. Data and

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[10] For descriptions of the flood systems, see Smathers, King and Patterson 1995, for descriptions of the sprinkler systems, see Patterson, King, and Smathers 1996 and 1996a.

[11] Based on personal communication with Marshall English, Professor of Biological and Ecological Engineering at Oregon State University, March 15, 2006.

[12] Ibid.

maps of the distribution of irrigation technology in the basin are provided in the methodologies section.

2.4 Hydrology

The surface water system is comprised of the three upper sub-basins, the Lost River sub-basin, and the project. Water enters the basin through precipitation and groundwater influx[13]. Precipitation varies widely across the basin, from a long term average of 12 to 14 inches annually at Klamath Falls to approximately 65 inches at Crater Lake (Rykbost and Todd 2003). Snowfall in the higher elevations within the basin accumulates during the cold winter months and serves as a source of late spring and summer inflows after rainfall has often stopped providing reliable flows. Groundwater will be covered in more depth in the next section.

The hydrology of the basin can be broadly categorized into two systems: the surface water coupled with the shallow groundwater system; and the deeper, less-directly aquifer less-directly connected to the surface water system that provides the bulk of agricultural groundwater in the region. Descriptions of these topics and how subirrigation may impact water management are provided below.

2.4.1 Surface Water

The three primary sub-basins within the basin above UKL are the Wood, Williamson and Sprague. Each of these channels water from the higher elevations in

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[13] The magnitude of groundwater influx is unknown but is likely very small and may potentially be negative (based on personal communication with Marshall Gannett, Hydrologist with the USGS, on November 4, 2006).

the northern portions of the basin through agricultural fields and into UKL, Oregon's largest natural lake by surface area. The area of UKL ranges from 60,000 to 90,000 acres depending on lake levels, and has an average depth of eight feet. It is the primary water storage reservoir in the basin, but its shallow depth makes storage of excess water between multiple seasons unfeasible. For example, record levels of precipitation fell on Klamath Falls between 1995 and 1998, yet the limited storage capacity of UKL barred inter-seasonal transfers of water to 2001, when critically low quantities were available. See Map 1 or Figure 4 for reference in the following description.

Water entering UKL is either channeled through the Link River Dam and into the Klamath River, or diverted into A-Canal, which is the main source of irrigation water for the western portion of Reclamation's project. A few miles south of Link River Dam, the Lost River Diversion channel moves water back and forth between the Klamath and Lost River sub-basins.

The Lost River is located southeast of UKL and originates in Clear Lake Reservoir. As it flows northwest, through the eastern project, it picks up additional water from Gerber Reservoir and enters the western project just past Harpold Dam. Once in the western project, the Lost River either gains or loses water at the diversion channel, depending on the time of year and irrigation demand. The Lost River terminates in Tule Lake (it is called the Lost River because it is a self-contained basin), from which excess outflows are pumped back into the Klamath River. The river then flows past Keno Dam and through two other hydropower dams prior to passing IGD at the boundary of the study area.

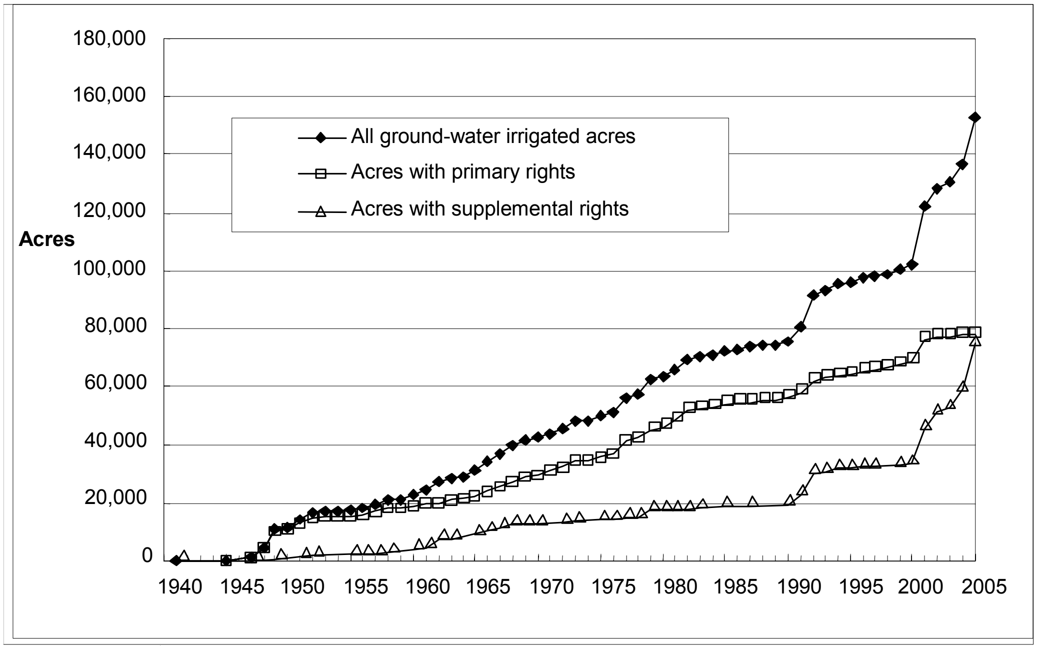
2.4.2 Groundwater

The geology of the basin helps to explain what little is known about the groundwater system. The majority of the basin is underlain by late Tertiary to Quaternary volcanic deposits. These tend to be permeable, but the region in the basin with the highest permeability falls in the Cascade arc in the northwestern portion of the basin. This region also receives the greatest amount of precipitation, and serves as a significant source of the basin's groundwater influx. Groundwater provides steady inflows to the major streams in the basin, and tends to integrate climatic conditions over multiple years. Thus, a dry year such as 2001 (with particularly heavy groundwater pumping) decreases groundwater recharge to the surface-water system over multiple years (Risley, et al. 2005a). Conversely, an extremely wet year would have the opposite effect.

Groundwater has been used for irrigation in the basin for approximately 50 years. Typically, groundwater levels have fallen during multi-year dry periods, but have recovered completely during subsequent wet periods. Recently, greater interest has been expressed in understanding the role of groundwater in future basin supplies, stimulating a joint study by the USGS and Oregon Water Resources Department (OWRD) launched in 1998, aimed at obtaining a better grasp of the groundwater dynamics in the basin. The expected completion date for this study is 2007 or 2008.

Primary and secondary groundwater pumping in the basin outside the project area in the 2000 water year was approximately 150,000 acre-feet (comprised of roughly 40,300 acres of groundwater-irrigated areas in California, and 19,300 acres in Oregon)[14]. Issuance of supplemental groundwater pumping permits in Oregon increased dramatically during 2001 in response to the lack of available surface water supplies (see Figure 2 below). In 2000, only one-third (19,300) of the roughly 60,000 acres permitted with primary groundwater rights were irrigated with groundwater. The source of this discrepancy lies in differences between actual and permitted pumping.

Figure 2: Historical Groundwater Rights in Oregon



Source: USGS[15]

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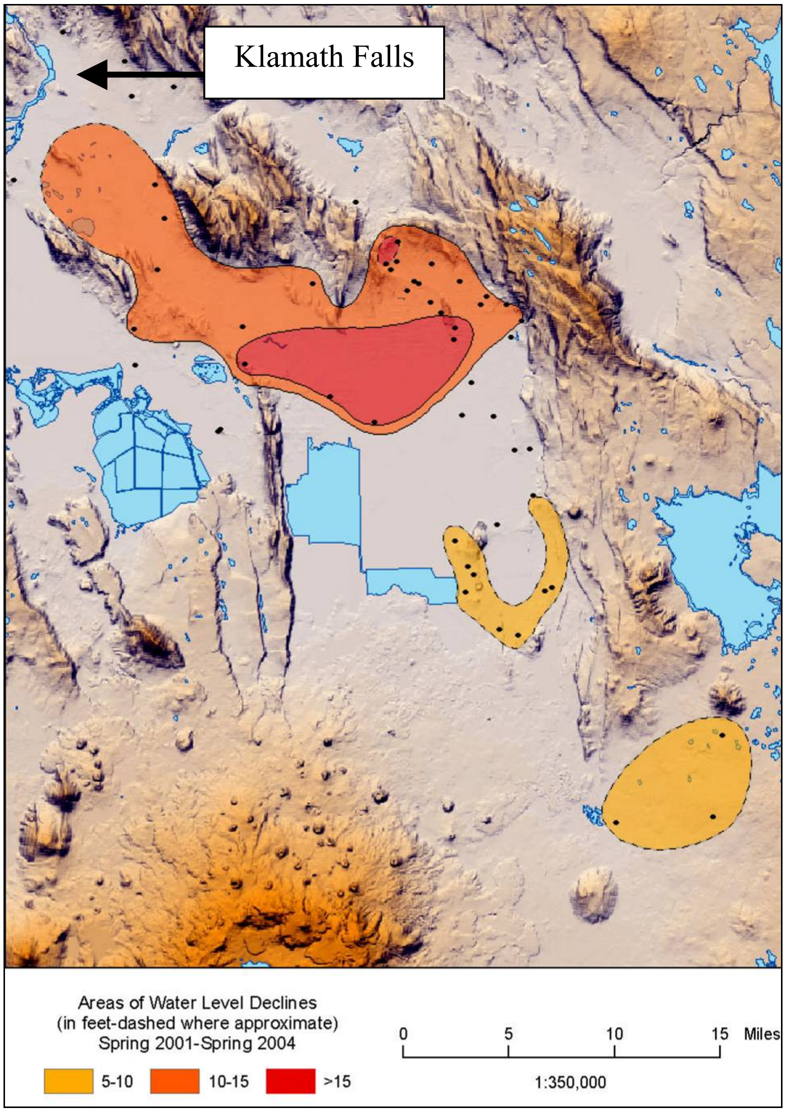
[14] Based on personal communication with Marshall Gannett, Hydrologist with the USGS, on November 4, 2006.

[15] Based on personal communication with Marshall Gannett on March 15, 2006.

Water bank payments have provided further incentives for groundwater pumping, resulting in roughly 56,000 and 76,000 acre-feet of additional pumping in 2003 and 2004. This represents a 37 and 51 percent increase, respectively, in groundwater pumping over 2000 levels (McFarland, et al. 2005). Much of the additional pumping occurred in a relatively small area in the vicinity of the Oregon-California border. In this area alone, pumping for the water bank has increased three-fold relative to historic pumping in the same area. These increases in pumping have resulted in inter-annual declines in groundwater of up to 15 feet between 2001 and 2004 in areas of high pumping (see Map 3 below). Klamath Falls is located in the upper left (northwest) corner of this map, and Clear Lake is the body of water located on the right (east) side of the map.

Map 3: Declines in Groundwater Levels: 2001 to 2004



Source: McFarland, et al. 2005

Because of the present lack of a physically-based model to predict the response of the groundwater system to particular pumping scenarios, studies such as this must make inferences about how much groundwater is available to irrigators in the short- and long-term using basic hydrological principles and historic observations. Making such inferences can be challenging, particularly given the sensitivity of the basin’s economy to groundwater availability. If groundwater recharge rates are incapable of sustaining long term pumping greater than historical averages without intolerable aquifer drawdown or impacts on streamflow, then groundwater may only be a small part of the solution to the increased water demands in the basin. If, on the other hand, groundwater pumping is found to draw water from the abundant sources of the Cascades to the northwest and result in acceptable impacts to streamflow and groundwater levels, then it may provide much needed supplies during the year.

2.4.3 Subirrigation

Due to the topography and soil conditions in some parts of the basin, groundwater often lies just below the soil surface and can “subirrigate” the root zone of plants and crops in the absence of surface irrigation or precipitation. The extent of subirrigation varies widely across the basin. In conjunction with Oregon State University, Reclamation has been developing estimates of the potential for subirrigation in the basin in order to estimate water returns from idled lands.

To illustrate the potential impact of subirrigation on returns from land idling, compare a hypothetical irrigated acre of alfalfa in the Wood River sub-basin to one in the project, each of which consumes 2.5 acre-feet through evapotranspiration. The Wood River flows through a relatively flat, marsh-like plain situated down gradient from Crater Lake. The Wood River acre is located adjacent to the stream and has groundwater levels inches (or a few feet) from the surface. The hypothetical project acre, on the other hand, is located a few miles from the Klamath River and has groundwater levels well below the root zone. Now imagine that both of these acres are idled to provide water for the Reclamation water bank. How much water is freed up by idling these acres? Imagine that crops or vegetation on the Wood River acre continue to consume 1.5 acre feet through subirrigation, whereas only 0.5 acre feet are consumed on the project acre. The net reduction in water use (which is the total volume of “bankable” water) is 1 acre-foot on the Wood River acre and 2 acre-feet on the project acre. In this example, idling the Wood River acre could increase diversions (and hence instream flow) far less than idling the project acre.

3 INSTITUTIONAL AND ECONOMIC CONSIDERATIONS

The following sections provide a background on the institutional, legal and economic factors which influence water supply and allocation in the basin.

3.1 <u>Institutions and Law</u>

"Institutions are collective conventions and rules that establish acceptable standards of individual and group behavior" (Bromley 1982). Three of these institutions are of particular importance in the basin: the prior appropriation doctrine, which is the overriding legal structure guiding water allocation in the basin; the ESA, which drives requirements for minimum lake levels and river flow requirements to preserve threatened and endangered species of fish; and the U.S. Farm Bill, which provides a significant source of funding irrigators through various farm programs administered by the NRCS. These three institutions are described below.

3.1.1 Prior appropriation and instream transfers

> "…the circumstances of an earlier era required extraordinary assurances of security in water rights in order to facilitate land settlement…intensifying water scarcity may be largely attributable to institutions which promote both allocative inflexibility and the perception of abundance" (Vaux 1986).

The prior appropriation doctrine specifies how water is allocated in the western U.S. The central tenant of the doctrine is "first in time, first in right", meaning that the priority of a right is based upon how early it was established. Accordingly, if the water supply any given season is limited, right holders with the most recent appropriation dates (junior appropriators) are the first to lose their right that year. Water rights under the doctrine are usefructory: that is, they are a right to use the water; ownership is in the hands of the states. Water use is tied to a specific location of application, location of withdrawal from the source, use (i.e. farming) and period of time during each year. If the rights holder wants to change any of these, applications must be filed with the local water master. Water must also be beneficially used without waste (the specific definitions of “beneficial” and “without waste” are somewhat vague and have been debated for quite some time) with no breaks in beneficial use for greater than five years. If such a break has occurred and is brought to the attention of the water master, the right is considered forfeited. Finally, water rights are based upon the quantity of water diverted as opposed to the quantity consumed.

Instream flows have long been known to have value [e.g. Berrens et al. characterizes the value of instream flows in New Mexico using contingent valuation methods (1996)], but only recently were instream flow rights recognized as “beneficial” in Oregon and California (in California they are qualified as flows for fish and wildlife). Both temporary and permanent transfers of water instream use have occurred in recent years, as evidenced by the success of the Oregon Water Trust (OWT), a non-profit organization whose mission “is to restore surface water flows for healthier streams in Oregon by using cooperative, free-market solutions”[16]. As of 2005, OWT has contributed over 140 cubic-feet per second (cfs) to Oregon’s streams

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[16] See the Oregon Water Trust website at http://www.owt.org/, accessed on July 22, 2006.

by negotiating with irrigators and other water rights holders to purchase both permanent and temporary instream rights. Their efforts are typically targeted at streams where small increases in flow can contribute significantly to the quality of fish habitat. This allowance in the prior appropriation doctrine has opened the door to permanent or temporary land idling in the basin for the sake of instream flow augmentation.

Marbut (2004) and Young (1986) provide a thorough explanation of some of the major impediments to water trading under the prior appropriation doctrine. Two are particularly significant in the Klamath. First, since the water right is for water diverted instead of consumed, the property right is incomplete – irrigators do not have rights to specific quantities of use, but rather to quantities of diversion, a fraction of which is expected to return to the source. For example, if the IE of an upstream irrigator increases (by switching from flood to sprinkler irrigation, for example) and that irrigator uses the recovered water to irrigate a larger area, consumptive use increases even though the diversion stays the same. This decreases return flows to downstream irrigators, who now have less water available in the stream for their use. The prior appropriation doctrine specifically forbids any water trading, transfers, changes in use or movement of point of diversion if the change negatively affects any third party. Accordingly, the above example would not be legally allowable. These restrictions limit the applicability of water trading in the basin.

The second major institutional restriction on water trading is that water rights in the basin have not yet been adjudicated. The prior appropriation doctrine was codified into Oregon law in 1909, making all rights established after that date officially part of the priority structure. A state authority must adjudicate all rights established prior to 1909 in order to verify their validity. In the Upper Klamath basin, a significant fraction of the water rights were established prior to 1909, including many large rights such as that held by Reclamation for their irrigation project[17] and federal reserved water rights held implicitly by Native American Tribes within the basin[18]. These latter rights will not be legally acknowledged until adjudication is complete, but are likely to displace many junior rights holders currently irrigating in the basin. Adjudication in the basin has been ongoing since 1975, and although a great deal of progress has been made, it will likely continue for some time. 700 claims were originally filed, and 5,600 contests were filed in protest to those claims (Hathaway and Welch 2003). Without quantified, adjudicated water rights, it has been challenging for irrigators to trade water.

Although water trading under the prior appropriation doctrine is restricted by the lack of consumptive use rights and prohibition against third-party impacts, water trading from agricultural rights can and does take place under its jurisdiction. The Oregon Water Resources Department (OWRD) processes approximately 250 applications for transfers each year, each of which must ensure that no third-party

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[17] This brings up a noteworthy fact: individual irrigators within the project do not hold rights to use water but are instead part of irrigation districts, which receive water from Reclamation based upon their priority within the project.

[18] Federal reserved water rights were officially recognized in the 1908 Supreme Court case Winters v. United States (207 U.S. 564.3). This case established that Native American tribes held implicit water rights as part of the establishment of reservations. The decision made these water rights senior to all others.

effects will be created (Jaeger 2004). Within the basin, the Reclamation water bank has been transferring significant volumes of water from agriculture to instream flows to meet NOAA requirements. Many of the transfers into the water bank would not be institutionally feasible between private irrigators, but political pressure in the basin has allowed the bank greater flexibility (a formal declaration by the Governor of Oregon allows the OWRD greater flexibility[19]). The same sort of allowances have been made recently in the southwestern United States, where severe water shortages have caused otherwise rigid barriers to become less restrictive in the face of need.

3.1.2 The Endangered Species Act and Biological Requirements

The ESA is a wide-reaching piece of federal legislation passed in 1973. The purpose of the ESA is to protect threatened and endangered species (listed species) and to provide direction for their recovery. The role of economic analysis in the listing of threatened and endangered species is limited – considering the least costly recovery approach is acceptable, but consideration of the benefits provided by the species is prohibited (Huppert 1999). For example, economic analysis is conducted when critical habitat for threatened and endangered species is initially proposed; areas expected to experience severe economic impacts may not be designated as critical habitat. Benefit-cost analysis is not used prior to listing a species, although benefits are implicitly considered when choosing recovery priorities (i.e., recovery of grizzly bears and coho salmon receives far greater attention than recovery of less visible

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[19] Based on personal communication with Marshall Gannett, Hydrologist with the USGS, on November 4, 2006.

species). It is considered a “taking” to kill any member of a listed species, and is punishable by criminal and civil laws. Congress established that the FWS and NOAA would be the agencies responsible for management of listed species, dividing responsibilities into land- and ocean- based organisms, respectively. In the Klamath Basin, the threatened anadromous coho salmon became the responsibility of NOAA, whereas the endangered Lost River and shortnose suckers fell under the jurisdiction of FWS. Although all individuals within the U.S. are legally bound to not directly or indirectly “take” a member of the species, the requirements on government agencies managing land within the “critical” habitat[20] of a listed species are more stringent. Under Section VII of the ESA[21], either FWS or NOAA is required to create a BiOP which gives the land-managing agency specific directions to enhance species recovery. The agency present in the basin is then held to proactively pursue species recovery. This obligation is what led Reclamation to curtail water deliveries to irrigators within their project in 2001.

The organization and requirements of the ESA have been the subject of criticism since its inception. Although it is not allowed in the listing process, economists have conducted benefit-cost analyses on various recoveries and concluded that results were mixed (Brown and Shogren 1998; Gerber-Yonts 1996). Boersma et al. (2001) analyzed the success and failure of recovery plans, concluding that the more successful plans typically have sufficient funding, are developed by interdisciplinary

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[20] Critical habitat is the area of threatened or endangered species habitat deemed particularly important to the survival of that species by NOAA or FWS.

[21] Endangered Species Act. 1973. 16 U.S.C.A. Section 1536: Interagency Cooperation.

teams and ultimately address the biological needs of the species. However, the authors also note that few species have legitimately recovered and subsequently been delisted. In terms of recovery, trade-offs often exist between political palatability and efficiency due to threshold effects[22]. If resources are distributed too widely throughout a basin due to political and equity considerations, the lowest possible benefits to society often result (Wu et al. 2003).

FWS has mandated minimum lake level requirements in those bodies of water that harbor either the shortnose or Lost River sucker. Clear Lake and Gerber Reservoirs have been assigned minimum annual lake levels, whereas UKL has been assigned monthly minimum level requirements that vary according to expected inflow. NOAA mandates variable minimum flows past IGD to promote recovery of the threatened coho salmon. In April of each year, the Natural Resources Conservation Service (NRCS) forecasts expected irrigation season inflows to the basin based upon early year snowpack and precipitation data. These forecasts are used by Reclamation in their annual Operation Plan to establish minimum monthly lake level requirements and IGD flows according to a schedule laid out in the BiOPs issued by FWS and NOAA in 2002. NRCS revises these estimates mid-irrigation season as more data becomes available.

Had the ESA been more relaxed it its requirements to maintain minimum lake levels and flows in the hydrosystem, no reduction in farm profits would have occurred in 2001 (Burke 2003). Adams and Cho (1998) construct an economic model of the

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[22] A minimum level of conservation is often necessary prior to realization of any recovery benefits

Reclamation project in order to assess the impact of the lake level requirements on farm profits. They found that the expected average cost of maintaining ESA lake levels is approximately $2 million annually, with those costs exceeding $15 million in severe drought years. Their research does not consider the possibility of additional groundwater pumping or land idling outside of the project, which may significantly mitigate these impacts. According to the USGS in their assessment of the Reclamation Water Bank, "Overall, a more continuous approach for setting flow and lake level requirements would likely be more favorable from biologic, hydrologic, and water management perspectives" (McFarland, et al. 2005).

3.1.3 The U.S. Farm Bill

The Farm Bill provides billions of dollars in annual support to farmers and ranchers across the U.S. in the form of subsidies and farm programs. Significant funds from the Farm Bill have been directed at the basin, particularly after 2001 when the issues faced by irrigators in the basin became an issue of national concern. One of the programs within the Farm Bill is the Environmental Quality Incentives Program (EQIP), managed by the NRCS. The goal of this program is to simultaneously promote agricultural production and environmental quality through structural and management improvements on farm and ranch lands[23]. Interest in EQIP has been growing, as evidenced by the increase in funding from $1.3 billion over seven years to $5.8 billion over five years, 39 percent of which has been directed at water

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[23] NRCS Environmental Quality Incentives Program (EQIP). Accessed on January 15, 2006, from http://www.nrcs.usda.gov/PROGRAMS/EQIP/.

management and conservation goals such as increasing IE (Frisvold 2004). One of the tasks of EQIP is to reduce agricultural water use by promoting water saving irrigation technology. To support this goal, NRCS will provide up to 75 percent of the funds (up to a maximum of $450,000) necessary to help farmers and ranchers purchase and install sprinkler irrigation technology to replace less efficient flood technologies. Once they receive aid under EQIP, the farmers must ensure the federal government that they will continue to use the sprinkler systems for between one and 10 years, depending on the contract.

Although the NRCS has been unable to provide data on the specific numbers of acres converted from flood to sprinkler technology under EQIP in the basin, significant acreages throughout the basin have reportedly been parts of the program[24]. Although sprinkler systems have greater IE than flood systems, research has suggested that in a basin such as the Upper Klamath that has relatively little capacity for deep percolation due to the presence of a shallow aquitard[25], the higher return flows from the less efficient flood irrigation may largely balance out the lower quantity of water initially applied by the sprinkler system (Huffaker and Whittlesey 2003)[26]. Furthermore, the tens of millions of dollars spent on these programs in the basin were done so in the presence of much lower energy prices than irrigators will face after the

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[24] Based on personal communication with Terry Nelson, NRCS Watershed Planner, Portland, OR in July 2005

[25] A relatively impermeable barrier comprised of fine-grained, compressed, or compacted material that prohibits or retards the upward migration of groundwater.

[26] Runoff from flood irrigation does contribute to subirrigation in non-crop areas in the basin, which may be substantially diminished if large areas of flood irrigation are transferred to sprinker.

contract expiration with PacifiCorp, bringing into question whether replacement of flood technologies with more energy intensive sprinkler technologies will lead to undesired consequences for those irrigators participating in the program. Cattaneo (2003) has demonstrated that approximately 17 percent of all EQIP program participants withdraw due to the inclusion of unprofitable practices in the initial proposal. This behavior indicates that many of the irrigators participating in this program may be in no position to bear the additional costs imposed by dramatically increasing energy rates.

3.2 Economics

Although economic instruments do not provide a complete solution to the challenges facing the basin, more effective use of water markets and water banks and more appropriate valuation of water may substantially lessen conflicts and uncertainties over water resources. These topics, along with a brief overview of issues related to energy prices, are covered in the following sections.

3.2.1 Water Markets

Although the prior appropriation doctrine and physical characteristics of water have limited the extent of water trading, economists have noted the advantages of a more flexible market system for decades (Howe, Shurmeier and Shaw 1986; Vaux 1986). In environments of fully committed water resources (such as in the Colorado basin and Southern California), water markets have been shown to effectively reallocate water between competing users (Bjornlund 2003). Easter, Dinar, and

Rosegrant (1998) suggest that incentives must be changed such that “users support the efforts to reallocate water”, which will provide many of the efficiency gains of any normally operating market. Kaiser and Phillips (1998) show how market mechanisms helped to ease conflict over groundwater in Texas’ Edwards Aquifer, which was experiencing unsustainable withdrawals. Studies have also been conducted demonstrating institutional constraints present in Reclamation projects (Moore and Negri 1992) and on the efficiency gains to both irrigators and taxpayers from transfers of Reclamation-subsidized water to both project and non-project users (Wahl 1989). In politically delicate water conflicts, Dinar and Wolf (1994) suggest that purely economic solutions can often be non-optimal if political issues have not been properly considered.

In the presence of minimum environmental flow requirements, Willis and Whittlesey (1998) demonstrate that water markets are the most cost-effective policy. Willis et al. (1998) have shown the cost-reducing benefits of using contingent contracts for preservation of instream flow during critically low flow years on the Snake River. During similarly low flow years on the Snake River, water used for hydropower is estimated by another study to be ten times more valuable than water used for irrigation, providing motivation for the establishment of interruptible water markets (Hamilton, Whittlesey, and Halverson 1989).

Jaeger (2004) constructed an economic model of the basin, investigating what would have happened in 2001 had a fully functioning water market been present. The model replicates a market by curtailing water deliveries only to the lowest value farmland. Initial results that replicated the events of 2001 confirmed that profit reductions under the no trading scenario were approximately $33.4 million (losses were calculated at $35 million for the actual event). Given the 20-fold difference between the maximum and minimum marginal value of water applied to land in the basin, water markets reduced the impact on economic profits to $8.3 million when water use was optimized, a 75 percent reduction in losses.

Many conditions are necessary for a fully functioning market. According to Griffin and Hsu (1993), three elements must be present for a water market to be feasible: transferable diversion and consumptive rights, well-studied return flows to internalize third party effects, and some institutional mechanism to oversee the trading. Livingston (1998) adds that reallocation of the resource given changing conditions must be possible, and Ciriacy-Wantrup (1956) points out that institutions underlying markets must create sufficient security and flexibility - critically important when marketing a common property resource. Howe, Schurmeier and Shaw (1986) identify five shortcomings of water markets: property rights are often difficult to designate given the lack of available information; the market prices may not take into consideration full opportunity costs due to geographic boundaries and negative externalities; the supply is not predictable, so the market is not predictable; markets may understate social values, such as environmental concerns, community impacts and equity; and the geographic separation of small parties causes information transfers facilitating market clearing prices to be challenging. An additional shortcoming is that markets have social costs, as demonstrated by Bjornlund and McKay (2000), who conduct over 300 phone interviews with buyers and sellers of water rights in a rural-to-rural water market in southern Australia. They conclude that although water markets do create substantial economic gains, individuals within irrigation communities can experience financial hardship and social dislocation as a result of their introduction.

3.2.2 Water Banks

A water bank is an institutional structure that serves as a clearinghouse for the purchasing and selling of water rights in a market. In this respect, the Reclamation water bank in the basin is not truly a bank, in that it is taxpayer funded (causing distortionary taxes) instead of self-perpetuating and has only one buyer instead of many. Water banks were originally created to allow water transfers between agricultural users, but have increasingly focused on transferring those rights to urban or environmental uses. For example, Idaho's water banks began transferring water between agricultural uses and have steadily moved toward greater numbers of transfers from agriculture to instream flow since their formation in 1979 (Green and Hamilton 2000; Simon 1998). In 1991, a five-year drought prompted development of the California water bank, which purchased more than 800,000 acre-feet of water and sold approximately 650,000 acre-feet, (leaving 150,000 for environmental flows) (Loomis 1992). Studies have also been conducted on the shortcomings of water banks, one of which is inflexible pricing. Green and O'Connor (2001) demonstrated that fixed water prices in the Idaho water bank have obstructed instream flow goals set by Reclamation for the Lower Snake River, but point out that more flexible pricing causes potentially negative community effects and increases administrative costs. Burke, Adams and Wallender (2004) have evaluated the shortcomings of the Reclamation water bank in the Upper Klamath basin, established in 2002. The above authors show that extending bank boundaries to include regions outside of the project, which have lower marginal values of applied water, would significantly reduce the cost of bank operations.

3.2.3 Energy Prices

Few studies have investigated the impact of dramatic increases in energy prices on farm profits and land retirement. Jaeger (2004a) conducted a study of the economic impacts of abrupt energy price increases on irrigated agriculture in the Upper Klamath basin. He finds that the most significantly impacted parties will be those who use high-pressure sprinkler irrigation systems. Three different estimates of future energy expenditures were compared: economic projections contrasting current with expected future costs, cross-checking with the energy expenditures of other similar agricultural regions that have standards prices, and engineering estimates based on the energy demands of the irrigation and delivery systems. Taking the average of these approaches, he finds energy prices rise from roughly $4 per acre to $40 per acre, very similar to the values used in this analysis. Jaeger then subtracts these additional costs from per acre rents on agricultural land and finds that all soil class V acres and a meaningful fraction of soil class IV acres may not be profitable after energy prices rise. Sprinkler irrigators who are capable of switching to less energy-intensive technologies, such as efficient sprinkler systems or flood irrigation, may do so.

Owners of those economically vulnerable acres that cannot make these changes due to the expense or the physical characteristics of the land may have to retire those acres. Studies have also shown the efficiency benefits of energy and water desubsidization in the San Joaquin Valley Reclamation project (Ulibarri, Seely, and Willis 1998).

3.2.4 Water value

The institutional, economic, and physical characteristics of water make its valuation a challenging task. The value of water can be defined in a number of ways. One is approximating the value of the water as an input to an economically profitable venture. In the case of agriculture in the Klamath, the value of water would then be indirectly estimated by observing the increase in land rent when water is applied; this is the approach chosen for this analysis. Another approach is to capture the various components of land value in a model and statistically separate out the value of water, controlling for other possible influences. Faux and Perry (1999) used this approach (called hedonic analysis) to estimate the value of agricultural water in Malheur County, Oregon at $32 per acre, $35 per acre, $67 per acre, and $105 per acre for soil class V, IV, III, and II lands respectively. A third approach values water as if it were traded in a market. This market may involve trading only among irrigators, or may involve expanding the market to other uses (e.g., water trading between agriculture and urban uses in Southern California). In the Klamath, this study focuses primarily on a market between irrigators, brokered through a water bank. The value of water would then be the price where the buyers' marginal willingness to pay was equal to the sellers' marginal cost. If there were 1000 acres of irrigable land in an agricultural economy and only 900 could be irrigated, the market price (and thus the marginal value of water) would be between the rent of the 900th and 901st most valuable acre (given perfect information). If it sold for more than this, too few acres would be irrigated and there would be excess supply; if it sold for less, then there would be excess demand and the price would be bid upward. With this in mind, in 1999 the Idaho Water Bank charged $10.50 per acre-foot for single-year leases[27]. Jaeger and Mikesell (2002) provide a review of recent Oregon and Washington Water Trust water rights and lease purchases. Based on these market transactions, annualized water right purchases averaged $9 per acre-foot, whereas yearly leases averaged $23 per acre-foot in Oregon and $57 per acre-foot in Washington. The authors note that this set of observations makes senses because irrigators incur fixed costs when land is idled for only a single year (i.e., from unused farm equipment), whereas in the long-run (as reflected in the $9 annualized value) irrigators are able to sell off this equipment and eliminate these costs.

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[27] Idaho Water Bank. Accessed on October 24, 2006, from http://www.idwr.state.id.us/waterboard/water%20bank/waterbank.htm

4 MODELING FRAMEWORK

This study has four objectives: 1) evaluate the costs of an abrupt increase in ESA flow requirements with and without water trading flexibility; 2) evaluate the impact of energy price increases on water availability and the distribution of irrigation technologies in the basin; 3) assess the sensitivity of farm profits to changes in ESA requirements; and 4) investigate the potential role of groundwater in future basin water supplies.

These objectives are addressed using a mathematical optimization model and a separate Geographic Information System (GIS)-based model of hydrologic, agronomic and economic data. The mathematical programming model links a series of irrigation seasons (from March to October), which are hydrologically interconnected by groundwater and lake levels. The model uses 1962 to 2002 data from Reclamation to represent potential future water conditions in the basin. Hereafter, 1962 through 2002 results imply results from years with similar hydrological conditions to those years rather than the years themselves. The model reflects farmer behavior by maximizing farm profits in the context of institutional and physical constraints. Multiple models are constructed to address the objectives, each with a specific arrangement of water bank flexibility, ESA requirements, net bankable returns, energy rates and groundwater availability. The following sections provide a description of the approach taken, an explanation of the data used in the model, and a detailed exposition of the model.

4.1 Description of Approach

Commenting on a linear programming (LP) model constructed to simulate economic and hydrologic dynamics in South Platte River agriculture, Robert Young, one of the central figures in the development of water resource economics, states, “Although the simulation greatly simplifies the actual physical and economic setting, it represents an inexpensive way to analyze the allocative and distributive consequences of alternative rules” (Young, Daubert and Morel-Seytoux 1986). This study centers on hydrological and economic LP and GIS-based models of the Upper Klamath basin. LP is a method of optimizing an objective function subject to a set of linear constraints, and has been widely used in water resource planning and management. In the basin model, total net farm revenues (the objective) are maximized (or optimized) subject to hydrologic, agronomic, economic and institutional restrictions (the linear constraints). The LP method was developed by G.B. Dantzig in the 1940s to manage the enormous complexities of World War II supply logistics (see Danzig 1963). Since that time, many computer programs have been developed to deal with LP problems in a more approachable manner; one of the most recent is the Generalized Algebraic Modeling System (GAMS), discussed below. GIS (Arc/Info) is also used throughout this study as a tool for both display and analysis of data. Unlike the LP model, GIS is not used to directly evaluate the research questions, but instead processes and inputs data to the LP model. In the following sections, a review of previous models and an overview of the model used in this study are provided.

4.1.1 Economic Optimization

Economists assume that a business will vary the levels and types of inputs and outputs given limited resources in order to maximize profits. The total revenue of a business is the output price multiplied by the quantity of units sold, and the total costs are simply the expenditures on all inputs (labor and capital). Profits are total revenues minus total costs, which the business tries to maximize. In an agricultural economy, the business is the farm or ranch, the revenue-providing outputs are crops, and the input expenditures include labor, equipment rents, seed, fertilizer, etc. Accordingly, maximization of profits can be considered the objective function of the farmers and ranchers, and the constraints include restrictions on the timing, quantity and availability of resource inputs in creating desired outputs.

4.1.2 Linear Programming

Here, the basics of LP optimization and a description of the LP program Generalized Algebraic Modeling System (GAMS) are provided. In an LP problem, the set of constraints can be visualized as establishing the geometric region of feasible solutions. In an LP problem with n variables, there will be an n-dimensional region of feasible solutions. The objective function is therefore an n-dimensional surface which slices through this region of feasible solutions, and can be moved within that space to maximize (or minimize) its magnitude. Assuming that the region is in fact bounded (a finite n-dimensional region), then one can visualize a point where a tangency between the objective function surface and the outer edge of the region will maximize the magnitude of the objective function. The simplex method is an iterative procedure designed to identify this point. It will solve any bounded linear programming problem in a finite number of steps (Hadley 1962). The method involves moving along an edge of the region of feasible solutions from extreme point to extreme point (basic feasible solutions in the language of linear algebra) until the optimal solution is found. This point is identified as the solution because it gives the greatest increase (or decrease) in the magnitude of the objective function over the initial starting condition[28].

A wide variety of computer programs are capable of optimizing an objective function subject to a set of linear constraints. GAMS, which is a computer programming language with built in linear and non-linear programming solvers, was chosen for this study due to facility of use and applicability. It is specifically geared toward solving these types of problems[29].

4.1.3 Previous River Basin LP Models

LP has been used to construct river basin models to study water allocation in dozens of previous studies. The goal of one LP study by Young, Daubert and Morel-Seytoux (1986), common to many such studies, was to "formulate a model of the hydrologic, economic, and agronomic system and the water allocation institution which characterize a stream-aquifer-based agricultural production system and then to employ the model to evaluate alternative institutional arrangements for managing the

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[28] For a more thorough description, see Hadley (1962) or Baumol (1977).

[29] For more details on GAMS, see the updated user's guide by Brooke, et al. (1998) and the online textbook by McCarl and Spreen (1997).

system". An LP model was used to demonstrate the substantial benefits of completely open water markets in the basin (Jaeger 2004). Adams and Cho (1998) apply an LP model to assess the impacts of various UKL level restrictions, and Burke, Adams and Wallender (2004) use the method to demonstrate that the adoption of irrigation efficiency improvements can have negative impacts on basin-wide water savings in the Klamath. A forthcoming study uses an LP model to show that highly variable, semi-arid hydrological systems are best modeled using models of individual seasons as opposed to the more popular long-run models when evaluating impacts on agriculture (Ewers et al. Forthcoming). McKinney and Kenshimov (2000) construct a large-scale LP model to optimize and analyze water resource and energy use and management in the Syrdarya basin, one of the tributaries to the Aral Sea. In another study, environmental water values for fisheries and wetlands are integrated into an economic-hydrologic LP river basin model using multiple, weighted objectives in a single objective function (Ringler and Cai 2003). McKinney and Cai (2002) construct a linked GIS-LP model of a river basin using GAMS, an integration which has immense analytical benefits. Finally, Ulibarri, Seely and Willis (1998) analyze the impact of energy and water subsidies in the San Joaquin Valley using an LP model of the hydrology and economy of the region.

4.1.4 Overview of Klamath Model

This project focuses on how water availability affects irrigator profits and land idling given a range of institutional, physical, and economic potentialities. It is therefore necessary to have information on the profits, fixed costs and variable costs which accrue to each acre of surface-water irrigated agriculture in the basin for the objective function. A simplified version of the objective function for the basin is included below.

$$\Pi = max\sum_i [\pi_i a_i^I - \phi_i a_i^D - \psi(e_i^I + e_i^G)]$$

Where:
Π=maximum net revenues from surface water-irrigated agriculture
i=location index (area, soil class and irrigation method)
π_i=net revenues from irrigating one acre in each location
ϕ_i=fixed costs incurred by idling one acre in each location
a_i^I, a_i^D=acres of land irrigated/idled in each location
ψ=energy price
e_i^I, e_i^G=irrigation/groundwater pumping energy use in each location

The above function represents the profits which accrue throughout the basin over the course of a single irrigation season. Annual profits which accrue to each irrigated acre are based on annualized land values. When acres are idled, profits are lost and additional fixed costs are incurred. The subscript i represents a particular irrigation technology nested within a soil class which is further nested within a Klamath assessor-defined area. These areas defined by i are assumed to have homogeneous crop rotation and thus evapotranspiration characteristics. Energy costs for groundwater pumping and irrigation are separated from the other implicitly included variable costs (built into profits, which are revenues minus fixed and variable costs) because they vary based upon PacifiCorp's energy price and are not internalized in current land values. The energy costs above (as modeled) are only non-zero if additional groundwater is being pumped or if electricity rates are greater than the historical value, driving irrigation energy costs higher than they have been historically.

It is also necessary to have information on the constraints on the key input - water. The first constraint states simply that the idled acres and irrigated acres in any soil class within any Klamath Assessor area must sum to the maximum agricultural acreage in that area:

$$a_i^I + a_i^D = \mathrm{A}_i$$

Where:
A_i=total acres in each location

The overall water balance in the basin is given by equating the monthly amount of water evapotranspired by agriculture to the monthly system inflows less the water used by the lakes (positive or negative) less the flow through IGD plus groundwater inputs:

$$\sum_i [a_i^I \varepsilon_{mi}^I + a_i^D \varepsilon_{mi}^D] = N_m - L_m - D_m + G_m$$

Where:
m=month index (march to october)
N_m=monthly inflow (exogenous)
L_m=monthly lake storage or recharge
D_m=monthly Iron Gate Dam flow
G_m=monthly groundwater contribution
$\varepsilon_{mi}^I, \varepsilon_{mi}^D$=evapotranspiration from irrigated/idled acres each location each month

The above equation is the key constraint on the objective function, or farm profits, in the basin. If the right hand side of the constraint is less than the agricultural water requirements any given month, profits are restricted. The annual inflows to the system enter at UKL, Clear Lake, Gerber Reservoir and in the form of groundwater accretions between Keno and Iron Gate Dams. These exogenous inflows are simply monthly and yearly historical data from Reclamation intended to replicate historical conditions. Lake water use is dependent upon whether lake levels increase or decrease any given month, and is institutionally constrained by FWS requirements. Minimum IGD flow is constrained by NOAA requirements, and groundwater is constrained by maximum pumping rates allowed to vary in a sensitivity analysis.

The model optimizes the objective subject to each of these constraints for each year that the model is run. This model can be static or dynamic (multi-period); the dynamic version of the model is used to investigate possible impacts on groundwater over various periods. Each of the constraints above, along with a more detailed objective function, is expanded and described in section 4.3.

4.2 Model Data

Construction of the basin model required a considerable amount of data. Data on the geography, agronomy, economics and hydrology of the basin were collected and used to support the model. The following sections discuss and present these data.

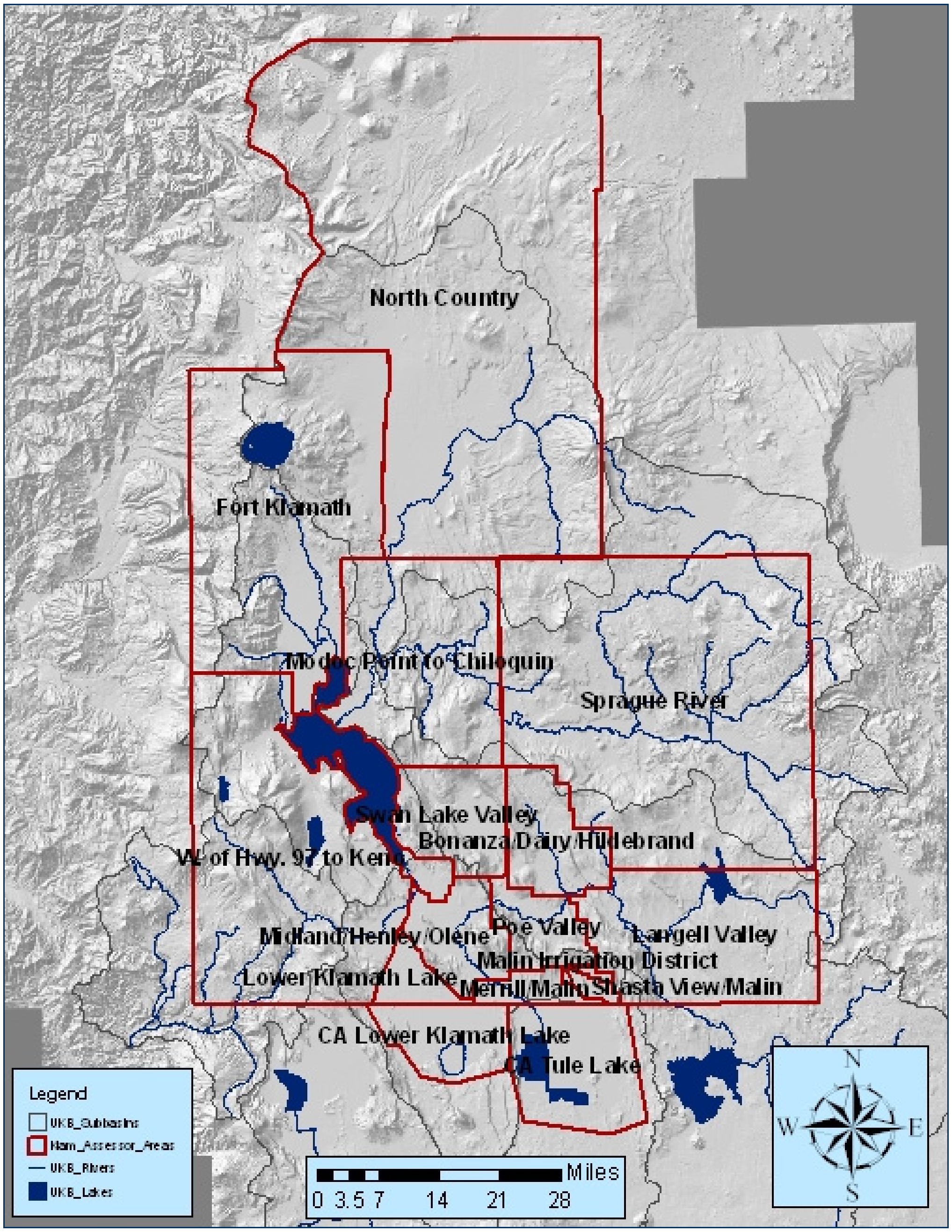
4.2.1 Geography

The above model is based upon a spatially heterogeneous agricultural landscape of economic and agronomic variables. The following section provides insights into the sources, assumptions and structure of the data used to represent that landscape.

4.2.1.1 Arrangement of Irrigated Agriculture

The basin is delineated into 14 areas in Klamath County, and an additional two areas in Siskiyou and Modoc Counties in California. The 14 areas in Klamath County were arranged according to the Certified Farm Use Study conducted annually by the Klamath County Assessor's (Assessor) office, which bases the areas upon sub-basins and irrigation districts arranged throughout the basin. The Certified Farm Use Study provides soil class acreages within each area, as well as typical crop rotations for each of these dozens of soil class-assessor area combinations. The geographic boundaries of each area were defined based on a map of these areas provided by the Assessor, which was digitized and brought into the GIS geodatabase. The two California areas not defined by the Assessor are defined according to the geographic extent of irrigated agriculture in the basin, which is based on GIS layers of the region from the California Department of Water Resources (CDWR). The Assessor areas and the CDWR areas were joined to form a basemap of the entire basin. These 16 areas are displayed on Map 4 below.

Map 4: Upper Klamath Basin Area Classification



Soil classes (from the NRCS GIS layer) were subsequently overlain upon an NRCS layer of agriculture in the basin, which was then incorporated into the

Assessor-provided area map in GIS. The result was a categorization of each area into soil classes. This process was repeated for irrigation technology data, based on NRCS data from a combination of satellite imagery analysis and field data collection. This provided the model a set of geographically differentiated areas with distinct characteristics (crop rotation, land value, irrigation technology) on which to run the analyses. Finally, a 10-meter Digital Elevation Model (DEM) from the USGS was added to the GIS basemap in order to allow slope analysis of the sprinkler-irrigated areas in the basin. Accordingly, there are 43 "soil units" in the basin, which are the acreages within a particular soil class in a given area (for example 36,828 acres of class IV soil in the North Country area would represent one soil unit). Each "irrigation unit" acreage is represented by either flood or sprinkler technology within each soil unit. There are a total of 78 of these. Each of the soil units is assigned a common land value and crop rotation, which will be discussed in further depth in the following sections.

4.2.1.2 Designation of Subregions

The areas defined above were aggregated into a separate categorization called subregions. These subregions include the upper sub-basins above UKL (the upper basins), the Lost Basin, and the project. The purpose of this classification was to provide an arrangement within the model capable of restricting water trades to those which are institutionally feasible due to the potential presence of third-party effects for certain transfers (i.e. from the upper basins to the project but not vice-versa).

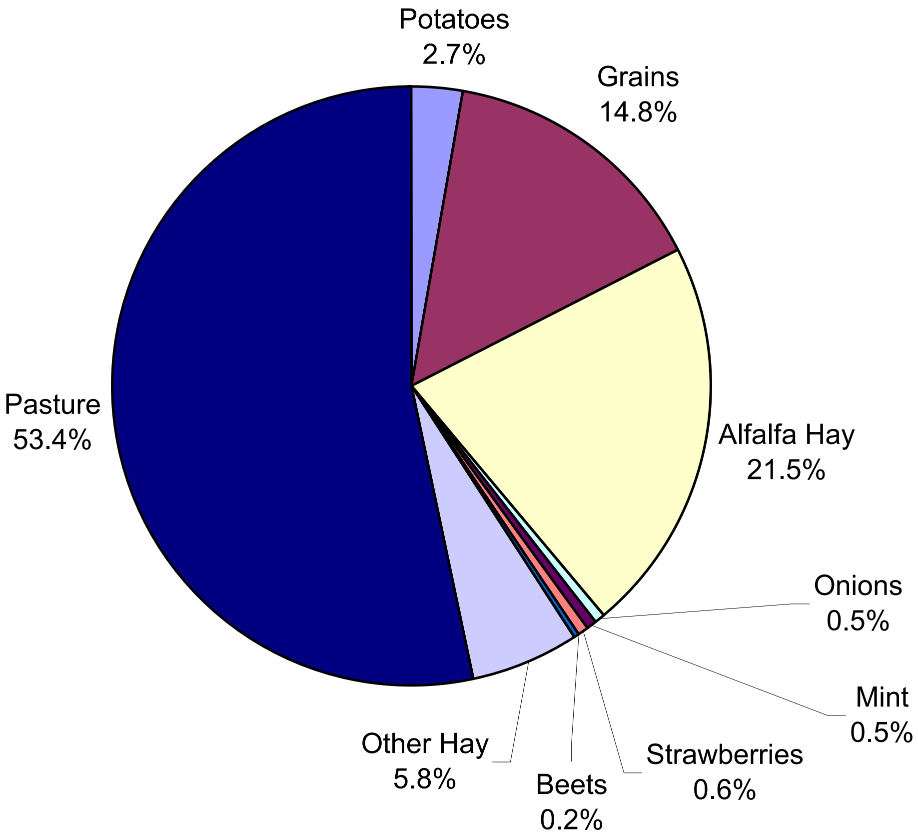
4.2.2 Agriculture

Agricultural information used in the basin model includes data on crop rotations, crop evapotranspiration, soil classes, and irrigation technologies within the basin. These are described below.

4.2.2.1 Crop Rotations

In order to calculate the overall ET of the irrigation units described above, it was necessary to collect data on typical crop acreages for these areas. Given the model specification, it was necessary to have crop acreages in each of the soil units that were representative of a typical year. The "typical year" of acreages was represented by historical crop rotations for each soil class within each area. This is based upon the assumption that the average fraction of each crop in each soil unit will be given by the crop rotation of that soil unit. For example, if the representative crop rotation for area A, soil class II is one year of potatoes, five years of alfalfa, and then two years of grain, it is assumed that the soil unit (area A, soil class II) will be planted with 62.5 percent alfalfa, 12.5 percent potatoes and 25 percent grain. By extension, each acre in the soil unit can be seen as this same representative mix. Representative crop rotation data for the soil units within the 14 areas in Klamath County came from the Klamath County assessor's Certified Farm Use Study for 2005-06 (LeQuieu 2006) and Reclamation crop reports for 2000 and 2002 through 2004. 2001 was excluded due to the high quantity of idled acres in the project. For those soil units in the two areas in California, data came from the CDWR, Reclamation and the Tulelake Irrigation District. Crops included in the study include: pasture, potatoes, grains, alfalfa hay, onions, beets, mint, strawberries and other hay. A pie chart showing the composition of basin crops (as modeled) is provided in Figure 3 below. A table displaying more detailed data (the fraction of each crop in area rotations by soil class) is provided in Appendix A. These data are based on original values provided by the Klamath County Assessor and the other data sources mentioned above.

Figure 3: Crop Coverage in the Upper Klamath Basin



The original arrangement of Assessor area acreages was adjusted to remove groundwater-irrigated acres and adjust to NRCS acreages. Fractions of crops in each rotation (provided for each soil class in each area) were assumed to remain constant through these acreage adjustments. This analysis also assumes that the collective mix of crops in any soil unit cannot deviate from the representative rotation described above[30].

4.2.2.2 Crop Evapotranspiration

Crop evapotranspiration data were gathered from the Reclamation Agrimet system. This system is comprised of a network of automated climate-data gathering stations spread throughout the U.S. Each day, the reference evapotranspiration is logged based on a variety of climatic factors[31] (Reclamation 2003-2006). This value is then used to calculate daily evapotranspiration values for the crops cultivated in the region surrounding the stations. Daily data for Klamath Falls from 1999 and 2005 (those years available) were summed over each month and then averaged over the 7 years. The range of evapotranspiration values extends from 20.96 (potatoes) to 33.62 (alfalfa) inches of water from each acre.

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[30] Clearly, this limits irrigator flexibility, but it is also clear that the alternative – an entirely flexible model which has no restrictions on deviation from rotations – is highly unrealistic (otherwise all acres with appropriate conditions would permanently produce high-value potatoes) due to the agronomic impacts of different crops on the soil. Given the relatively minimal variation in aggregate soil unit crop evapotranspiration in the basin (see evapotranspiration section), major shifts in crop composition in any soil unit would need to occur for any significant reduction in water consumption to take place. This assumption likely mildly overstates the impact on irrigators.

[31] Evapotranspiration data from Bureau of Reclamation, 2005. "The Pacific Northwest Cooperative Agricultural and Weather Network Evaportranspiration Summaries". Retrieved August 15, 2005 from http://www.usbr.gov/pn/agrimet/etsummary.html.

Table 2: Monthly Evapotranspiration for the Major Crops in Upper Klamath Basin

	Crop Type (data in inches)								
Crop Evapo-transpiration	Potatoes	Grain	Alfalfa Hay	Onions	Mint	Straw-berries[32]	Beets	Other Hay[33]	Pasture
March	0.000	0.136	0.120	0.000	0.000	0.000	0.000	0.120	0.294
April	0.000	1.165	2.234	0.000	0.000	0.083	0.019	2.234	2.067
May	0.514	4.495	5.450	1.250	1.234	1.419	0.586	5.450	4.351
June	3.302	8.124	7.087	4.539	5.209	6.886	3.153	7.087	5.644
July	7.428	8.096	7.851	8.030	8.454	8.704	7.416	7.851	6.254
August	6.739	1.146	6.517	6.334	7.309	5.433	7.576	6.517	5.180
September	2.942	0.000	4.363	1.086	2.063	0.550	4.564	4.363	2.976
October	0.032	0.000	0.000	0.000	0.000	0.000	0.930	0.000	0.000
Annual Totals	**20.96**	**23.16**	**33.62**	**21.24**	**24.27**	**23.07**	**24.24**	**33.62**	**26.77**

To find the quantity of water consumed annually on a representative acre of each soil unit, monthly evapotranspiration values for each crop are multiplied by the share of each crop and summed over the irrigation season. These values are provided in Table 3 below. The range of annual evapotranspiration rates in these soil units is from 24.71 (Tule Lake, Soil Class IV) to 32.15 (Poe Valley, Soil Class II). As can be seen in Appendix A, the primary crops in Tule Lake are grain, alfalfa and potatoes, whereas in Poe Valley they are alfalfa and pasture.

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[32] Horseradish is also planted in the basin but not included here – no evapotranspiration data could be found for horseradish, so those acres are included in the strawberry data. Given the very small total acreage (<1 percent) in horseradish, any difference in actual evapotranspiration will have little impact on final results.

[33] No data were available for the "other hay" category (a crop type listed by the Klamath Assessor) in the Agrimet system, so Alfalfa Hay is used in its place.

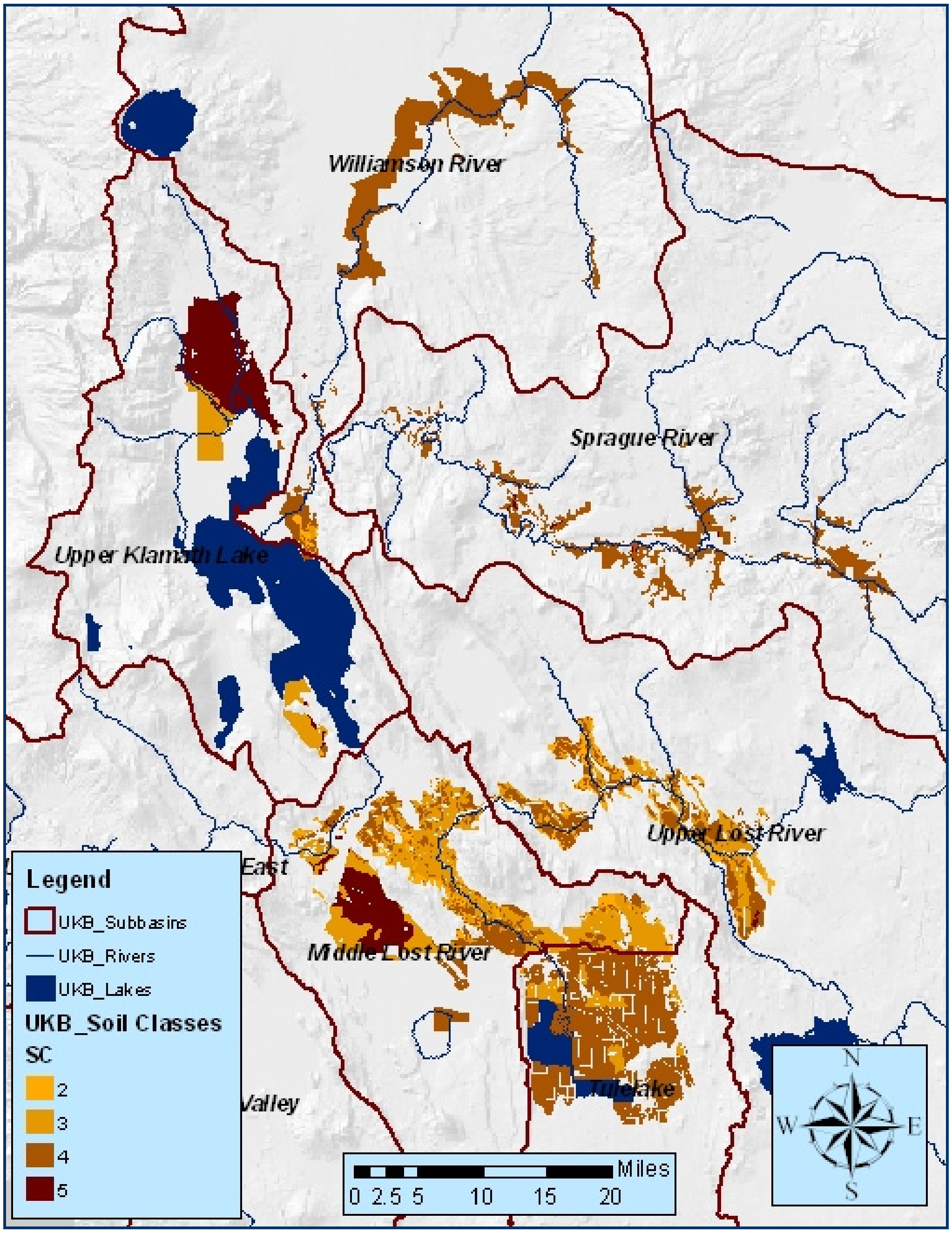
Table 3: Annual Evapotranspiration in each Area and Soil Class

	Soil Class (data in inches per irrigation season)				
Description	II	III	IV	V	Overall
Upper Basin Subregion					
Fort Klamath Valley	-	26.77	26.77	26.77	**26.77**
Modoc Point to Chiloquin	29.63	32.00	26.77	26.77	**27.19**
Sprague River	-	-	26.77	26.77	**26.94**
North Country	-	-	26.77	-	**26.77**
Lost Basin Subregion					
Bonanza/Dairy/Hildebrand	30.97	33.25	26.77	-	**29.68**
Langell Valley	32.41	29.81	26.77	26.77	**28.76**
Project Subregion					
Merrill/Malin	30.04	30.15	26.77	-	**28.71**
Poe Valley	32.15	29.98	26.77	-	**28.41**
Midland/Henley/Olene	30.15	30.74	26.77	-	**29.57**
Lower Klamath Lake	27.84	25.61	26.77	26.77	**26.31**
Malin Irrigation District	28.49	30.71	26.77	-	**29.39**
Shasta View Irrigation District	28.04	29.86	31.57	-	**29.83**
West of Highway 97 to Keno	30.48	29.27	26.77	26.77	**28.72**
Tule Lake/California Portion	25.01	27.39	24.71	-	**25.00**
LKL/California Portion	-	23.16	26.77	-	**26.61**

4.2.2.3 Soil Classes

Soil class data were obtained from the NRCS soil survey of the region conducted in 1985. See the map of soil classes on surface water-irrigated agriculture included below (Map 5). Note that the majority of acreage in the upper basins is classes IV and V, whereas project and Lost Basin acres tend to be classes II through IV (also observed in Table 4). This distribution of soil classes is a proxy for the distribution of land values, and motivates the assertion that introduction of water markets could stimulate upper basin irrigators to trade water into the project.

Map 5: Upper Klamath Basin Soil Classes of Surface Water Irrigated Acres



As described in the geography section above, NRCS soil class and agriculture data were used in concert with the area boundary data to form a layer of soil units across the basin. Soil surveys of most of Klamath County and the significant portions of Modoc and Siskiyou Counties were provided by the NRCS in GIS format. The final GIS-calculated acreages of each soil unit (for example, Poe Valley, soil class III) often significantly diverged from the values listed in the Assessor's 2005-2006 Certified Farm Use Study. This is assumed to largely be a reflection of the methods used by the assessor to calculate acreages from their taxlot map and the fairly coarse nature of the NRCS soil and agricultural maps. Methods used to rectify these differences and refine acreage estimates are described in the following paragraphs. The table included below provides the acreages for each soil unit used in the final model.

Table 4: Soil Unit Acreages

	Soil Class					
	II	III	IV	V	VI	Total
Upper Basins Areas						
Fort Klamath Valley	0	7,390	0	26,447	0	**33,837**
Modoc Point to Chiloquin	916	406	9,294	593	0	**11,208**
Sprague River	0	4,947	25,043	457	0	**30,447**
North Country	0	0	36,828	0	0	**36,828**
Lost River Basin Areas						
Bonanza/Dairy/Hildebrand	3,107	2,987	5,025	0	0	**11,119**
Langell Valley	3,333	10,167	11,263	240	0	**25,004**
Reclamation Project Areas						
Merrill/Malin	604	10,136	7,984	0	0	**18,723**
Poe Valley	1,888	1,630	5,867	0	0	**9,385**
Midland/Henley/Olene	4,252	19,703	9,115	0	0	**33,071**
Lower Klamath Lake (OR)	70	10,000	584	14,200	0	**24,855**
Malin Irrigation District	585	1,632	626	0	0	**2,843**
Shasta View Irrigation Dist.	526	5,055	439	0	0	**6,019**
West of Highway 97 to Keno	617	8,079	1,784	1,039	0	**11,519**
Tule Lake	0	6,830	55,446	0	2,240	**64,515**
Lower Klamath Lake (CA)	0	190	3,857	0	389	**4,436**
					Total:	**323,808**

Generally, when a conflict arose between agricultural acreages provided by the Assessor and the NRCS data, the NRCS geospatial data were given preference due to the more recent NRCS assessment of acreage within the basin. Once the initial acreage calculations were performed in GIS, several additional procedures were used to refine the values and make them suitable for this analysis.

The first procedure was elimination of groundwater-irrigated acres from the soil units. Both groundwater and surface water irrigated lands were included in these initial numbers from the Assessor. Groundwater used for irrigation was assumed to originate from the deeper aquifer, which was further assumed to be hydrologically disconnected from the surface water system over the course of a single irrigation season. Accordingly, groundwater irrigated acreages were removed from the model by paring down agricultural acreages in the NRCS GIS data. This trimming of acres was done geospatially by clipping the NRCS GIS layer based upon an outline of the project and Lost River basin acres provided by the Irrigation Training and Research Center in San Luis Obispo, California (Burt and Freeman 2005). These adjustments were checked for accuracy using estimates of groundwater-irrigated acreage provided by the Assessor[34]. The resulting acreages were assumed to be the only surface water irrigated acres in the lower portion of Klamath County[35]. This process eliminated

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[34] Excluding groundwater-irrigated acres may underestimate the amount of water in the hydrosystem due to return flows entering the system from groundwater used for irrigation. This is assumed to be captured in the hydrological calibration, discussed in the hydrology section below.

[35] In the tables that follow in this and later sections, it is worth noting that only 15 of the 16 areas in the have non-zero acreage. This is because the area designated as Swan Lake Valley is comprised

large areas within Langell Valley, Bonanza and Poe Valley, most often on the outer fringes of these areas and likely groundwater-irrigated. The final acreage within the project is roughly 215,000, which is close to the final value from Reclamation of approximately 200,000 irrigated acres. In the Sprague sub-basin, NRCS GIS data specifically separated groundwater from surface water-irrigated acres, making elimination of these groundwater acres straightforward. No other adjustments associated with groundwater were made to the upper basins.

Second, all acreage in soil classes poorer than class V were eliminated from the soil units under the assumption that these areas were miscategorized as agricultural acreage by the NRCS (with one exception[36]). In many cases, this may not be a valid assumption as certain class VI acres may be irrigable, which would imply that certain soil unit acreages are underestimated.

Third, several area-specific adjustments were made to calculated acreages given information provided by sources other than the NRCS. These include adjustments to aggregate Williamson basin acreage[37] and soil classes[38] and to the class V soil class in the Oregon area of Lower Klamath Lake[39].

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primarily of either extremely low-productivity ranchlands or groundwater irrigated soils, and is thus not included in the analysis.

[36] The exception to this rule is in Tulelake and Lower Klamath Lake in California, where the class VI acres were reclassified as class IV acres in order to make these acreages meet known cropping reports from Reclamation. Given that some higher soil classes may still be irrigable, the acreages in this model are a likely to be a subset of the actual acreages present in the basin.

[37] The assessor estimated 23,820 acres whereas NRCS estimated 56,807 acres. These differences are likely due to the uncertain extent of wild flood-irrigated acreage in this sub-basin. The USGS estimated approximately 40,000 acres, which was an intermediate value and set as a target for the adjustment. To adjust the acres in GIS to these values, the 36,828 acres closest to the Williamson River were selected.

4.2.2.4 Irrigation Technologies

Irrigation technology is relevant to this model for three reasons: flood versus sprinkler water consumption, crop yield and energy consumption. Crop yield and energy consumption will be discussed in the energy section of this chapter below. IE is often falsely assumed to determine the water consumption of a given irrigation technology. Typical IE values for flood systems range from 60 to 90 percent, and for sprinkler systems from 65 to 95 percent. For a hypothetical flood irrigation efficiency of 50 percent (for the sake of simplicity), if two feet of water are applied to a particular acre, crop consumptive use is one foot. If no return flow is assumed, a change in technology to a sprinkler system will result in significant water savings. However, depending on the hydrogeology of the basin, return flow may bring the majority of the unused water back into the stream. A study estimated that 63% of all irrigation diversions from the Snake River made it back to the stream in return flow (Hydrosphere Resource Consultants 1991 in Huffaker and Whittlesey 2003). Another study concluded that from a hydrological perspective, the only way to increase water availability in a basin is to decrease consumptive use; improving application efficiency simply changes the location and timing of water availability (Green and Hamilton 2000). In the Klamath basin, the shallow aquifer is hydrologically linked to the

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[38] There was no soil class data available for the Williamson sub-basin. Since there was no reasonable way to break the single NRCS GIS shape into different classes, the entire area was categorized as class IV, which was the predominant soil class according to the Assessor (70%). The remaining acres were categorized as 22% class III and 8% class V. This simplification underestimates the value of agricultural acreage in the Williamson.

[39] Approximately 14,000 acres of NRCS-designated class V NCL (non-irrigable class V soil) was reclassified as class V CL (irrigable class V soil) in order to bring the NRCS and Assessor acreage estimates into reasonable proximity to one another.

surface water system, and thus captures and stores the majority of unused irrigation water until it is returned to the surface water system (Burke 2001).

The modeling further assumes that there is no long-term impact of idling on pasture growth and success. Fixed costs do not consider the impact of multi-season idling of pasture, a long-lived crop which experiences significant losses in clover content when not irrigated for long periods. Clover provides protein to grazing cattle and allows for more rapid weight gain[40].

Data on irrigation technology came from multiple NRCS and CDWR GIS coverages of land use, in which agricultural land is broken into sprinkler- and flood-irrigated acres. These data were based on a combination of direct observation and reporting by irrigators. By overlaying these GIS layers upon the soil unit layers described above, acreages of irrigation technology within each soil unit were calculated. These are designated as irrigation units, as defined in the geography section above. A map and table of basin-wide irrigation technologies are provided below (Map 6 and Table 5). Note that of the 112,321 acres in the upper basins, 100,398 are in flood (10.6 percent). On the other hand, 58.6 percent of the 211,489 acres in the project and Lost Basin are sprinkler-irrigated. Although land values are lower in the upper basins, they may be more sheltered from increases in energy prices due to the lower energy requirements of flood irrigation.

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[40] Based on personal communication with Reg LeQuieu, Klamath County Assessor, on January 31, 2006.

Map 6: Upper Klamath Basin Irrigation Technologies

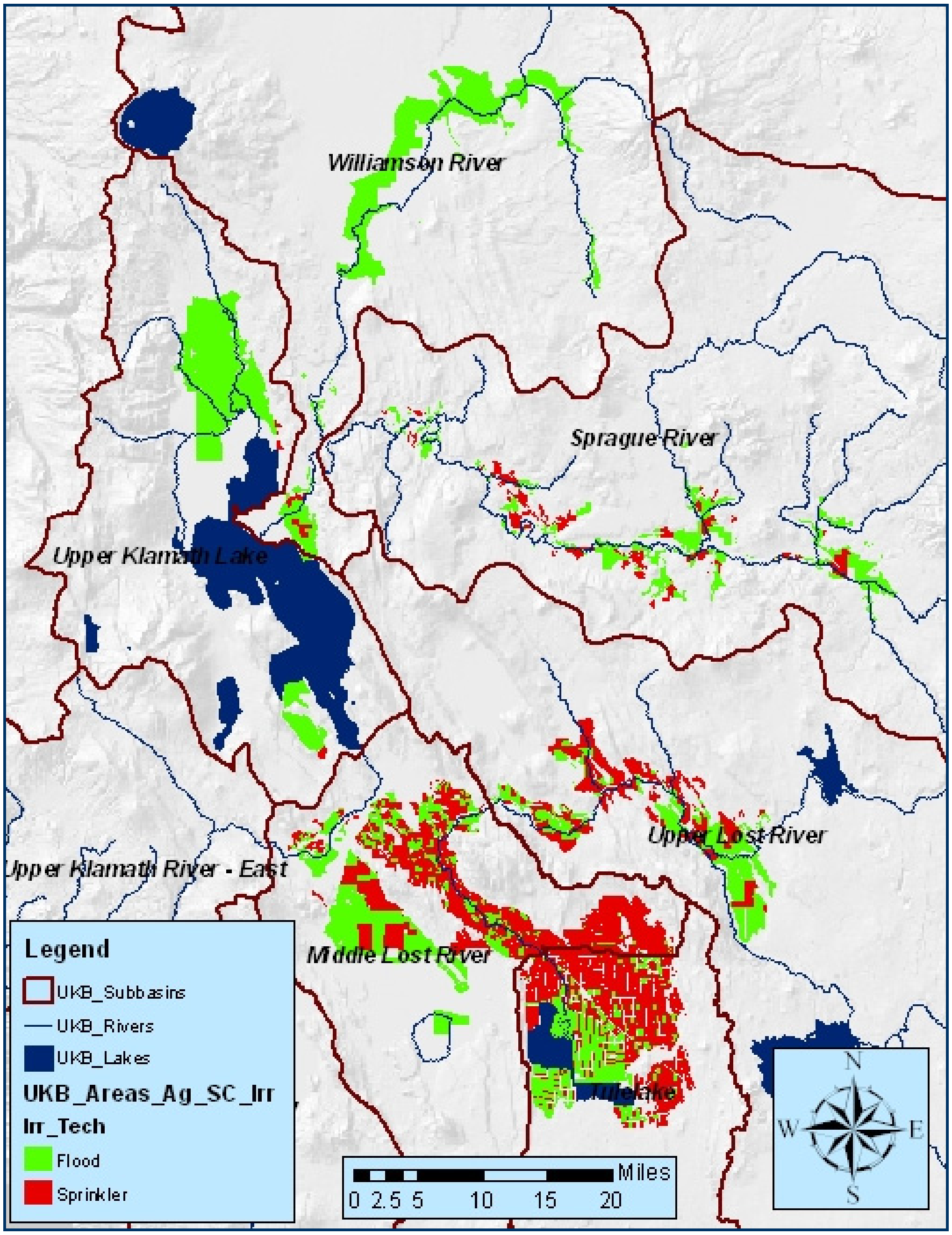

Table 5: Irrigation Unit Acreages[41]

	Soil Class and Irrigation Technology										
	II		III		IV		V		VI		Total
	Flood	Sprinkler	Flood	Sprinkler	Flood	Sprinkler	Flood	Sprinkler	Flood	Sprinkler	
Upper Basin Subregion											
Fort Klamath Valley	0	0	7,390	0	0	0	26,447	0	0	0	**33,837**
Modoc Point to Chiloquin	567	349	349	57	7,351	1,943	504	89	0	0	**11,208**
Sprague River	0	0	0	4,947	20,581	4,462	381	76	0	0	**30,447**
North Country	0	0	0	0	36,828	0	0	0	0	0	**36,828**
Lost Basin Subregion											
Bonanza/Dairy/Hildebrand	325	2,782	533	2,454	1019	4,006	0	0	0	0	**11,119**
Langell Valley	1,426	1,907	6,703	3,464	7,842	3,421	240	0	0	0	**25,004**
Project Subregion											
Merrill/Malin	64	540	583	9,553	2,096	5,888	0	0	0	0	**18,723**
Poe Valley	624	1,264	900	730	2,843	3,024	0	0	0	0	**9,385**
Midland/Henley/Olene	623	3,629	5,286	14,417	4,126	4,989	0	0	0	0	**33,071**
Lower Klamath Lake	14	56	8,281	1,719	294	290	7,444	6,756	0	0	**24,855**
Malin Irrigation District	0	585	0	1,632	0	626	0	0	0	0	**2,843**
Shasta View Irrigation District	32	494	72	4,983	36	403	0	0	0	0	**6,019**
West of Highway 97 to Keno	162	455	7,058	1,021	1,171	613	1,019	20	0	0	**11,519**
Tule Lake/California Portion	0	0	1,638	5,192	20,398	35,048	0	0	214	2,026	**64,515**
LKL/California Portion	0	0	190	0	3,857	0	0	0	389	0	**4,436**
Total	**3,837**	**12,061**	**38,983**	**50,169**	**108,442**	**64,711**	**36,035**	**6,941**	**603**	**2,026**	
									Flood Total:		**187,900**
									Sprinkler Total:		**135,908**
									Total:		**323,808**

4.2.3 Economics

The significant range of soil classes in the basin reflects a much more dramatic underlying spectrum of agricultural productivity. In an agricultural economy, the real market value of land reflects its discounted future stream of annual net revenues from farming (Jaeger 2004). Land values were based on information from the Klamath,

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[41] Note that these figures do not include recent increases in sprinkler-irrigated acreage due to NRCS EQIP spending.

Modoc and Siskiyou County assessors. The Klamath data are based upon a real market value analysis conducted by the Klamath Assessor in 2001. These values have not been adjusted for 2006, but likely provide a more realistic valuation due to recent market distortions introduced by the Reclamation water bank[42]. The Siskiyou and Modoc values are based on land sales information for the past few years[43]. A table showing these data for each soil unit is provided below. Note the significant differences between per-acre value both between soil classes and between areas.

Table 6: Average Market Values of Irrigated Lands in the Upper Klamath Basin

		Soil Class (data in $/acre)			Non-irrigated
	II	III	IV	V	VI
Upper Basin Areas					
Fort Klamath Valley	-	1,100	850	600	400
Modoc Point to Chiloquin	1,700	1,100	850	600	400
Sprague River	-	1,000	750	300	200
North Country	-	750	750	250	200
Lost River Sub-Basin Areas					
Bonanza/Dairy/Hildebrand	2,100	1,450	750	370	200
Langell Valley	2,100	1,450	750	370	200
Reclamation Project Areas					
Merrill/Malin	2,600	1,350	1,000	500	300
Poe Valley	2,600	1,400	1,000	500	300
Midland/Henley/Olene	2,600	1,400	1,000	500	300
Lower Klamath Lake	2,600	1,900	1,000	300	300
Malin Irrigation District	2,600	1,900	1,000	300	200
Shasta View Irrigation District	2,600	1,350	1,000	300	200
West of Highway 97 to Keno	1,700	1,100	850	600	400
Tule Lake/California Portion	2,600	1,800	1,100	400	300
Lower Klamath Lake/ CA	2,600	1,800	1,100	-	300

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[42] Based on personal communication with Reg LeQuieu, Klamath County Assessor, on January 31, 2006.

[43] Based on personal communication with and limited data from Dave Bensen and Lori Foster, the Modoc and Siskiyou County Assessors on November 15 and 22, 2005.

The linear programming model maximizes annual profits that accrue to each acre of property. These profits are constructed based upon the assumption that land value in an agricultural economy reflects the underlying profitability of the land. As land values are categorized in terms of soil units, it is assumed that soil class reflects underlying agricultural productivity[44]. Given the concept of Ricardian rents, land value is the discounted future stream of expected net revenues, implying that land rents are the land value multiplied by the current discount rate (see Conradie and Hoag 2004). Ricardian rents represent the economic profits which accrue to the land in an agricultural economy[45]. Thus, if the land value of interest is class II soils in Merill/Malin and the discount rate is 6 percent, then the annual rent which is attributable to that acre is 0.06 times $2,600 per acre, or $156 per acre per year. These marginal land values are included in the table below.

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[44] The variability in these land values within the same soil class reflects the fact the soil classification system does not capture all of the characteristics that contribute to agricultural productivity. For example, the general differences in value between the upper basin and project acres within the same soil classes (i.e. North Country class IV at $750/acre versus Malin class IV at $1,900/acre) reflect the relatively short growing season of the upper basins due to climate.

[45] Economic profits are fundamentally different than financial profits. When calculating economic profits, all factors of production are treated as costs that detract from net revenues. It is assumed that all factors of production (such as farm machinery, fertilizer or labor) are used such that their opportunity costs of switching to alternative uses are zero, or, such that there are no better uses for those factors. In the case of economic farm profits, net revenues would be crop sales minus all input costs, which would include the costs of employing all factors of production (including the manager's salary). Thus, economic profit in an agricultural economy is the value added to farm products by the land, or land rental rates. Farmers who do not own land are still willing to pay their entire expected economic profits in rent because these profits do not include their salary, which they receive from their efforts.

Table 7: Marginal Land Values in the Upper Klamath Basin

	Soil Class (data in $/acre/year)				Average
	II	III	IV	V	(Weighted)
Upper Basin Areas					
Fort Klamath Valley	-	66	51	36	43
Modoc Point to Chiloquin	102	66	51	36	55
Sprague River	-	60	45	18	45
North Country	-	45	45	15	45
Lost River Sub-Basin Areas					
Bonanza/Dairy/Hildebrand	126	87	45	22	79
Langell Valley	126	87	45	22	73
Reclamation Project Areas					
Merrill/Malin	156	81	60	30	74
Poe Valley	156	84	60	30	83
Midland/Henley/Olene	156	84	60	30	87
Lower Klamath Lake	156	114	60	18	58
Malin Irrigation District	156	114	60	18	111
Shasta View Irrigation District	156	81	60	18	86
West of Highway 97 to Keno	102	66	51	36	63
Tule Lake/California Portion	156	108	66	24	70
Lower Klamath Lake CA	156	108	66	-	68
Average (unweighted)	142	83	55	25	
Average (weighted)					64
Estimates from Malheur County, OR[46]	105	67	35	32	
Av. Marginal Water Value	121	68	37	9	

The goal of "maximizing net revenues" in the context of this analysis involves maximizing the value of water applied to land. The marginal values above represent the potential profit from irrigating a particular acre of land within a given soil unit. If that acre is idled, the marginal value of that acre is assumed to be zero unless partially

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[46] Estimates from Malheur County, OR based on a hedonic price study (Faux and Perry 1999)

subirrigated[47]. In certain regions, irrigators participating in the water bank have found that a certain fraction of their pasture crop is still viable due to subirrigation. Accordingly, they have maintained a fraction of their original grazing productivity during those months[48]. This led us to assume that the total fraction of productive land on any given idled acre would be the ratio of subirrigation to evapotranspiration (if subirrigation is 1.5 feet and ET is 2.5 feet, 60 percent of the land is assumed to make net revenues). Thus, only the non-subirrigated fraction of each acre is assumed to incur curtailment costs, and the remaining portion of each acre is assumed to earn normal levels of net revenue[49].

Additionally, idled lands incur fixed costs due to market inflexibilities. In an agricultural economy, there would be few or no fixed costs in the presence of a perfect market; fixed costs are primarily the consequence of market imperfections such as transaction costs and imperfect information. For example, if a perfect market is

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[47] One limitation of the model is that no deficit irrigation is allowed. This reduction in irrigator flexibility may overestimate the impact of curtailed irrigation water.

[48] The calf/cow pairs and yearlings raised by ranchers depend on pasture grown by irrigators. Yearlings are one year-old cattle that are sent to graze in pasturelands (such as those in the Klamath basin) to add weight over the summer months prior to being moved onto a feedlot and then butchered. If the pasture grazed upon by these cow/calf pairs and yearlings is idled, the lost profit is not from declined crop sales, but rather from decreased herd sizes. The issue is that herds must have continual access to food. Past experience with ranchers idling pasture in the Wood River sub-basin has shown that they have flexibility in the number of yearlings they choose to bring up from California, where they store their cow/calf pairs for the winter. Typically, a herd may be comprised of 25% cow/calf pairs and 75% yearlings, which are bid upon by the ranchers prior to the start of each season. As long as 25% of the pasture acreage can be preserved for any rancher, the cow/calf pairs can survive and the yearlings can go elsewhere (based on personal communication with Ron Hathaway, Livestock Extension Agent with Oregon State University on January 18, 2006).

[49] This assumption likely overstates the benefit of subirrigation, as the majority of acres will be incapable of capturing the full amount of water available, particularly acres where a fallow crop is planted. The alternative, that no profits are gained from idled acres, flies in the face of observed evidence.

assumed, the tractor used on an idled 160 acre farm would be assumed to transfer directly to its next highest use on some other farm. As the farmer would be receiving the rental income for the tractor which was previously provided by the use of the tractor for farming, no fixed costs are incurred. In reality, however, finding other farmers who need a tractor for that particular season is often impossible due to imperfect information, and once that opportunity has been found, the relocation costs may be prohibitive due to transaction costs. These costs that are incurred by the farmers are the "fixed costs" of the model, which will be present whether or not the irrigator sells crops that season. Thus, idling land results in both foregone economic profits and lost fixed costs. Fixed costs for each soil unit are proved in Table 8 below. These fixed costs are from the Oregon State University Extension service crop enterprise budgets.

Table 8: Annual Fixed Costs Incurred from Irrigation Curtailment

	Soil Class (data in $/acre/year)				
	II	**III**	**IV**	**V**	**Average (weighted)**
Upper Basin Areas					
Fort Klamath Valley	-	25	25	25	25
Modoc Point to Chiloquin	154	140	25	25	40
Sprague River	-	162	25	25	25
North Country	-	25	25	25	25
Lost River Sub-Basin Areas					
Bonanza/Dairy/Hildebrand	195	185	25	25	115
Langell Valley	128	31	25	25	41
Reclamation Project Areas					
Merrill/Malin	174	169	25	25	108
Poe Valley	159	92	25	25	64
Midland/Henley/Olene	159	181	25	25	135
Lower Klamath Lake	169	63	25	22	39
Malin Irrigation District	151	141	25	25	117
Shasta View Irrigation District	155	148	163	25	150
West of Highway 97 to Keno	128	92	25	25	78

	Soil Class (data in $/acre/year) II	 III	 IV	 V	Average (weighted)
Tule Lake/California Portion	121	121	25	19	35
Lower Klamath Lake (CA)	121	121	25	-	29
Average (unweighted)	151	113	34	24	
Average (weighted)					55

These fixed costs assume that idling occurs at unpredictable times during rotations (year 0-5 of a 5 year alfalfa rotation) and is forced upon the farmers. This overestimates costs, since farmers are expected to wait until the end of a given rotation (i.e. between alfalfa and potatoes), prior to idling land. This way, they would not incur any of the productivity losses associated with an abridged multi-year rotation. On the other hand, the curtailment costs assume that all labor will find additional work elsewhere. This includes working landowners whose salary is comprised of both land rent and farm labor/management. This may considerably underestimate costs, as a certain percentage of the labor force will not be capable of finding work elsewhere. Overall, it is impossible to predict whether assumptions about the effects of subirrigation and the magnitude of fixed costs would have a positive or negative influence on calculated impacts of land idling.

4.2.4 Hydrology

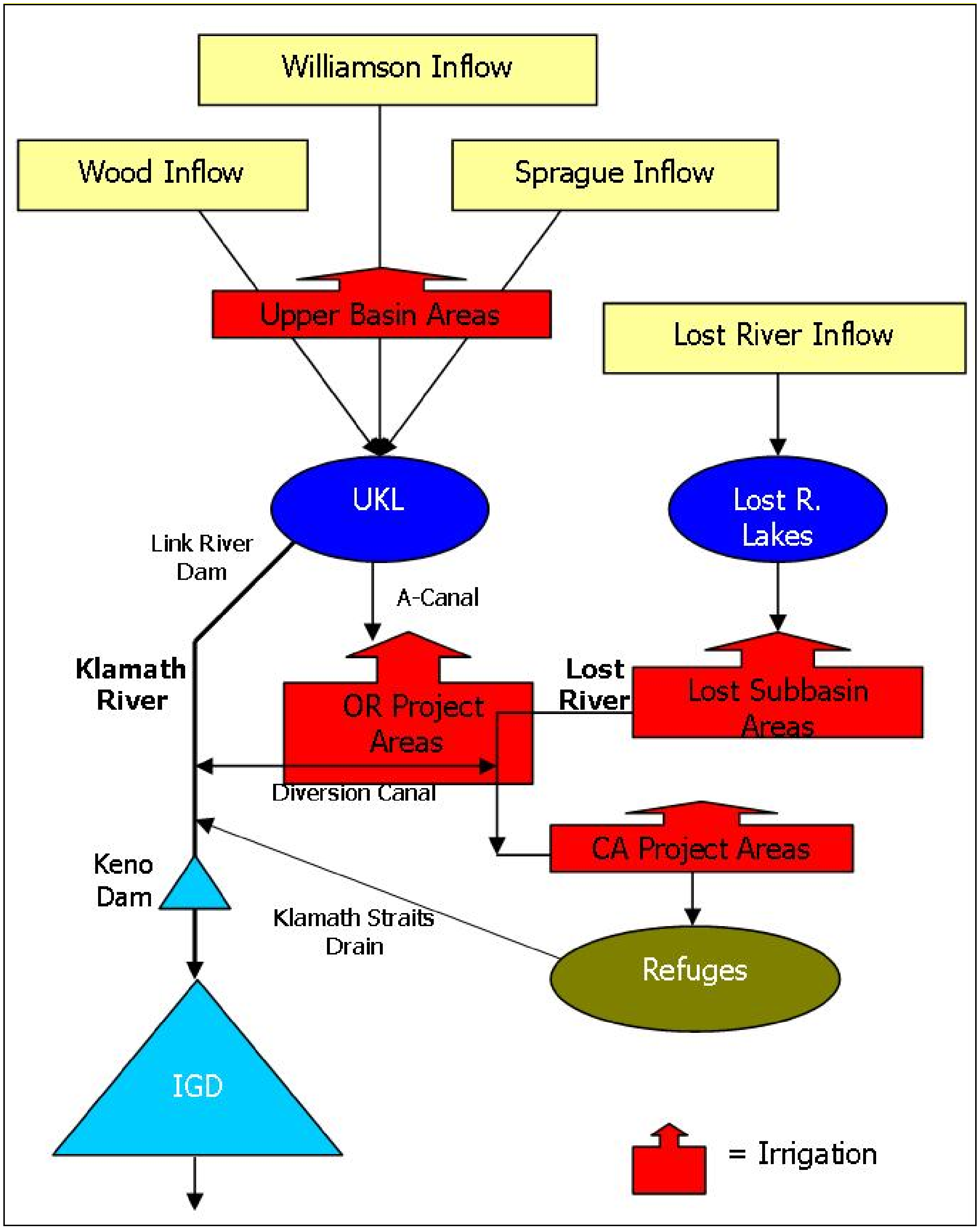
Precise modeling of any hydrosystem is an impossible task. Even approximate modeling of the Upper Klamath basin presented many challenges. First, little is known about the recharge rate or general response to pumping of the aquifers beneath the basin, making quantification of the dynamic response of groundwater to withdrawal uncertain. Second, the surface water system is more certain but by no means straightforward to quantify – outflows through deep percolation and inflows through spatially heterogeneous precipitation and groundwater accretions confounded attempts at modeling precision. Additionally, inter-seasonal transfers required estimation of groundwater and lake level recharge rates based on limited historical data. The sources of hydrological data and how these challenges were addressed are discussed in the following paragraphs.

4.2.4.1 Surface Water Hydrology

In order to properly and reasonably represent possible flows within the basin, the model was divided into three sub-regions: the upper basins, the Lost River basin, and the project. The project can receive water from either of the other two, but the Lost and upper basins are only allowed to receive water from sources contained within their boundaries. Figure 4 below displays the organization of subbasins in the Upper Klamath Basin. The Williamson, Wood, and Sprague Rivers flow through irrigated agriculture (upper basin areas) and into Upper Klamath Lake, which delivers water to the project by way of the A-canal and to the Klamath River through Link River Dam. The Lost River flows from Clear and Gerber Lakes (Lost River Lakes on the diagram), which delivers water to the Lost basin areas. The Lost River flows through the project, is augmented by Klamath River water through the Lost River diversion canal, and then flows into the California portion of the project and to the wildlife refuges. Water flowing out of the refuges is then pumped back up along the Klamath Strait

Drain and into the Klamath River, which flows past Keno Dam, and finally Iron Gate Dam.

Figure 4: Diagram of the Upper Klamath Basin Hydrosystem



Three main elements in the surface water system are described in the following paragraphs: measured inflows, fluctuation of lakes and refuges, and outflows past Iron Gate Dam.

4.2.4.1.1 Inflows

Data Description and Sources

Irrigation season inflow data are derived largely from Reclamation's modsum spreadsheet of hydrological data for the basin, which has data spanning the period from 1961 to 2005 for inflows to UKL, Clear Lake, Gerber Reservoir, and accretions between Keno and IGD. Reclamation calculated these inflows by summing the monthly volumetric changes in lake level with outflow volumes. This approach controls for evaporation, which was not included in the basin water balance calculated for this analysis (see the model calibration section for a more thorough discussion of this issue). Crop water consumption occurs in meaningful quantities between March and October, which were considered to be the beginning and ending points of the season. Ideally, seasonal inflows to the upper basins (Sprague, Williamson and Wood River subbasins) without the influence of agriculture would have been available. However, due to the long-standing presence of agriculture, finding unaltered flow data was impossible. Instead, inflows to UKL and agricultural crop evapotranspiration in the subbasins above the lake were summed to generate total inflows to the three subbasins. It was assumed that the number of irrigated acres above the lake - used to calculate the crop evapotranspiration - has remained constant between 1961 and 2005.

Inflows to the Lost River subbasin available to agriculture were also derived from the modsum dataset, which included historical monthly flows into Clear Lake and Gerber Reservoir. As no irrigated agriculture exists above these water bodies, no additional sources needed to be included. Inflows from Bonanza Springs, taken from data provided by Burt and Freeman (2003), were also included in Lost River inflows.

On the quality of the Reclamation inflow data overall, Burt and Freeman (2003) state, "based on discussions with those involved with data collection efforts, we concluded that many important reported values are incorrect or take into account unidentified uncertainties". The USGS clarifies some of these data issues in a 2006 report. The stretch of Klamath River between Link River Dam (at the exit of UKL) and Keno Dam was losing flow through the 1960s and 1970s, and gaining from in the 1980s and 1990s. Given that Keno measurements were maintained by the USGS and rated internally as "good" or "excellent", the source of the discrepancy was pinned to systematic errors on several measurements taken by Reclamation within project boundaries. These errors contribute to uncertainty within this analysis, as flow data in Link River (which partially constitute our overall inflow to UKL measurement) are considered by the USGS to be of questionable quality (Risley, et al. 2006).

Finally, additional flows entering the system between Keno Dam and IGD by way of groundwater and surface inflows were available on the modsum spreadsheet. IGD is approximately 60 miles down the Klamath River from Keno Dam, where the latter sits fairly close to the outflow of UKL. Reclamation calculated these values by simply subtracting the monthly flows at Keno Dam from the monthly flows at IGD[50]. These "Keno to IGD" inflows were added to total available inflow for the irrigation season[51]. These additional inflows were important to include, as they provided the hydrosystem with enough water to meet IGD flow requirements. Monthly evaporation from Lower Klamath Lake and Tulelake Refuges were provided by Burt and Freeman (2003) and included in the outflow data. Potential unaccounted sources of inflow include inflows to the basin through springs, groundwater and other streams, and outflows through deep percolation, evapotranspiration from non-crop vegetation and evaporation from standing surface water. Available inflow data between 1961 and 2005 are graphically shown in Figure 5 below. Note the wide range of seasonal inflows, varying from roughly 450,000 (1992) to over 1.8 million acre-feet (1983).

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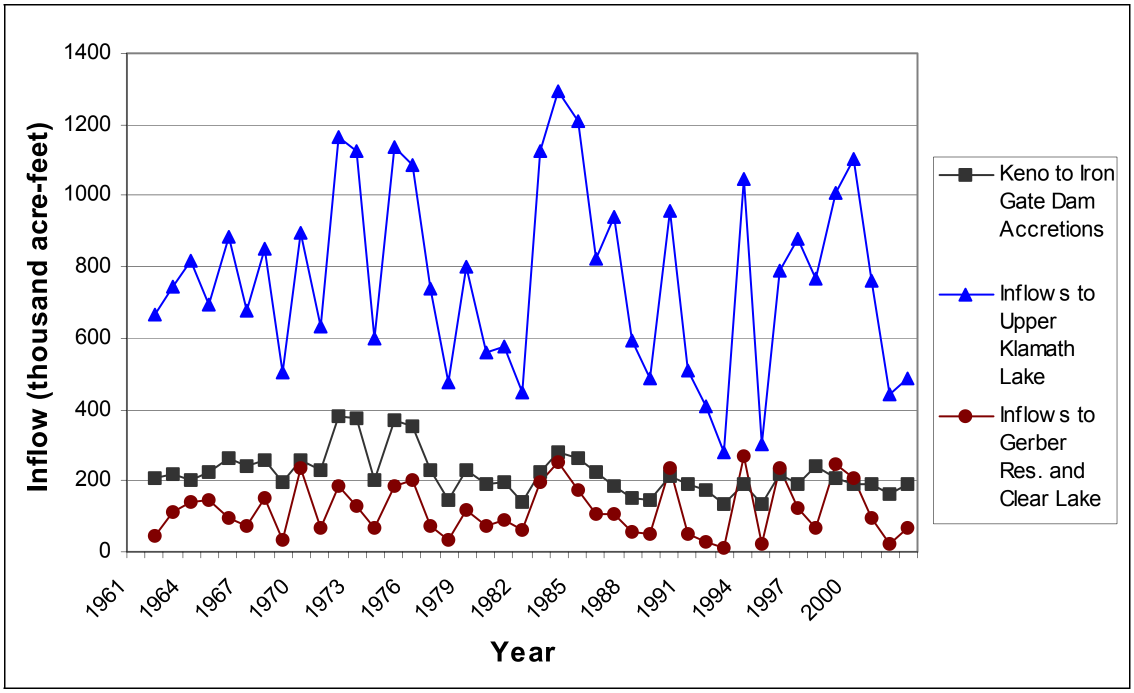
[50] The IGD flow data used in this study were assumed to have come directly from the USGS but apparently do not. Issues that may arise due to differences between USGS and Reclamation IGD data are discussed in the IGD data section below.

[51] There are some endogeneity issues with these data – they are likely partially dependent upon lagged agricultural uses, and significant changes in agricultural uses from historical levels would more than likely change these values. Given current ESA requirements, it is unlikely that greater amounts of surface water would be used for agriculture than have been used historically. Decreased agricultural water applications means that more water remains in the system, but less water is transferred from surface water to groundwater through distributed agriculture applications. The impacts of these changes on the subject flows are uncertain.

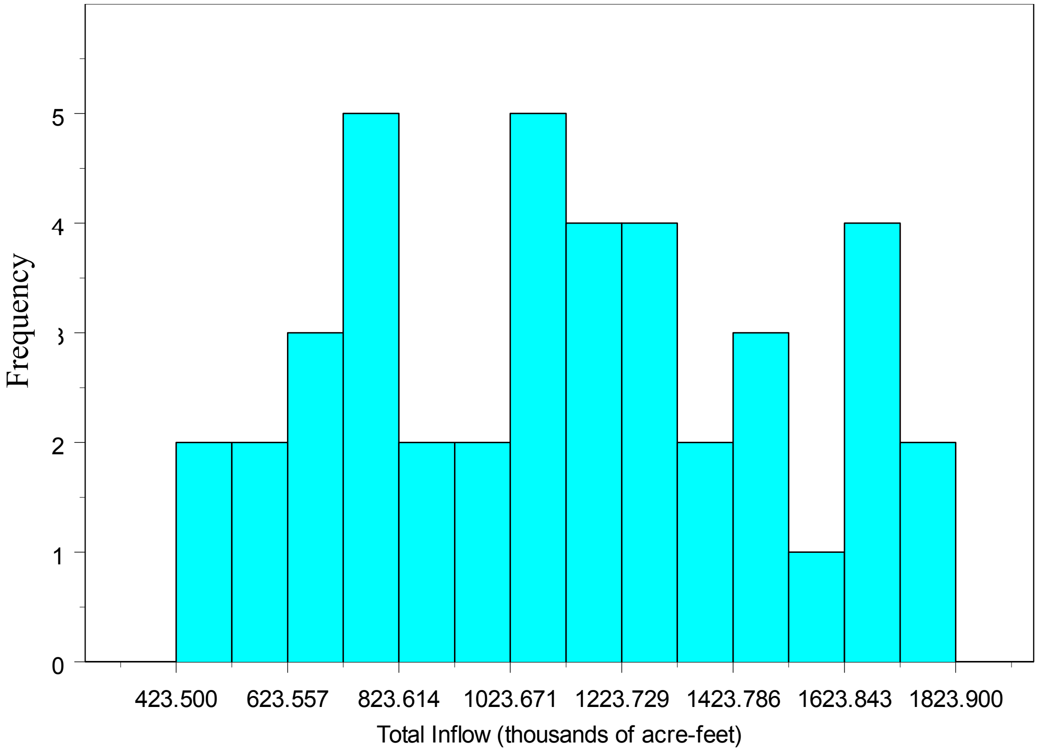
Figure 5: Historical Annual Upper Klamath Basin Inflows



Inflow Arrangement

Given the data described above, the goal was to model a wide variety of possible futures based upon the inflows of past years. With that goal in mind, attempts were initially made to develop a distribution of inflows to the hydrosystem which could be sampled to provide random inflow data to the multi-period model. It was quickly discovered that this was not a feasible option given the data available, as this would have been attempting to develop distributions for four sets of inflows from a single 41 year monthly data set. Such a multi-dimensional distribution would have required many more years of data to satisfy basic statistical requirements. Instead, actual historical inflow data from the Reclamation modsum dataset was used to represent alternative future flow potentialities. As no attempt is made to develop a distribution from these data, no statistical rules are infringed upon. Inflows vary sufficiently in these years (both across and within years) to provide a wide range of possible year combinations. Strings of these years would then be randomly selected and run in sequence to replicate future scenarios faced by water managers facing stochastic inflows. For reference, a histogram of the aggregate annual inflows to the basin is provided in Figure 6 below. The horizontal axis is measured in thousands of acre-feet, and the vertical axis represents the frequency of inflows in that interval of annual flows. Note that no readily apparent pattern is visible in the inflow data, further supporting a non-distribution-based approach.

Figure 6: Histogram of Inflows to the Upper Klamath Basin



4.2.4.1.2 Lakes and refuges

Lakes in the basin serve as both intraseasonal and interseasonal water-transfer mechanisms. Replicating this role in the creation of the model was crucial, so lake levels are treated as choice variables each month of each year.

Lake Level Data

Historical lake level data had three purposes in this project: provision of the initial lake level for each model run, calibration of the hydrosystem (as described in section 4.4), and use in developing algorithms of lake level transfers between years for the dynamic model. Water level data for UKL, Clear Lake and Gerber Reservoir were obtained from Reclamation. Elevation data for each lake spans from 1962 to 2005. Figures 7 through 9 show the monthly UKL, Gerber and Clear Lake levels between 1962 and 2002, which are the years used for the analyses in this paper. The differences in lake depth and the drainage area above each lake are apparent in their respective hydrographs. Due to physical constraints, the elevation of UKL can only vary a total of roughly six feet, compared to 40 feet for Gerber Reservoir and 20 feet for Clear Lake. Furthermore, the area that drains into UKL is substantially larger than the area draining into either Clear Lake or Gerber Reservoir. As a result of these differences, the hydrographs look significantly different. The maximum elevation (4143.3 feet above mean sea level) of UKL is achieved in the beginning of almost every season, whereas the lake levels entering the irrigation season in Gerber Reservoir and Clear Lake may be only a fraction of their maxima. As a result, these latter two reservoirs tend to bring a more dynamic element to the management of water in the basin because their depletion carries over from one season to the next.

Figure 7: 1962 to 2002 Monthly Upper Klamath Lake Levels

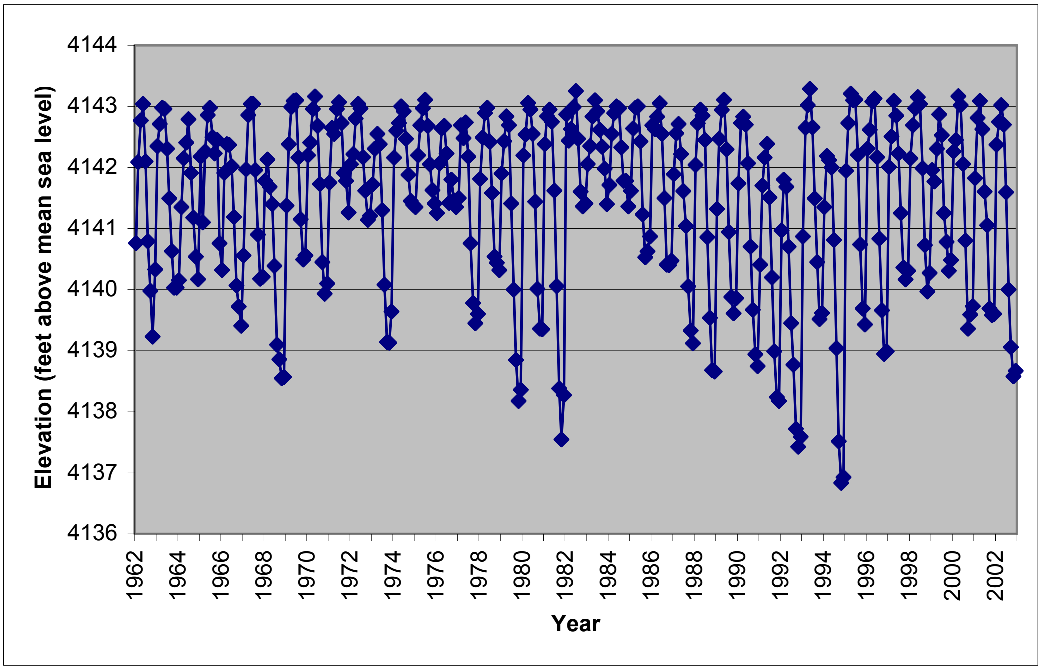


Figure 8: 1962 to 2002 Montly Clear Lake Levels

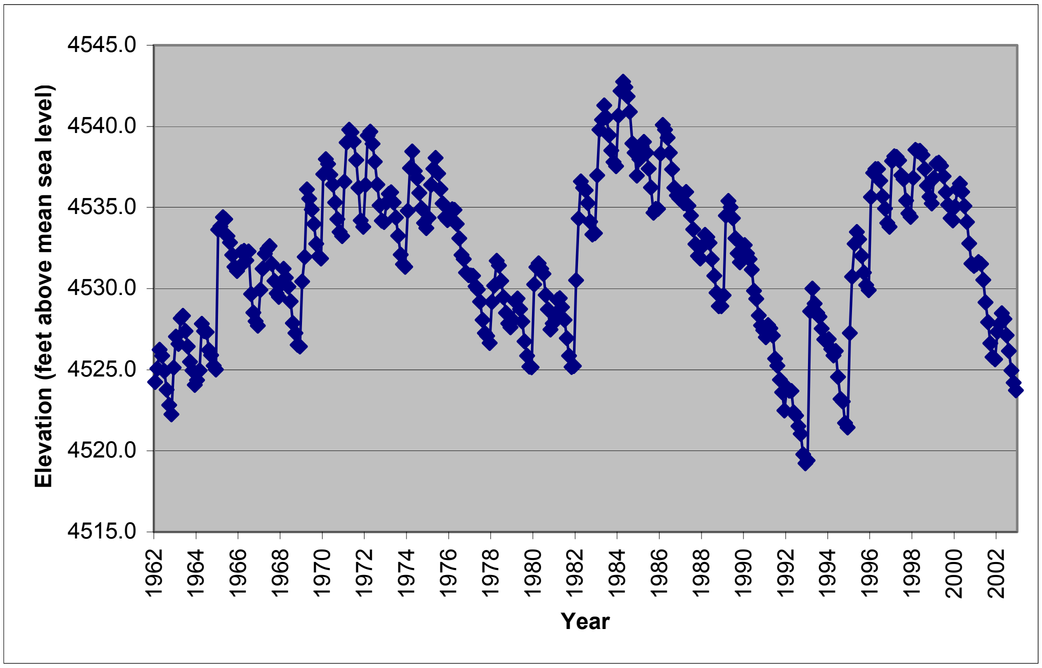
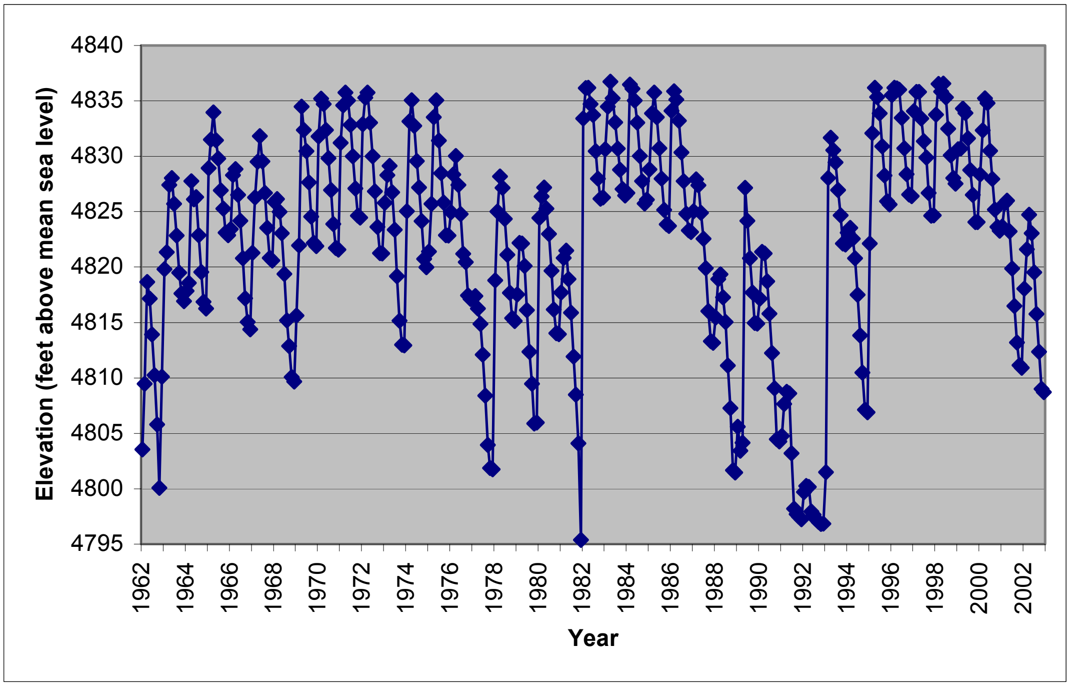


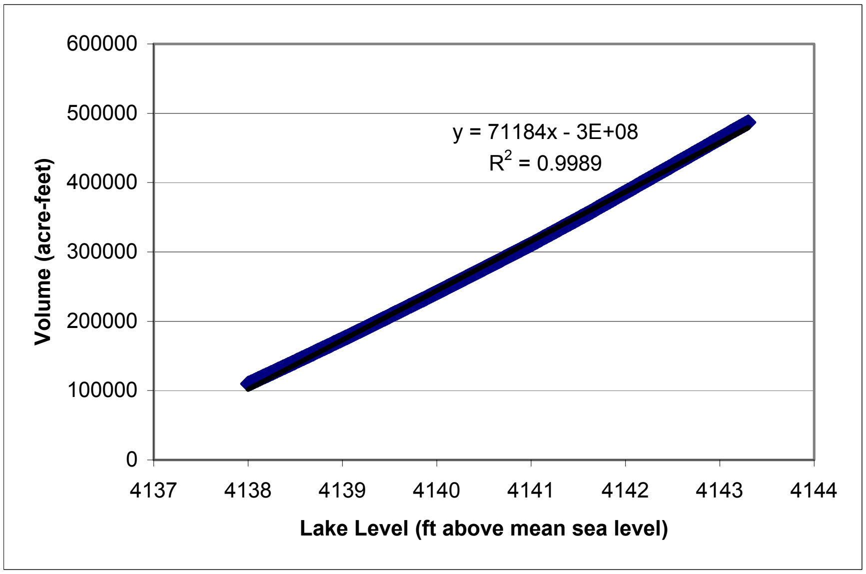
Figure 9: 1962 to 2002 Monthly Gerber Reservoir Levels



Lake Elevation-Volume Relationships

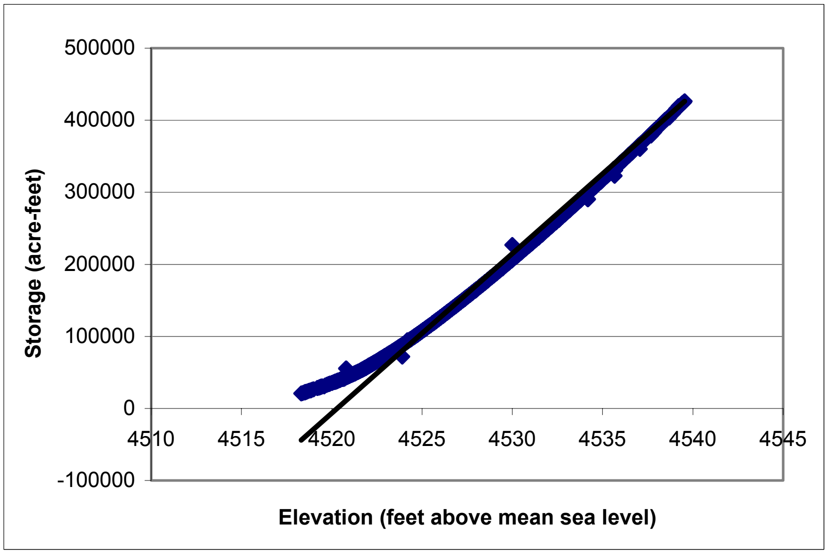
In order to convert lake level data to volumetric information that could be incorporated in the hydrological model, it was necessary to estimate the volume-per-foot of each lake. These data were provided by Reclamation. For modeling simplicity, it was desirable to include only a single value for the volume-per-foot of each lake to avoid piecewise linearization of the relationship between elevation and storage. Although piecewise linearization would have been more accurate, it greatly complicated the modeling exercise in GAMS and was not included in the basin model. To develop this constant coefficient and test whether a single linear relationship would be adequate, linear regressions were fit to the elevation/storage relationships for each of the three basin lakes. As can be seen from Figures 10 to 12, the R^2 values for each linear fit were greater than 0.98, indicating that a single estimate was adequate for modeling purposes. This will introduce error in the elevation-volume relationship at very low and high lake elevations. Based on the below diagram, each foot of UKL is assumed to contain 71,184 acre-feet of water.

Figure 10: Upper Klamath Lake Area Capacity versus Elevation



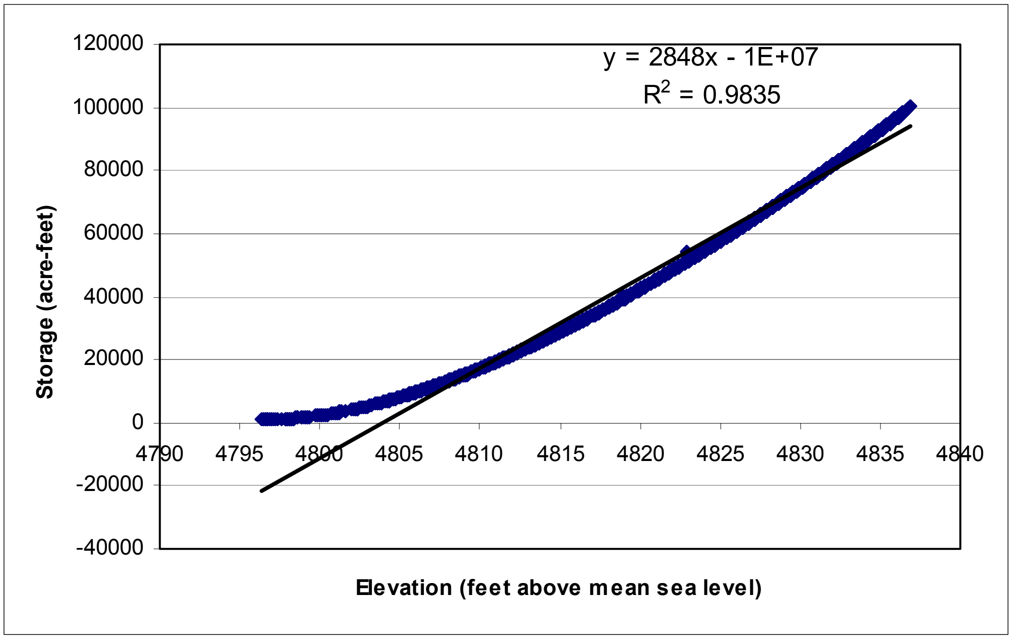
In the case of Clear Lake, there are approximately 22,123 acre-feet of water per foot of lake. Note that the relationship becomes significantly nonlinear at low lake levels. This will overestimate the contribution of the lake to basin water supplies at these elevations.

Figure 11: Clear Lake Elevation versus Storage



Each foot of Gerber Reservoir is assumed to contain approximately 2,848 acre-feet of water. Note that the relationship becomes even more significantly nonlinear at low lake elevations than in Clear Lake, contributing similarly to the analysis.

Figure 12: Gerber Lake Elevation versus Storage



FWS Lake Level Requirements

As described above, FWS has imposed minimum lake level requirements on UKL, Clear Lake, and Gerber Reservoir to promote recovery of the Lost River and shortnose suckers. In creating these requirements, FWS created four different "year types" based upon historic April through September inflows to UKL. Annually, the year-type is determined based upon inflows projected by the NRCS at the beginning of each irrigation season. These year types include above average, below average, dry, and critically dry. Lower estimated inflows result in lower lake level requirements.

Table 9, below, displays the end-of-month level requirements at UKL. These requirements are available in the FWS BiOP (FWS 2002).

Table 9: FWS End-of-Month Upper Klamath Lake Level Requirements

Month	Water Year Type (feet above mean sea level) Above Average	Below Average	Dry	Critically Dry
March	4,142.5	4,142.7	4,141.7	4,142.0
April	4,142.9	4,142.8	4,142.2	4,141.9
May	4,143.1	4,142.7	4,142.4	4,141.4
June	4,142.6	4,142.1	4,141.5	4,140.1
July	4,141.5	4,140.7	4,140.3	4,138.9
August	4,140.5	4,139.6	4,139.0	4,137.6
Sepember	4,139.8	4,138.9	4,138.2	4,137.1
October	4,139.7	4,138.8	4,138.2	4,137.3

Clear Lake and Gerber Reservoir each have a single minimum lake level requirement for the entire irrigation season. These requirements are 4,798.1 feet above mean sea level at Gerber Reservoir and 4,520.6 feet above mean sea level at Clear Lake (Reclamation 2003-2006).

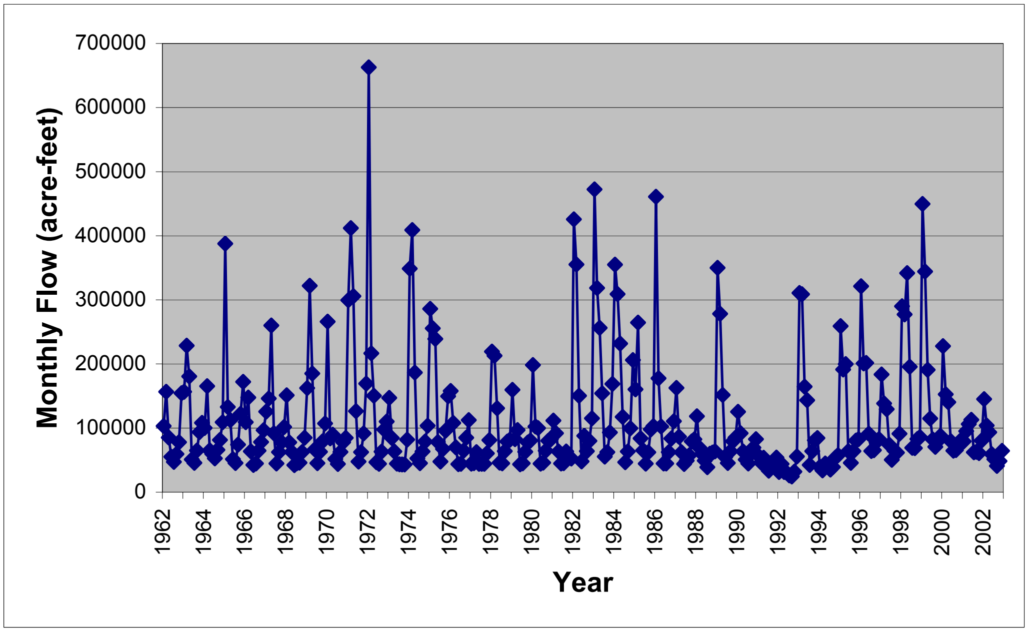
4.2.4.1.3 Iron Gate Dam

Iron Gate Dam Data

Historical IGD flow data were obtained from USGS and Reclamation. USGS historical flows were used for both model validation and calibration and allow for a qualitative assessment of the capacity for the basin to maintain future flows. These flow data are considered to be of "excellent" quality by the USGS (Herrett, et al. 2003). Model analyses were conducted using Reclamation IGD flow data in the modsum spreadsheet, which had been used to calculate their Keno to IGD accretions.

At the time of the data acquisition, it was assumed that Reclamation used the USGS data in their modsum spreadsheet. Towards the end of this work, it was discovered that Reclamation data were substantially different than USGS data during certain years. Given that USGS has very reliable gauging at IGD, use of Reclamation data was inappropriate. Rather than rerun all results, the magnitude of these differences were checked (USGS minus Reclamation yearly inflow). Between 1962 and 1995, the differences were found to be due only to Reclamation rounding error (maximum roughly 450 acre-feet). After this point, the four years meaningfully impacted were 1996 (12,125 acre-feet), 1997 (minus 40,441 acre-feet), 1999 (33,649 acre-feet), and 2001 (10,617 acre-feet). This would intensify the flow requirement in 1996, 1999, and 2001, and lighten the requirement in 1997. Given the relative magnitude of inflows during these years (see Figure 5), it is unlikely that these values are substantial enough to meaningfully change the results. Figure 13 shows monthly USGS IGD flows between 1962 to 2002.

Figure 13: 1962 to 2002 Iron Gate Dam Inflow Data (March to October)



Iron Gate Dam Flow Requirements

NOAA has imposed minimum flow requirements at IGD to promote recovery of the Lower Klamath basin population of coho salmon, which are dependent upon inflows from the Upper Basin for both water quantity and quality. As opposed to the four year types of FWS, NOAA created five year types based upon the same historic distribution of seasonal inflows to UKL. These year types include: wet, above average, average, below average and dry. Lower expected inflows to UKL result in lower IGD flow requirements. The 2002 NOAA BiOP allows Reclamation to use the 70 percent exceedence criterion in estimating seasonal inflows based upon NRCS early season projections. NRCS provides a probability distribution of expected flows for the coming season. The 70 percent exceedence criterion is the flow value expected to be exceeded 70 percent of the time based on the distribution (i.e., if the expected mean inflow to UKL is 450,000 acre-feet, the 70 percent exceedence flow may be 400,000 acre-feet, depending on the shape of the distribution). The purpose of this criterion is to allow conservative projections of inflows when making the seasonal IGD requirement determination. This risk adverse approach attempts to avoid the situation where final flows are low and IGD requirements are high.

Unfortunately, the NRCS has not projected inflows throughout the subject study period (1962 to 2002). Yet on average, the 70 percent exceedence criterion reduces the burden of IGD flow requirements and was therefore an important consideration to include in the model. To solve this problem it was assumed that the actual Reclamation inflow data represented the historical projections by the NRCS and simply applied the exceedence criterion to those values and then determined the annual flow requirement. The 70 percent exceedence value is based upon a stream flow forecasting algorithm run by NRCS, incorporating historical hydrological data and current flow, snowpack, and groundwater conditions. Rather than attempt to gather the necessary data to calculate these values, the observed NRCS calculations from Reclamation Operation Plans between 2003 and 2006 were averaged (i.e., the projected inflow in 2006 was 820,000 acre-feet, and the 70 percent exceedence inflow is 772,000 acre-feet, so the coefficient used to calculate the exceedence inflow by NRCS was 772,000 divided by 820,000 or 0.941). The average NRCS exceedence value, which is 0.859, is multiplied by each annual inflow prior to determining whether that year should be classified as dry, below average, average, above average, or wet. This value may depend largely upon inflow, potentially introducing error to the year type determination. This calculation need not take place for the UKL requirements, as FWS simply mandates a 50 percent exceedence criterion, meaning that Reclamation flow values need not be adjusted at all prior to determining the FWS year type. This implicitly means that NOAA requirements are less stringent than they appear. For the relationship between projected inflow and NOAA/FWS year type classifications, see any of the Reclamation Operations Plans between 2003 and 2006. The table below depicts the short term required flows each month given the water year type, as presented in the 2002 NOAA BiOP.

Table 10: Short Term NOAA Iron Gate Dam Flow Requirements

	Water Year Type (cubic feet per second)				
Date	**Wet**	**Above Average**	**Average**	**Below Average**	**Dry**
March 1-15	8,018	1,953	2,143	2,190	688
March 16-31	6,649	4,009	2,553	1,896	695
April 1-15	5,932	2,955	1,863	1,826	822
April 16-30	5,636	2,967	2,791	1,431	739
May 1-15	3,760	2,204	2,784	1,021	676
May 16-31	2,486	1,529	1,466	1,043	731
June 1-15	1,948	1,538	827	959	641
June 16-30	1,921	934	1,163	746	617
July 1-15	1,359	710	756	736	516
July 16-31	1,314	710	735	724	515
August	1,149	1,039	1,040	979	560
September	1,341	1,316	1,300	1,168	731
October	1,430	1,346	1,345	1,345	907

Table 11 below displays the long-term monthly NOAA flow requirements aimed at coho recovery. Under their obligations under section VII of the ESA, Reclamation is largely responsible for finding additional water to meet these new requirements. Note that the increases are fairly significant throughout the irrigation season. These differences are explored more fully in the results section.

Table 11: Long-Term NOAA Iron Gate Dam Flow Requirements

	Water Year Type (cubic feet per second)				
Date	**Wet**	**Above Average**	**Average**	**Below Average**	**Dry**
March	2,300	2,525	2,750	1,725	1,450
April	2,050	2,700	2,850	1,575	1,500
May	2,600	3,025	3,025	1,400	1,500
June	2,900	3,000	1,500	1,525	1,400
July	1,000	1,000	1,000	1,000	1,000
August	1,000	1,000	1,000	1,000	1,000
Sepember	1,000	1,000	1,000	1,000	1,000
October	1,300	1,300	1,300	1,300	1,300

4.2.4.2 Groundwater Hydrology

Groundwater is the most uncertain aspect of the model. The groundwater system in the Klamath may be capable of producing massive quantities of water, or it may be much more restricted than expected. Since there is presently no capability to predict the response of the groundwater system to specific pumping scenarios, groundwater availability is treated as a flexible, externally imposed constraint on the model. The primary linkage between groundwater and the objective function is through energy cost, which is dependent upon groundwater depth. Depending upon assumptions made about the relationships between groundwater pumping, and annual recharge rate, energy costs could be vastly different. The groundwater component of the model is very simplistic, and is intended to serve primarily as a qualitative indication of groundwater response to irrigator decision-making. The particular components of this model are spelled out in the model section below.

4.2.5 Energy

In this section, an overview of the data used in the basin model is provided to calculate the costs of energy rate increases in the basin. Irrigation energy costs are described first, then enter into a discussion of the capacity of land to switch from sprinkler to flood irrigation if necessary.

4.2.5.1 Energy Consumption

In order to accurately assess the impacts of energy price increases on irrigation and groundwater pumping costs, it was necessary to develop estimates of energy consumption for sprinkler irrigation, flood irrigation and groundwater pumping. Since sprinkler systems must be kept under significant pressure, their energy costs are much higher, making them more sensitive to changes in energy costs. Estimates of energy costs in the basin were made by Jaeger in 2004 with the help of several irrigation energy specialists. Detailed calculations are provided in Appendix C. Projected energy costs are summarized in Table 12 below.

Table 12: Flood, Sprinkler and Groundwater Energy Costs to Irrigate One Acre

Year	Energy Price (per kWh)	Flood Irrigation[1] Low ET[3] (per acre)	Flood Irrigation[1] High ET[4] (per acre)	Sprinkler Irrigation[2] Low ET (per acre)	Sprinkler Irrigation[2] High ET (per acre)	GW Pumping[5] low ET[6] (per acre)	GW Pumping[5] high ET[6] (per acre)
2006	$0.006	$0.53	$0.80	$3.50	$5.25	$0.80	$1.19
2007	$0.009	$0.80	$1.19	$5.25	$7.88	$1.19	$1.79
2008	$0.014	$1.19	$1.79	$7.88	$11.81	$1.79	$2.69
2009	$0.020	$1.79	$2.69	$11.81	$17.72	$2.69	$4.03
2010	$0.030	$2.69	$4.03	$17.72	$26.58	$4.03	$6.04
2011	$0.046	$4.03	$6.04	$26.58	$39.87	$6.04	$9.06
2012	$0.068	$6.04	$9.06	$39.87	$59.80	$9.06	$13.59

Notes:

1. Assumes 29.42 kWh per acre-foot of pumping
2. Assumes 232.97 kWh per acre-foot of pumping
3. Assumes 3 feet of applied water per acre
4. Assumes 4.5 feet of applied water per acre
5. Assumes 2.94 kWh for each acre-foot of water pumped up one foot
6. Assumes groundwater is being pumped 15 feet to the surface (may be conservative)

The PacifiCorp contract ends in 2006 and higher energy costs begin in 2007. Rates will increase at a rate of 50 percent per year until 2012 when regional market rates are reached (these final rates are uncertain). Over the course of this 6-year period, energy prices will increase at least 10-fold, impacting sprinkler irrigators up to $50 more per acre than flood irrigators. Groundwater pumping costs will also increase, but not as significantly. The cost of pumping 10,000 acre-feet an average of 10 vertical feet (assuming a linear relationship between marginal pumping cost and groundwater depth as is assumed in the model calculations) will increase from approximately $2,000 to approximately $20,000. This is likely to be a significant cost only when groundwater depth is drawn down substantially.

It is assumed here that the irrigators are not capable of reducing their energy costs through any means other than shifting to flood irrigation (if possible given their land). It may be possible for irrigators to switch to other sprinkler methods that consume less energy or have higher irrigation efficiency. However, in this study, irrigator options are restricted to converting to flood technology – an exhaustive analysis of the optimal mix of irrigation technologies in the basin is beyond the scope of this study. Aside from economic considerations, certain physical characteristics of sprinkler-irrigated acres may make switching to flood irrigation impossible. Specifically, if slopes are too steep or soil texture[52] is too loose, engineering flood systems could be cost-prohibitive[53]. Since soil texture data were not available, it was assumed that sprinkler acres with slopes greater than four percent could not switch to flood[54].

4.2.5.2 Issues with Switching from Sprinkler to Flood Irrigation

The GIS-based model was used to calculate surface slopes in the basin from a 10-meter DEM and the refined layer of agricultural acreage. Map 7 below shows a semi-transparent slope-categorized layer overlain upon a hillshade[55] of the basin. The extent of sprinkler irrigation is also shown on this map, with areas likely incapable of

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[52] *Soil texture* indicates the relative proportions of clay, silt, and sand within the soil. High sand content indicates that much greater volumes of water need to be applied for water to reach the far end of a flood-irrigated field.

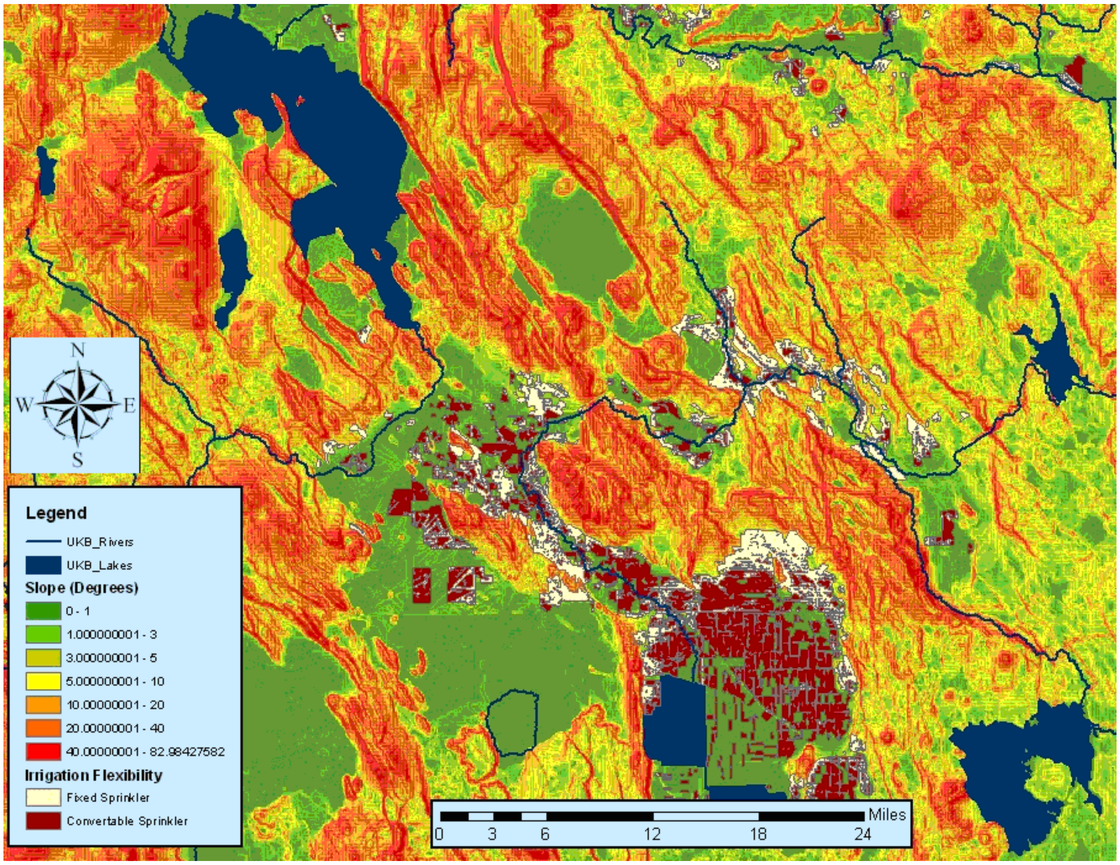
[53] Based on personal communication with Drs. Richard Cuenca and Marshall English of the Bioresource Engineering Department at Oregon State University on March 7 and 15, 2006.

[54] Ibid.

[55] A hillshade is a visually intuitive representation of topography constructed from a DEM in ArcView.

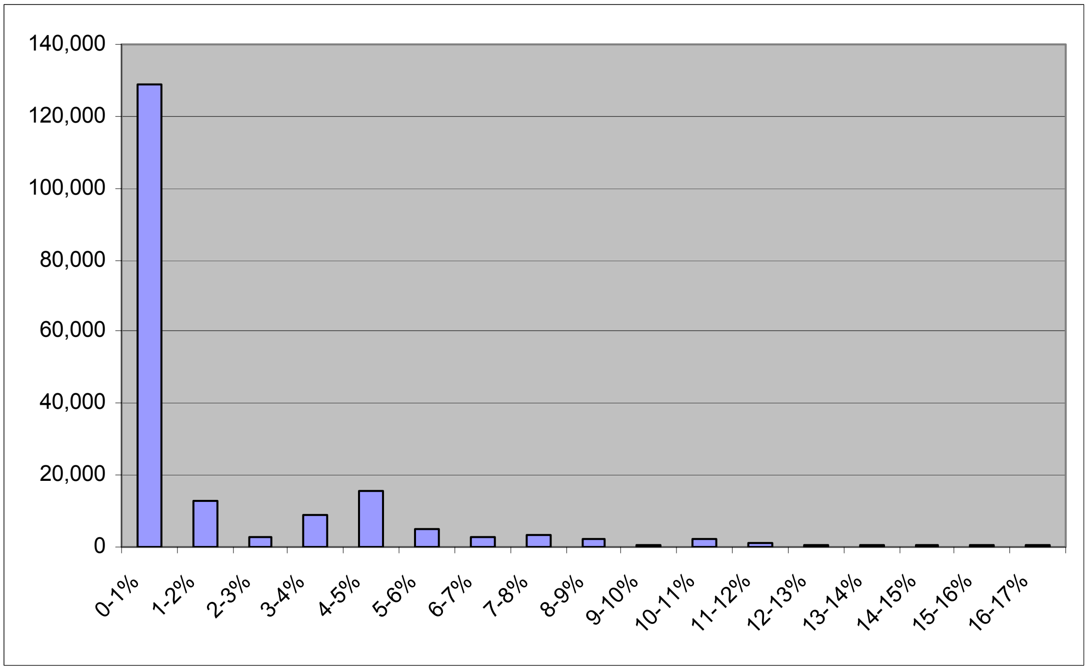
switching from flood to sprinkler highlighted in a lighter shade. This analysis indicated that of the 136,000 acres of sprinkler irrigation in the basin, roughly 52,000 acres are fixed and the remaining 84,000 acres are potentially convertible.

Map 7: Fixed and Convertible Sprinkler-Irrigated Acres



The results of the energy analysis are sensitive to the chosen maximum slope of four percent used in the fixed-convertible designation. Lower slopes would result in fewer convertible acres, whereas higher cutoffs would result in greater acreages. To cross-check the assumed cutoff level, the distribution of slopes on flood-irrigated acres across the basin were investigated. Based on this criterion, one would expect to see the significant majority of these acres at slopes lower than four percent. The distribution of slope on flood and sprinkler acres is portrayed on Figure 14 below. As can be seen, the majority of acres have slopes between zero and one degree, but the GIS data indicates that there are also a significant number of flood-irrigated acres between four and five percent. Although slopes up to 17 percent were observed, it is physically impossible to flood irrigate at slopes significantly greater than four percent. These high values are likely the consequence of overlaying spatially approximate NRCS irrigation technology data on much more precise USGS elevation data. Ideally, these randomly dispersed high sloped acres would not have been included in the flood dataset.

Figure 14: Slope Distribution of Flood-Irrigated Acres (Rise over Run)



Several economic and institutional considerations further complicate the decision to switch technologies. There will be a cost incurred by switching from sprinkler irrigation to flood irrigation in the form of initial capital costs to make the switch (including laser leveling, flood basin formation and re-piping), opportunity costs of not using the sprinkler system (flood systems may have lower crop yield[56]), and potentially increased labor costs (flood systems require greater operator-hours). Furthermore, irrigators on project lands have restrictions placed on their current diversions of 2.3 acre feet per acre, limiting their irrigation technologies to sprinkler in many cases because of the relatively low irrigation efficiency of flood systems. Conversion to flood irrigation under these restrictions would result in considerable losses in crop productivity since insufficient water would be made available to the crops. In this study, it is assumed that this restriction (2.3 acre feet per acre) is relaxed by policymakers to accommodate conversions to flood irrigation in response to higher energy rates.

Crop yield under sprinkler and flood irrigation methods depends largely on management of the irrigation system. In theory, the two systems can get identical annual yields if the system is designed appropriately and if the timing and magnitude of water application is appropriate. Flood systems tend to suffer greater yield losses from mismanagement than sprinkler systems due to the many factors involved in their successful operation. First, flood basins must be appropriately leveled on a fairly regular basis – if this is not done, topographic differences will cause uneven water application to the field and yield losses will result. Second, depending on the average

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[56] In an experimental setting in Australia, Morris (2004) observed a significant increase in per-acre maximum yields with sprinkler systems (15 tons per hectare versus 9 tons per hectare for flood systems). If using center-pivot sprinkler systems, this yield increase may be counterbalanced by lost acreage at the corners of a square farm.

slope, size and soil texture of the flood basin, over-saturation can occur in areas nearest the flood gate and dry areas can occur furthest away. A Kansas State University Extension Service study compared flood and sprinkler corn yields under various levels of water application. At full application (where the crop was getting exactly the water it needed) and with perfect timing, yields were identical. At all other levels, flood systems yielded between 10 and 20 percent lower volumes of corn. This converted directly to a loss in revenues, which converted to a loss in net revenues of between 15 and 40 percent (O'Brien, et al 2000). Ultimately, yield differences between flood and sprinkler irrigation are most pronounced in water sensitive, high value row crops. Crops such as pasture and alfalfa are likely to have similar yields regardless of irrigation technology[57]. Data from a 1995 study by the University of Idaho Extension Service is shown in Table 13 below. Note that the total annual costs for the sprinkler irrigation are considerably higher than for flood. Given this, the wide adoption of sprinkler may be explained by yield benefits, flood management challenges, or farm level complications not captured in this 1995 study.

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[57] Based on personal communication with Paul Patterson, Extension Specialist, University of Idaho Extension Service, July 27, 2006.

Table 13: Data on Irrigation Systems in the Upper Klamath Basin

Type of Irrigation System	Depreciation, Interest and Insurance[1]	Labor Cost[2]	Pre-Irrigation Losses[3]	Land Use Efficiency[4]	Adjusted Land Charge[5]	Irrigation Efficiency[6]	Total Annual Costs
Flood Systems[7]							
Earthen head ditch with siphon	$11.50	$50.23	4%			60%-90%	$61.72
Concrete head ditch with siphon	$35.77	$25.11	4%			60%-90%	$60.89
Gated pipe system	$20.50	$25.11	4%			60%-90%	$45.61
Surge flow gated pipe system	$53.31	$18.99	4%			60%-90%	$72.30
Cablegation gated pipe system	$32.33	$17.15	4%			60%-90%	$49.48
Averages	**$30.68**	**$27.32**					**$58.00**
Sprinkler Systems[8]							
Solid set	$165.72	$43.75	15%	96%	$5.00	70%-85%	$214.47
Hand line	$41.21	$77.00	15%	96%	$5.00	65%-80%	$123.21
Wheel line	$57.09	$24.08	15%	96%	$5.00	65%-80%	$86.17
Center Pivot	$57.09	$9.10	8%	83%	$25.00	70%-85%	$91.19
Center Pivot w/ Corners	$74.37	$9.10	8%	95%	$6.00	70%-90%	$89.47
Averages	**$79.10**	**$32.61**			**$9.20**		**$120.90**

Notes

1. Assumes a 3 percent inflation rate from date of data collection adjusted to 2001 dollars
2. Assumes $8.75 per hour
3. These do not include distribution or deep percolation losses. Source: Rogers et al. 1997
4. The fraction of total land that is irrigated with the given technology. Unused land is often dryland farmed
5. Base land value of return*(land adjustment-1). Assumes a $1,200 per acre value and a 10 percent rate of return. land adjustment is the reciprocal of the land use efficiency
6. Can vary signficantly depending upon management
7. Source: Smathers, King and Patterson 1995
8. Source: Patterson, King and Smathers 1996; Patterson, King and Smathers 1996a

4.3 Klamath Model

The following sections present background information on the development of the basin model, the trade and no-trade formulations of the objective function, and the constraints that apply to each objective function.

4.3.1 Background

This section provides the economic background on the theoretical foundation of the objective function. For reference, lists of indices, variables, and parameters are provided toward the end of this chapter. For each location and soil class, net revenues per acre are expressed as revenues from farming minus variable and fixed costs any given year:

$$\pi_{ij} = \sum_{n} (p_n y_n s_{ijn} - v_n s_{ijn} - f_n s_{ijn})$$

Where:
i=index for farm use area: Fort Klamath Valley (i_1), Modoc Point to Chiloquin (i_2), Sprague River (i_3), North Country (i_4), Bonanza/Dairy/Hildebrand (i_5), Langell Valley (i_6), Swan Lake Valley (i_7), Merrill/Malin (i_8), Poe Valley (i_9), Midland/Henley/Olene (i_{10}), Lower Klamath Lake (i_{11}), Malin Irrigation District (i_{12}), Shasta View Irrigation District (i_{13}), West of Hwy. 97 to Keno (i_{14}), Tule Lake (i_{15}), Lower Klamath Lake in California (i_{16})
j=soil class index: II (j_2) to V (j_5)
n=crop index: alfalfa (n_1), potatoes (n_2), grain (n_3), strawberries (n_4), onions (n_5), peppermint (n_6), sugar beets (n_7), other hay (n_8), and pasture (n_9)
π_{ij}=net revenues from farming each acre
p_n=price of crop k grown on share s_n of all acres
y_n=yield for crop k grown on share s_n of all acres
s_{ijn}=share of each crop in each farm use area and soil class based on observed cropping rotations (s=0.4 for a crop grown four years during a 10-year rotation)
v_n=variable costs associated with crop n
f_n=fixed costs associated with crop n

To find the profits that accrue to each acre, refer to the concept of Ricardian rents (Ricardo 1912), where land prices in an agricultural economy are assumed to represent the present value of a permanent stream of expected net revenues:

$$P_{ij} = \sum_{y=1}^{\infty} \pi_{ij} (1+r)^{-y}$$

Where:
y=index for the year
P_{ij}=real market value of each acre in each farm use area and soil class
r=discount rate (assumed here to be 6%)

The infinite sum above reduces to:

$$\sum_{y=1}^{\infty}(1+r)^{-y}=\frac{1}{r}$$

Solving for net revenues,

$$\pi_{ij}=P_{ij}r$$

Since real market value data are available, this gives us a means of extracting expected net revenues from land values. Previous studies analyzing how water constrains agricultural production have also used Ricardian rents (e.g. Jaeger 2004; see Conradie and Hoag 2004 for a more thorough explanation). If irrigation is curtailed in the short term, then irrigators will forego expected profit and will continue to pay the fixed costs. Thus, short run losses at each location and soil class are the sum of foregone profits plus fixed costs, or:

$$c_{ij}^{D}=\pi_{ij}+\sum_{n}f_{n}s_{ijn}$$

Where:

c_{ij}^{D}=cost of irrigation curtailment (or land idling) on each acre in each farm use area and soil class

The first component of curtailment costs is based on market data which are assumed to reflect actual costs, technologies, cropping patterns, and revenues; the second component, fixed costs, is taken from relevant crop enterprise budgets for the basin.

4.3.2 The Objective Functions

The model reflects irrigator behavior by maximizing the total net revenues from farming irrigable acres in the basin. Acreage is broken into Assessor area, soil class and irrigation technology. Broadly, the objective function states that aggregate profits any year are the profits of those acres farmed minus the fixed costs of those acres not farmed minus energy costs incurred over and above historical levels. The following represents the formulation of the model where flexible trading from the upper basins and Lost Basin to the project is allowed.

$$\Pi_y = Max\sum_i\sum_j\sum_k\{\pi_{ij}a^I_{ijky} + ((1-\frac{\pi_{ij}}{\pi_{\max}}\eta_k)\pi_{ij} - \chi_k)a^{Ic}_{ijky}$$
$$+[\alpha_{ij}(\pi_{ij}+\phi_{ij})-\phi_{ij}](a^D_{ijky}+a^{Dc}_{ijky})\} - (\psi_y-\psi^c)\sum_i e^I_{iy} - \psi_y\sum_a e^G_{ay} + \lambda s_y$$

Where:
k=irrigation technology index: flood (k_1) and sprinkler (k_2)
a=sub-region index: upper basins (a_1 represents farm use areas i_1 through i_4), lost basin (a_2 or farm use areas i_5 and i_6) and the project (a_3 or farm use areas i_7 through i_{16})
Π_y=maximum net revenues from surface water-irrigated agriculture in any given year
$a^{I,D}_{ijky}$=acres of flood and fixed sprinkler land irrigated/idled each year, area, soil class and technology
$a^{Ic,Dc}_{ijky}$=acres of convertible sprinkler land irrigated/idled each year, area, soil class and technology
$e^{I,G}_{iy}$=irrigation/groundwater energy use in kilowatt-hours each year and farm use area/sub-region
s_y=the volume of storage in the system in october of each year
χ_k=per acre present value of capital, opportunity and labor costs of switching from sprinkler to flood irrigation
α_{ij}=subirrigation evapotranspiration divided by crop evapotranspiration in each area and soil class
ϕ_{ij}=fixed costs for each area and soil class ($\sum_n f_n s_{ijn}$)
η_k=flood versus sprinkler yield coefficient
$\pi_{\max}$=highest profit per acre in basin ($156/acre)
ψ_y=energy price per kilowatt-hour each year
ψ^c=energy price in the original Pacificorp contract to irrigators ($0.006 per kilowatt-hour)
λ=the value per acre foot of water storage between years

The following section presents a description of the above model, then qualifies the flexible trading model with assumptions, and finishes with a depiction and description of the no-trade model formulation.

4.3.2.1 Descriptive Overview of the Model

Here, a description of how the objective function above operates is presented. All expressions in the first line of the function are summed over Assessor area, soil class and irrigation technology. The first two expressions represent the profits to the farmers for crops irrigated. The term $\pi_{ij}a^{I}_{ijky}$ represents the total profits accruing to all "fixed" sprinkler and flood acres.

The term $+((1-\frac{\pi_{ij}}{\pi_{\max}}\eta_k)\pi_{ij}-\chi_k)a^{Ic}_{ijky}$ represents the profits that accrue to convertible acres. This is a more complex formulation due to the necessity to model yield and annual cost penalties accruing to irrigators switching from sprinkler to flood irrigation. Sprinkler irrigators may wish to switch from sprinkler to flood irrigation to ease the burden of rising energy prices. Acres with flood and fixed sprinkler irrigation are lumped together in one category, and acres that are capable of converting from sprinkler to flood irrigation are in another. The delineation between fixed and convertible sprinkler irrigation was determined based upon a GIS analysis described above. There are initial capital costs, potentially long-run labor cost increases, possible long-run productivity losses and opportunity costs from idling sprinkler equipment which are anticipated to result from such a transfer. These are amalgamated into a per acre measure of disincentive to transfer from sprinkler to flood (χ_k) and a coefficient reflecting differences between the crop yield of flood and sprinkler irrigated acres (η_k). χ_k is assumed to be \$30 based on average depreciation, interest, and insurance payments for a flood irrigation system from Smathers, King, and Patterson 1995 (see Table 13). This assumes that there is no fixed cost associated to idling sprinkler equipment.

As can be seen in the objective function, yield is assumed to increase linearly with land value: $(1-\frac{\pi_{ij}}{\pi_{\max}}\eta_k)$. This is based on the idea that more profitable lands grow crops more sensitive to the even and precise application of water over the season (i.e., potatoes or horseradish). These crops are also more sensitive to appropriate management decisions[58]. Here, η_k is assumed to be 0.25[59]. In theory, if land profitability were zero, then this function would be equal to one, indicating no yield penalty on those acres for converting to flood irrigation. If, on the other hand, land profitability is equal to $\pi_{\max}$ (the highest per acre-profitability in the basin), then this function is equal to 0.75, indicating that only 75% of the profits per acre will result if acreage is converted to flood irrigation. If acres convert from sprinkler to flood, this yield coefficient is multiplied by profits per acre, and the annualized penalty is then subtracted from these yield-adjusted profits. If instead these acres remain in sprinkler, both the yield coefficient and the annualized penalty are equal to zero, making this formulation identical to the fixed sprinkler and flood formulation. More detail is provided in Appendix D.

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[58] Based on personal communication with Paul Patterson, Extension Specialist with the University of Idaho Extension Service on July 27, 2006.

[59] Based on results from O'Brien, et al. 2000 – see section 4.2.5.2.

The term $+[\alpha_{ij}(\pi_{ij}+\phi_{ij})-\phi_{ij}](a^{D}_{ijky}+a^{Dc}_{ijky})$ is an amalgamation of fixed costs incurred by idling acres and the supplemental profits that accrue to those acres due to subirrigation. The latter term in the expression ($a^{D}_{ijky}+a^{Dc}_{ijky}$) represents the total fixed and convertible acres that are idled. When the total idled acres are multiplied by the subirrigation coefficient times the profits plus fixed costs ($\alpha_{ij}(\pi_{ij}+\phi_{ij})$), the returns to the basin from dryland farming and ranching are calculated. Previous experience with water banking in the Wood River basin suggests that ranchers who sell their water rights for the season continue to ranch with a smaller herd[60]. The first coefficient, α_{ij}, represents the subirrigation coefficient of an individual acre, which is the feet of subirrigation divided by the total feet of evapotranspiration for that acre. Subirrigation is given in the following table:

Table 14: Subirrigation per Acre in Different Klamath Assessor Areas

Area	Acre-feet per Acre Idled (acre-feet)
Wood, Williamson[61]	1.04
Sprague	1.5
Project, Lost Basin	~2.25[62]

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[60] Based on personal communication with Ron Hathaway, Livestock Extension Agent with Oregon State University on January 18, 2006

[61] No contracts have been established between Reclamation and irrigators within the Williamson basin. Due to similarities of topography and hydrology, the subirrigation in the Williamson is assumed to follow that in the Wood basin.

[62] Here, Reclamation compensates irrigators based on the evapotranspiration of the particular crop planted. This value represents an estimated average.

Note that fixed costs are added to profits in calculating the return from subirrigation as a compensatory measure, because fixed costs are multiplied by all idled acres (not taking into consideration subirrigation) and subtracted from overall profits.

The next component of the model, $-(\psi_y - \psi^c)\sum_i e^I_{iy} - \psi_y \sum_a e^G_{ay}$, represents the irrigation and groundwater pumping costs due to increased energy prices. The term ψ^c is the current energy costs. If projected future energy costs (ψ_y) are the same as current prices ($0.006 per kWh), then irrigation energy costs are zero. This makes sense given that it is assumed that the current energy costs are internalized into the profits accruing to land. The irrigation and groundwater-pumping component of energy costs are described in more detail in the constraints section below.

The last component of the model, $+\lambda s_y$, represents the marginal value of inter-annual water storage in the basin lakes and reservoirs. The storage element is not included in the final calculation of profits - it is included in the objective function only to more appropriately reflect realistic management decisions. The single-year model would not to transfer water from one year to the next without some value placed on storage within the objective function. Accordingly, the total volume of stored water in the system (over and above minimum allowable levels) is multiplied by a coefficient that represents the marginal value of an acre-foot of water in storage between October of one year and March of the next. To estimate that relationship, the model was run several times to assess which value generated model lake levels most similar to those observed historically. The best fits (which can be observed in the model validation section) was at $0.0003 per acre-foot, which is considerably lower than one may expect. However, note also that UKL levels recover almost entirely during the winter months, making October storage virtually worthless in that lake. On the other hand, historical data indicates that levels of Clear Lake and Gerber reservoir have rarely recovered completely during those months, giving storage a positive value. This estimation of storage is likely oversimplified and inaccurate for two reasons. First, the four months not included in the model make accurate estimates of transfer value very difficult due to the highly variable recharge during those months. A 12-month model would help to address this issue. Second, the value of water in storage should vary based upon the lake level (i.e. marginal value should be zero if lake levels are maximized and higher when lake levels are at their minimum). Instead, this value is assumed to be invariant. Next, the assumptions present in the trade model depicted above are explored.

4.3.2.2 Assumptions of the Trade Model

The trading model is not intended to replicate realistic conditions – it is currently institutionally impossible for large-scale trading to take place in the basin. However, the purpose of the trading model is to investigate the magnitudes of benefits that could result from lessening these institutional constraints. In this section the assumptions necessary for trading to occur are discussed.

The trading section of the model assumes that there are no third party effects or transaction costs associated with transfers. This assumption may be reasonable on a broad level given that both the upper basins and Lost Basin will always be the source of water transfers rather than the recipient due to model constraints. However, this is also assumed for the flexible intra-sub-basin transfers that, depending on the direction of the transfer, may cause third party effects. This will overestimate the benefits accruable to trading. Additionally, the fully flexible trading scenario assumes that adjudication is complete and that water rights are fully defined. As mentioned in the water markets section above, without fully defined and flexible rights, trading simply cannot take place. Finally, in order to effectively monitor the water transfers, it is necessary to be able to quantify the transfers that occur. This is currently infeasible in the basin due to a lack of measurement infrastructure. The model assumes that each individual right and use can be quantified and tracked. Currently, when water shortfalls occur, individual irrigation districts with later priority rights receive smaller quantities of water from Reclamation. The irrigation districts are then expected to resolve allocation issues within their borders. In the following paragraphs, the model formulation where trading is not allowed is described.

4.3.2.3 No-Trade Formulation

In the trading model, the value of the objective function is given by the profitability of land, forcing the model to maximize farm profits. In reality, however, the allocation of water is dictated by the prior appropriation doctrine, which organizes water rights based upon historical precedent. Since GAMS operates based on maximization of an objective function, it was necessary to construct an objective that could be maximized independent of profits. The maximization problem was organized by using weighted values that represent the order in which areas receive water within the basin. The no-trade model calculates the value of the objective function using these values[63]. The objective function and a constraint unique to the no-trade formulation are given below.

$$\Pi_y = Max \sum_i \sum_j \sum_k [\pi_i^{nt} a^I_{ijky} + (\pi_i^{nt} - \chi_k) a^{Ic}_{ijky}] - (\psi_y - \psi^c) \sum_i e^I_{iy}$$
$$- \psi_y \sum_a e^G_{ay} + \lambda s_y$$

Where:

π_i^{nt} =Artificially introduced price in each area reflecting priority structure within the basin

Subject to:

$$\frac{\sum_k (a^I_{ijky} + a^{Ic}_{ijky})}{\sum_k (A_{ijk} + A^c_{ijk})} = \frac{\sum_k (a^I_{i(j+1)ky} + a^{Ic}_{i(j+1)ky})}{\sum_k (A_{i(j+1)k} + A^c_{i(j+1)k})}$$

Where:

A_{ijk} =total flood and fixed sprinkler land available in each farm use area, soil class and irrigation technology

A^c_{ijk} =total convertible sprinkler land available in each farm use area, soil class and irrigation technology

Here, Π_y does not represent actual profits that year, but simply an arbitrary value that is maximized. Once this model has determined the variable values (i.e., lake levels, land in production, etc.), the values are post-processed in a function that generates the actual basin profits (very similar to the trade model formulation). The constraint shown above requires that water be applied to each soil class within an area in even proportions (i.e., if 50 percent of Bonanza acres are irrigated, 50 percent of each soil class within Bonanza must be irrigated). Without this requirement, the

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[63] For another example of a weighted objective function in linear programming, see Ringler and Cai (2003).

model would have no rule for applying water to the different soil classes and would generate unpredictable and inconsistent results. Post-processing would then result in wide variations in profits, depending on how the model chose to distribute water between soil classes with wide-ranges of profitability. Although this assumption may be overly restrictive due to the potential for intra-soil class trading during dry years, no framework for predicting such trading was available.

All of the components of the objective function necessary to make appropriate economic decisions (i.e., irrigation and groundwater pumping costs) are included in this version of the model, and have already been described above. Note that the conversion cost is still being subtracted from convertible acre profits. This essentially stabilizes the model and keeps all of these acres in sprinkler irrigation; without this term, conversions from sprinkler to flood would occur arbitrarily and unpredictably. Since this version of the model cannot be used for the energy analysis since conversions from sprinkler to flood are based upon actual profitability of each acre, this formulation presents no issues.

The weight schedule (and by proxy, the priority structure[64]) for the trade model is included in Table 15 below. Note that the highest priority areas are the upper basins [Sprague, North Country (Williamson), Fort Klamath (Wood), and Hwy 97 to Chiloquin] and the Lost Basin (Bonanza/Dairy/Hildebrand and Langell Valley). Since adjudication is incomplete, the upper basins, which feed into UKL, cannot be kept

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[64] The priority structure for the no-trade model is based on priority designations contained in the 2002 Reclamation Crop report (Reclamation 2002) and on personal communication with John Hicks, a current hydrologist at Klamath Reclamation, and Ben Everett, former hydrologist at Klamath Reclamation, on August 7 and 8, 2006. When a project area could not be given a designation based on available information (such as the area West of Highway 97 to Keno), it was assigned a “C” priority.

from using as much water as they need, and as a result were not impacted by the low flows of 2001. The Lost Basin functions somewhat as a separate hydrological system, making a high priority designation appropriate because they neither supply nor receive water from any other area of the basin. Its water supply is based entirely upon snowmelt in the adjacent mountains, local groundwater, and reservoir storage in Clear Lake and Gerber Reservoir. The Lost Basin receives limited (if any) water from the western portion of the project; if enough water is available, the Lost Basin gets first priority to that water; if not, there is no way to bring water from the project up past Harpold Dam. Once water reaches the project, the first areas to receive water are Merrill/Malin, Midland/Henley/Olene, and Tulelake. All remaining areas receive water last.

Table 15: Priority Structure for the No-Trade Model

Sub-Region	Assessor Area	Priority Level[1]
Upper Basins	North Country (Williamson)	A
	Fort Klamath (Wood)	A
	Modoc Pt. to Chiloquin	A
	Sprague	A
Lost Basin	Bonanza/Dairy/Hildebrand	A
	Langell Valley	A
Project	Merrill/Malin	B
	Midland/Henley/Olene	B
	Tulelake	B
	Poe Valley	C
	Lower Klamath Lake (OR)	C
	Malin Irrigation District	C
	Shasta Irrigation District	C
	Lower Klamath Lake (CA)	C
	West of Hwy. 97 to Keno	C

1. A is the highest priority level and C is the lowest

4.3.3 Constraints

Here, constraints include physical parameters such as total water available due to precipitation, institutional parameters such as ESA, and agricultural parameters such as evapotranspiration due to various crops.

4.3.3.1 Land Constraints

The total quantity of land in any given area must be less than or equal to the total land in that area. The land remaining is the balance between these two:

$$a_{ijky}^{I} \leq A_{ijk}$$
$$a_{ijky}^{D} = A_{ijk} - a_{ijky}^{I}$$
$$a_{ijky}^{Ic} \leq A_{ijk}^{c}$$
$$a_{ijky}^{Dc} = A_{ijk}^{c} - a_{ijky}^{Ic}$$

4.3.3.2 Irrigation Constraints

The total amount of water utilized by irrigators is comprised of all evapotranspiration from land that is used for agriculture and land that is idled. The evapotranspiration of idled lands depends upon the area's subirrigation.

$$I_{ijmy} = \sum_{k} [\varepsilon_{ijm}^{I}(a_{ijky}^{I} + a_{ijky}^{Ic}) + \varepsilon_{ijm}^{D}(a_{ijky}^{D} + a_{ijky}^{Dc})]$$

Where:

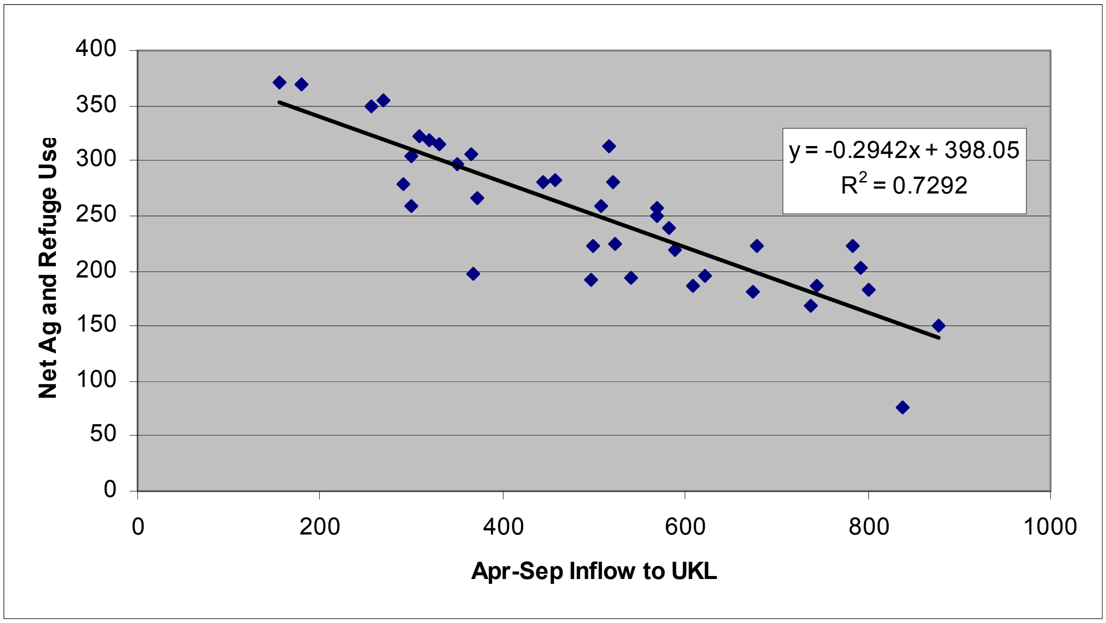
$$\varepsilon_{ijm}^{I} = \sum_{n} \xi_{nm} s_{ijn}$$

m=month index: march (m_1) through october (m_8)
I_{ijmy}=amount of water used by irrigators each year and month in each farm use area and soil class
ξ_{nm}=average evaporation by each crop each month of the season
$\varepsilon_{ijm}^{I,D}$=evapotranspiration from each irrigated/idled acre in each farm use area and soil class each month

Impact of Inflow Magnitude on Agricultural Water Consumption

In their 2005 report on the Reclamation Water Bank, the USGS noted a strong negative correlation between inflow into UKL and net agricultural diversions (the total volume of water consumed by agriculture). This relationship was assumed to exist because of a negative interaction between soil moisture content (correlated with overall inflows) and transmission losses in irrigation canals moving water both to and from agricultural fields. As transmission losses increase in dry years, net diversions increase correspondingly. This relationship is built into the hydrological model and is shown in Figure 15 below. The agricultural evapotranspiration requirements for each year are multiplied by a coefficient between approximately 0.6 and 1.4 depending on that year's inflows to UKL. The year with the inflow closest to the mean (roughly 500,000 acre-feet) has a coefficient closest to one. This has the effect of intensifying the impact of dry years. The source of these data are the Reclamation modsum table from 1961 to 2002. 2001, 2003 and 2004 were excluded due to excessive groundwater pumping (2001) and water bank interference (2003 and 2004).

Figure 15: Net Agricultural Use versus Inflow to Upper Klamath Lake



4.3.3.3 Water Balance for Each Geographic Sub-Region

In order to more accurately represent the Klamath hydrosystem, the basin was divided into three parts based on geographic and hydrological delineations: the upper basins, the Lost Basin and the Reclamation project. The upper basins were restricted from using any water within or below UKL to meet their needs. The Lost Basin was restricted to using lost inflows or storage from Gerber Reservoir or Clear Lake. Both of the residual flows from these areas are available for project irrigation use.

Water balance for the upper basins

The total amount of irrigation water used in the upper basins must be less than or equal to the total inflow into the upper basins plus any groundwater inputs. Note that the total monthly inflows are assumed to include full historic irrigation consumption, so this should never bind. Here, the total amount of irrigation water is summed over areas one through four, which are the three upper sub-basins and the Modoc to Chiloquin farm use area.

$$\sum_{i=1}^{4}\sum_{j} I_{ijmy} \leq N_{a_1my} + G_{a_1my}$$

Where:

N_{amy} =Exogenous inflows into each sub-region each year and month. Lost inflows are the sum of flows into Clear Lake and Gerber Reservoir, and Project inflows are groundwater inflows between Keno Dam and Iron Gate Dam

G_{amy} =Groundwater pumping in each sub-region each year and month

Water balance for the Lost Basin

The irrigation use in the Lost Basin is constrained by the total available to those irrigators. Unlike the upper basins, the Lost Basin has experienced historic deficits in these flows. Note that the summation is occurring over farm use the Lost River areas, which are Langell Valley and the Bonanza/Dairy/Hildebrand Areas. The total available in this region includes the flows into Clear Lake and Gerber Reservoir, as well as any water made available by these storage reservoirs over the irrigation season. Groundwater pumping is also available.

$$\sum_{i=5}^{6}\sum_{j} I_{ijmy} \leq N_{a_2my} - \sum_{q=2}^{3} L_{qmy} + G_{a_2my}$$

Where:

q=lake index: Upper Klamath Lake (q_1), Clear Lake (q_2) or Gerber Reservoir (q_3)

L_{qmy} =Water use or contribution by each lake each year and month

Water balance for the entire irrigation system

This constraint requires that total irrigation water use is exactly equal to the balance remaining after inflows, lake uses, refuge use, IGD use and all groundwater inflows. In any given month and year, the sum of all irrigation use across storage units equals the sum of inflows over subregions minus the sum of lake contributions (may be positive or negative) over the three lakes, minus refuge use, minus dam use, and plus the sum of groundwater pumping over subregions.

$$\sum_i \sum_j I_{ijmy} = \sum_a N_{amy} - \sum_q L_{qmy} - R_{my} - D_{my} + \sum_a G_{amy}$$

Where:

R_{my} =Lower Klamath Lake and Tule Lake refuge use each year and month

D_{my} =Water use by Iron Gate Dam from sources above Keno Dam each year and month

4.3.3.4 Lake Levels

The lakes serve as monthly deposit and withdrawal mechanisms which have minimum requirements based upon ESA requirements. Excess water from the system is deposited into the lake or flows through IGD to the lower basin. If it flows through IGD, it will be captured in the IGD flow variable.

General Lake Level Framework

The lake level constraint states that the lake level must not fall beneath the minimum required by the FWS, and the maximum must not exceed the maximum capacity mark of the lake. The following constraints and equalities apply to UKL, Gerber Reservoir and Clear Lake. Note that evaporation is not included in these equations because they have already been removed from Reclamation inflow data.

$$\rho_{qmy} \geq l_{qmy} \geq l_q^{MAX}$$

Where:

ρ_{qmy} =yearly and monthly level requirement of each lake

l_{qmy} =yearly and monthly lake level of each lake

l_q^{MAX} =maximum lake level due to physical constraints

The total monthly use for each lake is determined by the decrease or increase in lake level caused by inflow and diversions. This is a critical choice variable which allows the irrigation district managers to distribute water over the course of the season through strategic use of these reservoirs. In the first month, the lake is managed assuming that the starting elevation of the lake (on March 1 in year 1) is at the historic March level for the year selected.

$$L_{qmy} = (l_{qmy} - l_q^{MAX}) * \upsilon_q$$

Where:

υ_q =volume per foot of each lake

In subsequent months, the use or contribution of water from the lake is calculated by multiplying the difference in lake levels by the volume per foot of the lake. A positive value reflects monthly consumption of water by the lake, whereas a negative value implies net monthly contribution to the system.

$$L_{qmy} = (l_{qmy} - l_{q(m-1)y})\upsilon_q$$

Increases and decreases in lake levels are restricted to historical maxima:

$$\Delta_q^{L1} \leq l_{qmy} - l_{q(m-1)y} \leq \Delta_q^{L2}$$

Where:

$\Delta_q^{L1,L2}$ =maximum decrease and increase in lake levels between months for each lake (feet)

Inter-Seasonal Transfer of Lake Levels

Although inflow data are exogenous and invariant once the model randomly chooses a particular year, the endogenous lake levels (which are choice variables) chosen by the optimization model have no relationship to historical data. To illustrate, if 1987 is randomly chosen, the model will begin with the March 1^{st} lake level from 1987 as the initial condition for the random sequence of years to come, then optimize lake levels to maximize profits for 1987, ending with optimal lake levels on October 31^{st}. If the next year chosen is 1965, how should the lake levels for the following March 1^{st} be calculated? This required developing relationships between historical recharge from October 31^{st} to March 1^{st} and a set of highly correlated historical predictive variables. If predicting the March 1^{st} lake level in 1963 is of interest, suitable variables would include 1963 January through March snowpack data from various NRCS Snotel sites, 1963 January and February inflows to each lake, and 1962 October 31^{st} lake levels. The latter variable was included with the assumption that March 1^{st} lake levels would be strongly correlated (either positively or negatively depending upon the lake) with lake levels from the previous October. After running several multiple regressions for each lake, the best fits are provided below. Note that he these coefficients are each significant at less then the 1 percent level (p-values for each coefficient are in parentheses below the value):

$\Omega_U = 4077.0016 + 0.0027J_U - 0.9846O_U$
(<0.0001) (0.0007) (<0.0001) $R^2=0.807$
$\Omega_C = 345.6648 + 0.0531J_C - 0.0763O_C$
(0.0012) (<0.0001) (0.0012) $R^2=0.9571$
$\Omega_G = 722.019 + 0.2663J_G - 0.1497O_G$
(0.0046) (0.0047) (<0.0001) $R^2=0.8197$

Where:
U,G,C = Subscripts denoting UKL, Clear Lake and Gerber Reservoir
Ω = annual recharge
J = Current year's January + February Inflow
O = Previous year's October 31st lake level

Snow level data were included in separate regressions for each lake, but adjusted R^2 were not improved by their presence.

Water Balance for the Lakes

Increases or decreases in monthly UKL levels are dictated largely by how the lake is managed. The constraint below requires that the monthly use of the lake be restricted to that quantity of water available. When the lake contributes to the system (i.e. the lake level falls), the value of L is negative.

$$L_{q_1my} \le N_{q_1my} + G_{a_1my} - \sum_{i=1}^{4}\sum_{j} I_{ijmy}$$

For Gerber Reservoir and Clear Lake:

$$\sum_{q=2}^{3} L_{qmy} \le N_{a_2my} + G_{a_2my} - \sum_{i=5}^{6}\sum_{j} I_{ijmy}$$

4.3.3.5 Iron Gate Dam Flow

The IGD flow requirement is a fairly straightforward constraint. Flow through IGD will be constrained by the NOAA flow requirements for each month and year type. Note that D is not the actual flow through IGD, which is given by D plus flow accretions between Keno Dam and IGD.

$$\sigma_{my}^{D}\delta_{m} \leq D_{my} + N_{a_3 my} \leq D^{MAX}$$

Where:
$\sigma^{\mathrm{D}}_{\mathrm{my}}$ =yearly and monthly Iron Gate Dam flow requirement
δ_{m} =monthly conversion from cubic feet per second (cfs) to acre-feet per month
$\mathrm{D}^{\mathrm{MAX}}$ =maximum Iron Gate Dam flow between 1983 and 2002 (acre-feet)

Changes in IGD flow are constrained by historic maximum decreases and increases.

$$\Delta^{D1} \leq (D_{my} + N_{a_3 my}) - (D_{(m-1)y} + N_{a_3 (m-1)y}) \leq \Delta^{D2}$$

Where:
$\Delta^{\mathrm{D1,D2}}$ =maximum decrease and increase in flows between months at Iron Gate Dam (acre-feet)

4.3.3.6 Groundwater

Historical (pre-2001) groundwater pumping for agricultural purposes (approximately 150,000 acre-feet from USGS figures cited above) is treated as a sustainable baseline for groundwater pumping with no impact on groundwater levels. All pumping in the model involves substituting groundwater irrigation onto acres previously irrigated with surface water. Groundwater was broken up into the sub-region level, such that independent supplies are available to the upper basins, the Lost

Basin and the reclamation project. The volume of pumping necessary to decrease groundwater levels one foot was assumed to be independent of depth. This implies that whether groundwater depths are at 25 feet or at 5 feet, 20,000 acre-feet of pumping will cause the same decline in groundwater tables. Based on hydrogeological relationships, this is a reasonable assumption[65].

Groundwater is assumed to decline one foot for 5000 acre-feet of additional pumping in the upper and Lost basins and one foot for 10,000 acre-feet of additional pumping in the Reclamation project. This latter value is based on the measured additional pumping over the 2004 season of 75,716 acre-feet and groundwater declines ranging from 10 to greater than 20 feet over the season (McFarland, et al. 2005). Assuming an average of 15 feet of decline, this is approximately 5,000 acre-feet per foot of groundwater decline over the season. In the absence of any other data, this relationship in the other two sub-regions is assumed to be 2,500 acre-feet per foot of decline.

$$\varphi_a (g_{ay}^{O} - g_{ay}^{M}) \leq \sum_m G_{amy}$$

Where:

φ_a =quantity of groundwater pumped in each sub-region to reduce level by one foot

$g_{ay}^{O,M}$ =the october/march depth to groundwater in each sub-region each year

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[65] Based on personal communication with Marshall Gannett, Hydrologist with the U.S. Geological Survey, on July 21, 2006

Annual groundwater pumping is never allowed to exceed certain institutional maxima (these are variable depending on the scenario), but is always greater than or equal to zero:

$$G_{amy} \leq \gamma_{am}$$

Where:
γ_{am} =The maximum allowable pumping per month in each sub-region

Between seasons, groundwater is assumed to recover a fraction of the total depth[66]. So, if fall groundwater levels in year one are at 20 feet below ground surface (bgs), and no off-season groundwater pumping and a recovery of 50 percent per year are assumed, then depth to groundwater will be 10 feet in spring of year two. Between spring of 2003 and spring of 2004, groundwater levels declined in the project region between two and nine feet (more areas decline by two than by nine feet), averaging approximately four feet. Pumping in the 2003 irrigation season was approximately 55,667 acre feet (McFarland, et al. 2005). Using the relationship given above, seasonal groundwater declines were approximately 11 feet. This implies a recovery of seven feet between fall of 2003 and spring of 2004. Thus, the off-season recovery rate is approximated at 0.6 feet of recovery for each foot of seasonal decline. This

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[66] This assumption is based upon personal communication with Marshall Gannett, Hydrologist with the USGS in Portland, Oregon, on March 15, 2006. Mr. Gannett is the lead hydrologist developing the Klamath groundwater model, and from his experience has found that it would be more accurate to allow recharge to occur as a fraction of groundwater depth rather than as a fixed quantity proportional to climatic data from recent years (the original intention in this analysis). Greater groundwater depth exerts greater recharge pressure on the surrounding aquifer, causing increased inter-seasonal groundwater recharge.

relationship is assumed to be constant for each sub-region and independent of depth. In reality, this relationship is not constant with respect to depth, but it is uncertain how the relationship would vary. At a certain depth, a new dynamic equilibrium may occur where regional groundwater recharge offsets increased pumping (McFarland, et al. 2005). No within season recharge is built into the model; all recharge is collapsed to the fall to spring period. The inter-seasonal recharge relationship is given below:

$$(1-\mu)g^{O}_{a(y-1)} = g^{M}_{ay}$$

Where:

μ=off-season (October 31st to March 1st) recharge coefficient

Here, if the depth to groundwater in October of year one is 10 feet and the recharge coefficient is 0.6, then the depth to groundwater in March of year two will be (1-0.6) *10 feet, or 4 feet. Alternatively, groundwater recovered 6 feet, or 60% of the total depth.

In the absence of any restriction on groundwater pumping, groundwater would be pumped continuously. A model configured with an unlimited capacity for groundwater pumping would be informative if the groundwater system were better known, as a sustainable pumping rate could be found. Instead, low, medium and high levels of groundwater availability are allowed. Table 16 shows these values and pumping/recovery values below.

Table 16: Groundwater Model Component Configuration

Sub-Region	Volume per foot of Groundwater System (acre-feet)	Example: GW Decline due to 50,000 acre-feet of pumping (feet)		Groundwater Availability Scenarios (acre-feet per month)			
		Seasonal	Annual	Base-Case	Low	Medium	High
Upper Basins	2,500	20	8	0	2,500	5,000	10,000
Lost Basin	2,500	20	8	0	2,500	5,000	10,000
Reclamation Project	5,000	10	4	0	5,000	10,000	20,000
Annual Total				0	80,000	160,000	320,000

Given that the total amount of additional (over the baseline assumed to be 150,000 acre feet) groundwater pumping in the basin was approximately 75,000 acre-feet in 2004, the low, medium and high scenarios assume that this volume is the same, doubled and quadrupled, respectively. If looking at pumping in the project alone, allowance for the low, medium and high scenarios restrict this sub-region to half of, the same as and double 2004 levels.

Groundwater declines are assumed to have no impacts on surface water flow. This is a strong assumption and should be addressed when more information on the relationship between groundwater depth and surface water flows becomes available.

4.3.3.7 Energy Costs

Energy costs may take a significant toll on irrigator net revenues. These are broken up into irrigation and groundwater pumping costs above and beyond the current levels. Additional sprinkler irrigation costs will only result from increased electricity prices. All energy costs for irrigation based on the Pacificorp contract rates are assumed to be incorporated into current costs, which would impact land value and thus calculated annual net revenues.

$$e_{iy}^{I} = \sum_{j}\sum_{m}\sum_{k} \varepsilon_{ijm}^{I} \omega_k k_k^{I} (a_{ijky}^{I} + a_{ijky}^{Ic})$$

Where:
ω_k =inverse of irrigation efficiency for sprinkler and flood technologies
k_t^I =kilowatt hours of energy used per acre foot of water pumped for each technology

As all farmland in the model is assumed to be currently surface water irrigated, any groundwater pumping which takes place will be in addition to current requirements. The energy consumed by groundwater pumping is a product of the groundwater pumped and groundwater depth.

$$e_{ay}^{G} = g_{ay} k^{G} \sum_{m} G_{amy}$$

Where:
k^G =kilowatt hours per acre foot of groundwater lifted one foot

4.3.4 List of Indices, Variables and Parameters

Indices

i=index for farm use area: Fort Klamath Valley (i_1), Modoc Point to Chiloquin (i_2), Sprague River (i_3), North Country (i_4), Bonanza/Dairy/Hildebrand (i_5), Langell Valley (i_6), Swan Lake Valley (i_7), Merrill/Malin (i_8), Poe Valley (i_9), Midland/Henley/Olene (i_{10}), Lower Klamath Lake (i_{11}), Malin Irrigation District (i_{12}), Shasta View Irrigation District (i_{13}), West of Hwy. 97 to Keno (i_{14}), Tule Lake (i_{15}), Lower Klamath Lake in California (i_{16})
j=soil class index: II (j_2) to V (j_5)
p=crop index: alfalfa (n_1), potatoes (n_2), grain (n_3), strawberries (n_4), onions (n_5), peppermint (n_6), sugar beets (n_7), other hay (n_8), and pasture (n_9)
y=index for the year
k=irrigation technology index: flood (k_1) and sprinkler (k_2)
a=sub-region index: upper basins (a_1 represents farm use areas i_1 through i_4), lost basin (a_2 or farm use areas i_5 and i_6) and the project (a_3 or farm use areas i_7 through i_{16})
m=month index: march (m_1) through october (m_8)
q=lake index: Upper Klamath Lake (q_1), Clear Lake (q_2) or Gerber Reservoir (q_3)

Constants and Exogenous Variables

p_n=price of crop k grown on share s_n of all acres
y_n=yield for crop k grown on share s_n of all acres
s_{ijn}=share of each crop in each farm use area and soil class based on observed cropping rotations (s is 0.4 for a crop grown four years during a 10-year rotation)
v_n=variable costs associated with crop n
f_n=fixed costs associated with crop n
P_{ij}=real market value of each acre in each farm use area and soil class
r=discount rate (assumed here to be 6%)
c^D_{ij}=cost of irrigation curtailment (or land idling) on each acre in each farm use area and soil class
τ_i=coefficient on each assessor area creating prior appropriation restrictions on trading
χ_k=per acre present value of capital, opportunity and labor costs of switching from sprinkler to flood irrigation
α_{ij}=the fraction of et on idled land due to subirrigation
ϕ_{ij}=fixed costs for each area and soil class ($\sum_n f_n s_{ijn}$)
η_k=flood versus sprinkler yield coefficient
ψ_y=energy price per kilowatt-hour each year
ψ^c=energy price in the original Pacificorp contract to irrigators ($0.006 per kilowatt-hour)
λ=the value per acre foot of water storage between years

A_{ijk} =total flood and fixed sprinkler land available in each farm use area, soil class and irrigation technology

A^{c}_{ijk} =total convertible sprinkler land available in each farm use area, soil class and irrigation technology

ξ_{nm} =average evaporation by each crop each month of the season

$\varepsilon^{I,D}_{ijm}$ =evapotranspiration from each irrigated/idled acre in each farm use area and soil class each month

N_{amy} =Exogenous inflows into each sub-region each year and month. Lost inflows are the sum of flows into Clear Lake and Gerber Reservoir, and Project inflows are groundwater inflows between Keno Dam and Iron Gate Dam

R_{my} =Lower Klamath Lake and Tule Lake refuge use each year and month

ρ_{qmy} =yearly and monthly level requirement of each lake

l^{MAX}_{q} =maximum lake level due to physical constraints

υ_{q} =volume per foot of each lake

$\Delta^{L1,L2}_{q}$ =maximum decrease and increase in lake levels between months for each lake (feet)

σ^{D}_{my} =yearly and monthly Iron Gate Dam flow requirement

δ_{m} =monthly conversion from cubic feet per second (cfs) to acre-feet per month

D^{MAX} =maximum Iron Gate Dam flow between 1983 and 2002 (acre-feet)

$\Delta^{D1,D2}$ =maximum decrease and increase in flows between months at Iron Gate Dam (acre-feet)

φ_{a} =quantity of groundwater pumped in each sub-region to reduce level by one foot

γ_{am} =The maximum allowable pumping per month in each sub-region

μ=off-season (October 31st to March 1st) recharge coefficient

ω_{k} =inverse of irrigation efficiency for sprinkler and flood technologies

k^{I}_{t} =kilowatt hours of energy used per acre foot of water pumped for each technology

k^{G} =kilowatt hours per acre foot of groundwater lifted one foot

Endogenous Variables

Π_{y} =maximum net revenues from surface water-irrigated agriculture in any given year

π_{ij} =net revenues from farming each acre

$a^{I,D}_{ijky}$ =acres of flood and fixed sprinkler land irrigated/idled each year, area, soil class and technology

$a^{Ic,Dc}_{ijky}$ =acres of convertible sprinkler land irrigated/idled each year, area, soil class and technology

$e^{I,G}_{iy}$ =irrigation/groundwater energy use in kilowatt-hours each year and farm use area/sub-region

s_{y} =the volume of storage in the system in october of each year

I_{ijmy} =amount of water used by irrigators each year and month in each farm use area and soil class

G_{amy} =Groundwater pumping in each sub-region each year and month

L_{qmy} =Water use or contribution by each lake each year and month

D_{my} =Water use by Iron Gate Dam from sources above Keno Dam each year and month

l_{qmy} =yearly and monthly lake level of each lake

$g^{O,M}_{ay}$ =the october/march depth to groundwater in each sub-region each year

4.4 Model Calibration

The agricultural economy of the basin – the focus of this study – is critically dependent upon its hydrological system. In order to ensure that the agricultural system receives historically appropriate quantities of water, it was necessary to calibrate the hydrological model. Calibration was conducted by balancing monthly inflows and outflows for each year, which produced positive or negative inferred inflow (defined below) values that were averaged and added back into the system. The hydrological components of this calibration are as follows:

- **Inflows**: inflow to UKL, inflow to Clear Lake, inflow to Gerber Reservoir, inflow between Keno and Iron Gate Dams[67], inflow at Bonanza Springs , and additional groundwater inflow[68].
- **Outflows**: agricultural evapotranspiration[69], outflow past IGD, "other evaporation", "refuge evaporation[70]". Evaporation from lakes is internalized in

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[67] Source of inflow data: 2006 Reclamation modsum spreadsheet

[68] "Additional groundwater inflow" includes only pumping greater than historically recorded (roughly 150,000 acre-feet). These were nonzero only during 2001 and 2002, which had seasonal pumping of 70,000 acre-feet and 40,000 acre-feet over historical pumping. These buffered the low flows of 2001 and met water bank requirements in 2002.

[69] It is assumed that the quantity of agricultural land in the basin was constant between 1962 and 2002, and that all available land was irrigated each year except for 2001 and 2002 (for the calibration). Evidence suggests that historically flexible flow and lake level requirements meant little idling was necessary. If this were untrue (in 1992 for example), inferred inflow values would be too high and impacts would be greater than results indicate. During 2001 and 2002, it is assumed that all land outside of the project was irrigated, but that only 25 percent and 90 percent of land was irrigated within the project. The former value was due to Reclamation curtailment and the latter due to voluntary land idling for the water bank. Jaeger (2004) estimates a smaller fraction of land in production during 2001, whereas Carlson and Todd (2003) estimate closer to 50 percent of land remained in production. According to the Government Accountability Office (GAO 2005), Reclamation did not keep records of

Reclamation flow data, which are comprised of monthly lake level changes plus outflow data (both converted to volume).

- **Inflows/Outflows**: Water use (increasing levels) or contribution (decreasing levels) by Upper Klamath, Clear, and Gerber Lakes[71].
- **Inferred inflow:** Inflow or outflow balance from the above, assumed to be unaccounted inflows or outflows over the unmonitored area (between UKL, Clear and Gerber Reservoirs and Keno Dam). As all flows into the upper basins are accounted for by measured inflows into UKL, all inferred inflow is distributed proportionally (based on share of land area) between the project and Lost basins.

The model for the calibration process is as follows:

$$\sum_s N_{sm} + \sum_l L_{lm} + slack_m = \sum_{ijk} a_{ijk}\varepsilon_{ijm} + D_m$$

Where:
s=index for inflows to UKL, Gerber, Clear and Keno to IGD
m=index for month (march to october)
l=index for lake (UKL, Gerber or Clear)
i=index for Klamath assessor-defined area
j=index for soil class within each area
k=index for technology within each soil class
N_{sm}=inflows to each area each month from Reclamation modsum
L_{lm}=inflows (negative is outflow) to system from each lake each month from historical lake level data
$slack_m$=inferred inflows (outflows if negative) to system each month
a_{ijk}=crop acreage in each technology, soil class and assessor-defined area
ε_{ijm}=evapotranspiration from one acre within each soil class and area each month (from crop rotation data)
D_m=outflows past Iron Gate Dam

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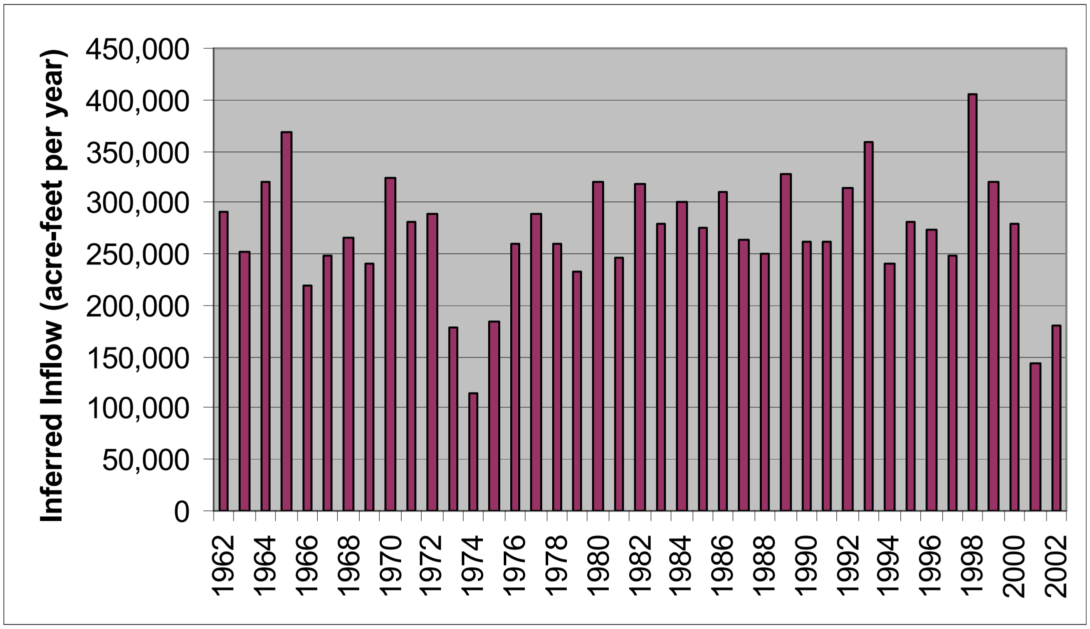
land idling for water bank operations in 2002, so 10 percent land idling is a rough estimate based on records from 2003 and 2004.

[70] Inflows at Bonanza springs, other evaporation, and refuge evaporation data are from Burt and Freeman 2003.

[71] Source of lake level and volume data: Reclamation.

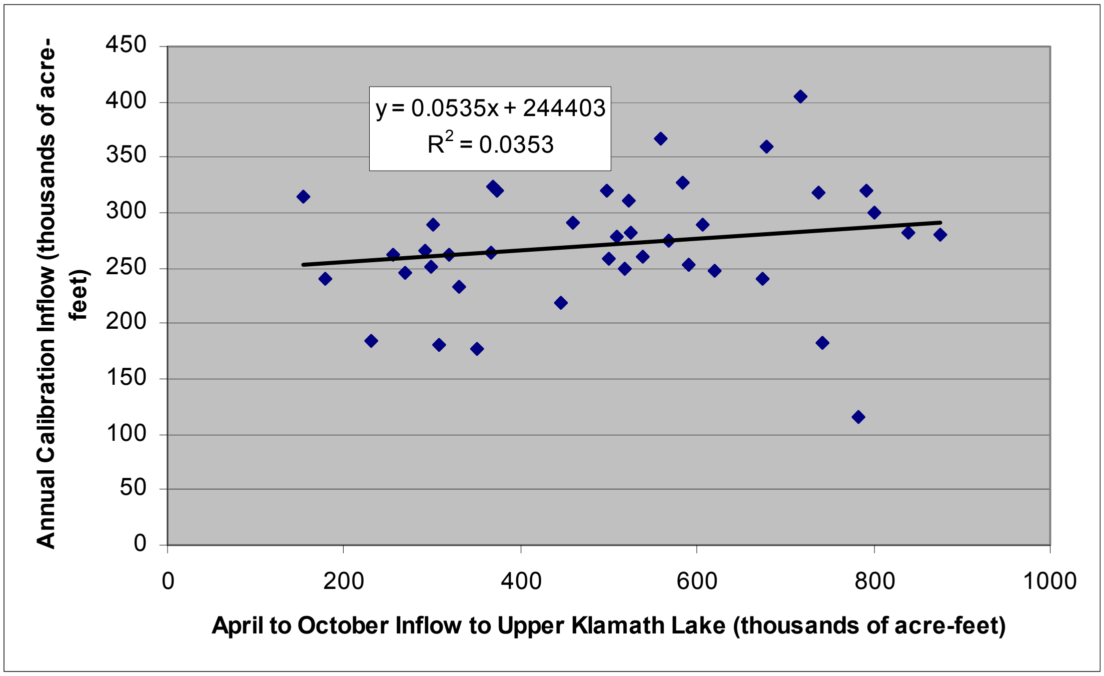
The inferred inflow values above (denoted by the variable *slack*) were calculated for each month and year between 1962 and 2002. The data used to calculate these and the more detailed monthly inferred inflow data are provided in Appendix E. Total inferred inflow values for each year, calculated from the above relationships, are shown in Figure 16 below. Note that the inferred inflow values capture all of the measurement error in the system, which may not be random. For a detailed investigation of these measurement errors, see Burt and Freeman (2003).

Figure 16: Inferred Inflow Values



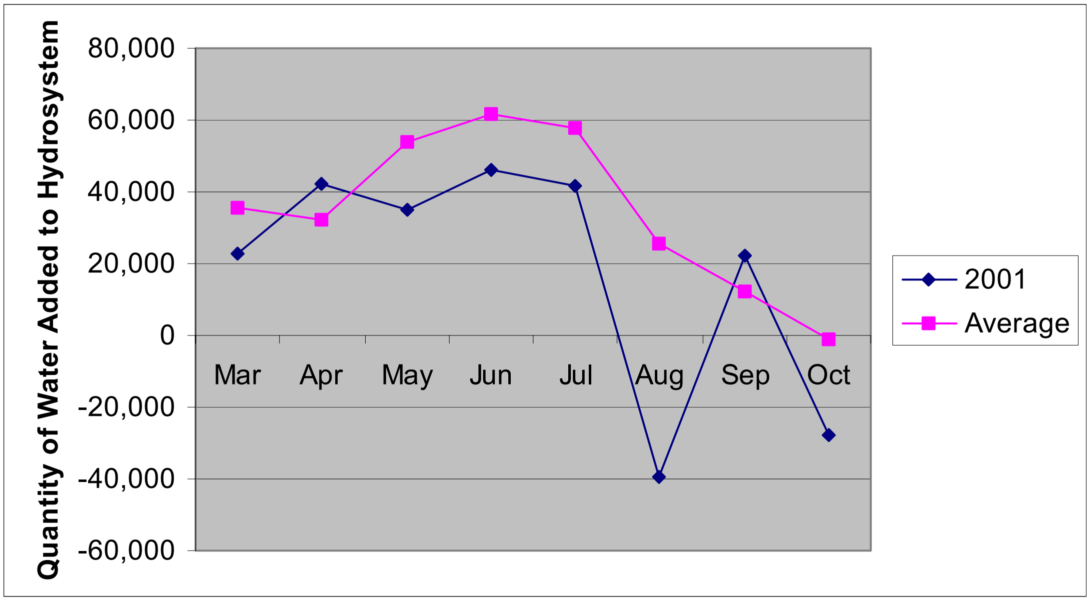
The intent was not to replicate the historical flows of each year; but to create hydrological conditions that are likely to occur in the future given historical data. Given that these inferred inflows are only estimates (both their temporal and geographic distribution are uncertain), adding the inferred inflows for each month and year (which vary tremendously) back into the model would likely lead to historically inaccurate hydrologic peaks and troughs during any given year. Instead, the 41 inferred inflow values for each of the eight months were averaged, resulting in a much smoother set of values to add to each year. If the inferred inflow values were positively correlated with the basin inflows, then averaging would be inappropriate, as it would lessen the impacts on water short years. Figure 17 shows the relationship between the annual inferred inflow values and the April to October inflows to UKL. There is a slight positive correlation between the two, but it was too weak to justify including even the linear relationship depicted in this figure.

Figure 17: Correlation between Inflows and USGS/Model Differences



Accordingly, these eight monthly inferred inflow values were included in the model as supplemental inflow (or outflow in October). These averaged inferred inflow values and those of 2001 are shown in Figure 18 below. Recall that it is assumed that only 25 percent of land in the project was irrigated during 2001, and that irrigators pumped an additional 70,000 acre-feet of groundwater that year. These both have the effect of reducing monthly calibration values, as lower evapotranspiration reduces outflows and higher groundwater pumping increases inflows. The August inferred inflow value for 2001 stands out starkly at over 60,000 acre-feet below the average for that month. During this month, large quantities of groundwater pumping coincided with a nearly one and a half foot drop in the level of UKL (roughly 100,000 acre-feet contributed to inflows), and a possible second cropping as water was made available from UKL (increasing outflows), explaining the unusually negative calibration value observed here.

Figure 18: Average and 2001 Monthly Inferred Inflow Values (Outflows minus Inflows)



The purpose of this calibration was to align hydrosystem inflows and outflows. By doing so, model results more accurately reflect the actual water available to agriculture during past years.

5 RESULTS AND IMPLICATIONS

This chapter is divided into two sections. The first section demonstrates the outcome of the model validation process. The second section presents the results and implications of the analyses.

5.1 Model Performance

Testing model performance is a critical step prior to gathering useful results. Here, the hydrological model is first validated, and then the no-trade model is tested to demonstrate that the model is producing meaningful results.

5.1.1 Hydrological Model Validation

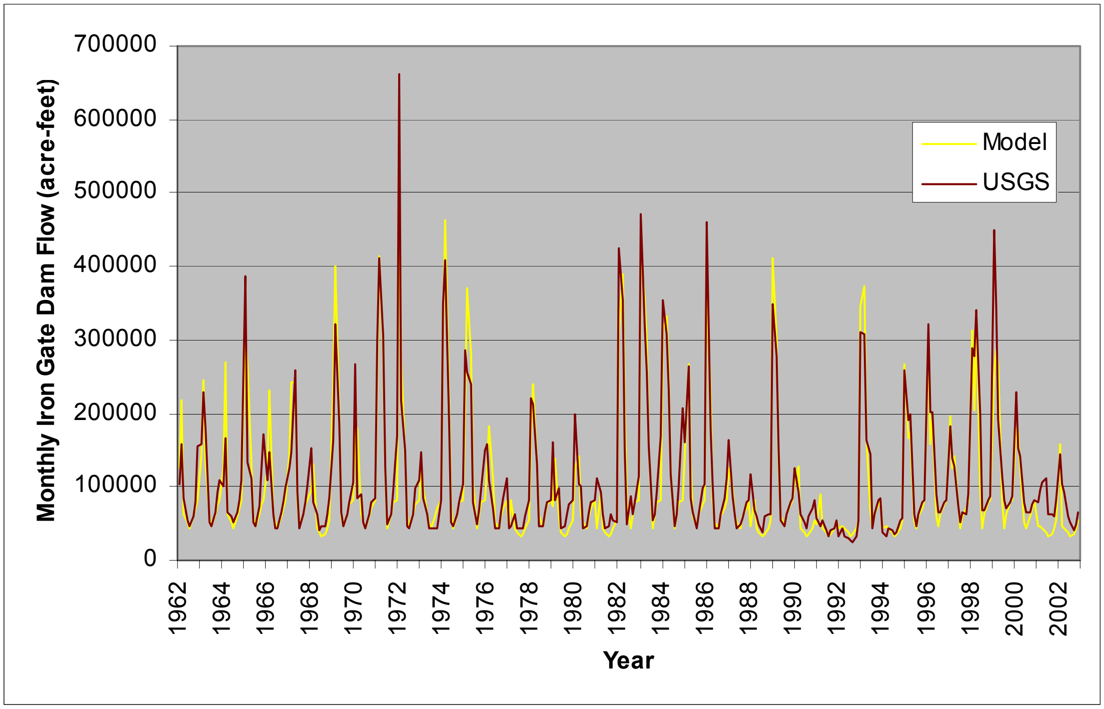
Once calibrated, the hydrological model was validated to ensure that the model was behaving as expected. Validation entailed first adjusting appropriate parameters to their historical levels, running the dynamic model for the years 1962 to 2002, and then observing resultant monthly and yearly flows and lake levels during those years. Ideally, the model would yield patterns of flow and lake levels similar to those observed historically at IGD, UKL, Clear Lake, and Gerber Reservoir. To match historical conditions, parameters used in the validation were fixed as follows:

- **Monthly groundwater availability:** No additional pumping was allowed on the historically surface-water irrigated acres included in the model

- **ESA requirements:** Current IGD and UKL level requirements were used to approximate the flexible historical PacifiCorp requirements for minimum hydroelectric flows
- **Energy price**: the historical level of 0.6 cents per kilowatt hour
- **Water trading:** No water trading is allowed
- **Subirrigation**: Reclamation subirrigation values are used

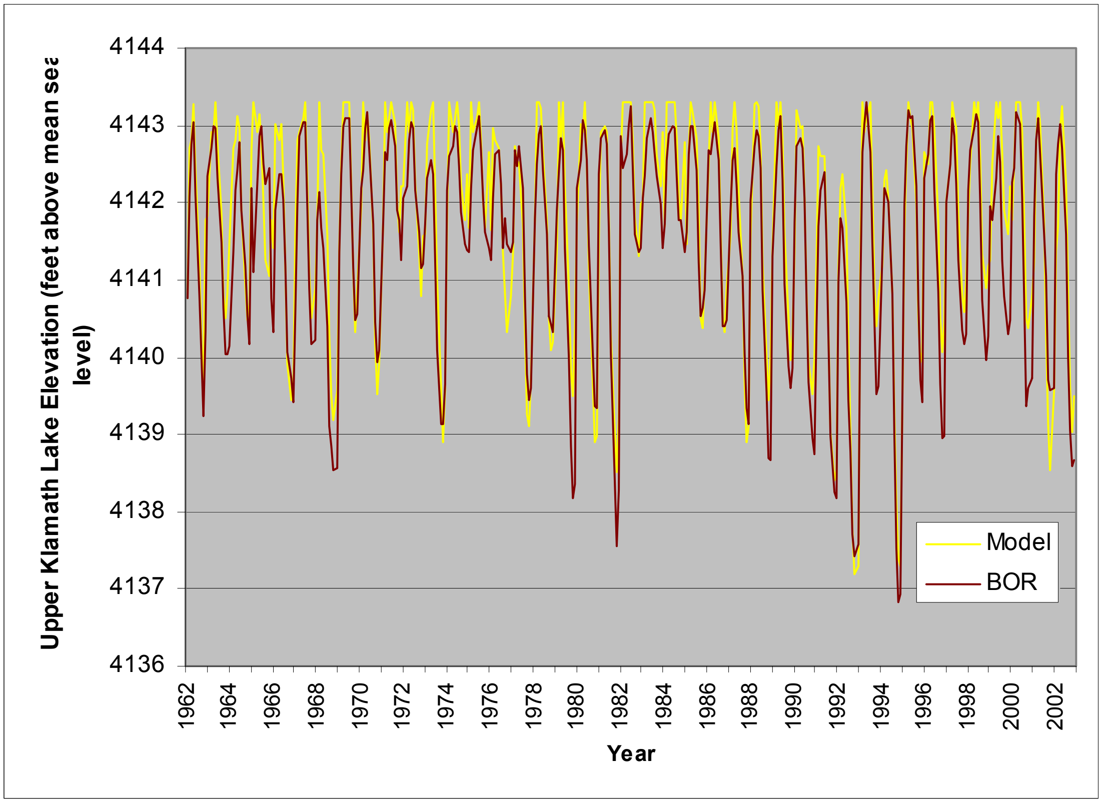
Model outflows from IGD compared favorably with USGS flow data, as observed in Figure 19 below ($R^2 = 0.8533$).

Figure 19: Iron Gate Dam Data Validation



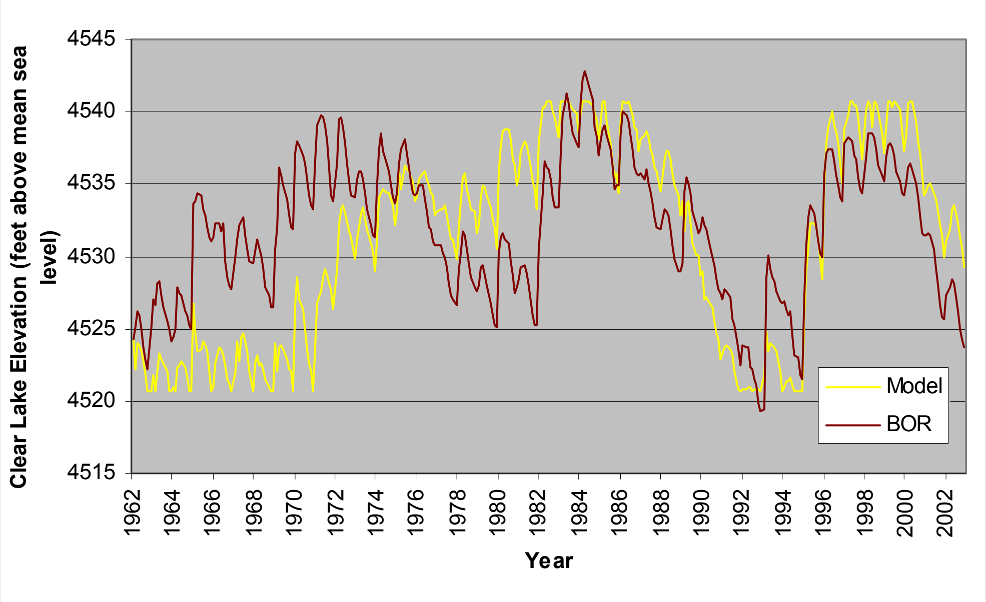
The relationship between Reclamation UKL level data and model outputs has an $R^2 = 0.8716$, as shown in Figure 20.

Figure 20: Upper Klamath Lake Level Validation



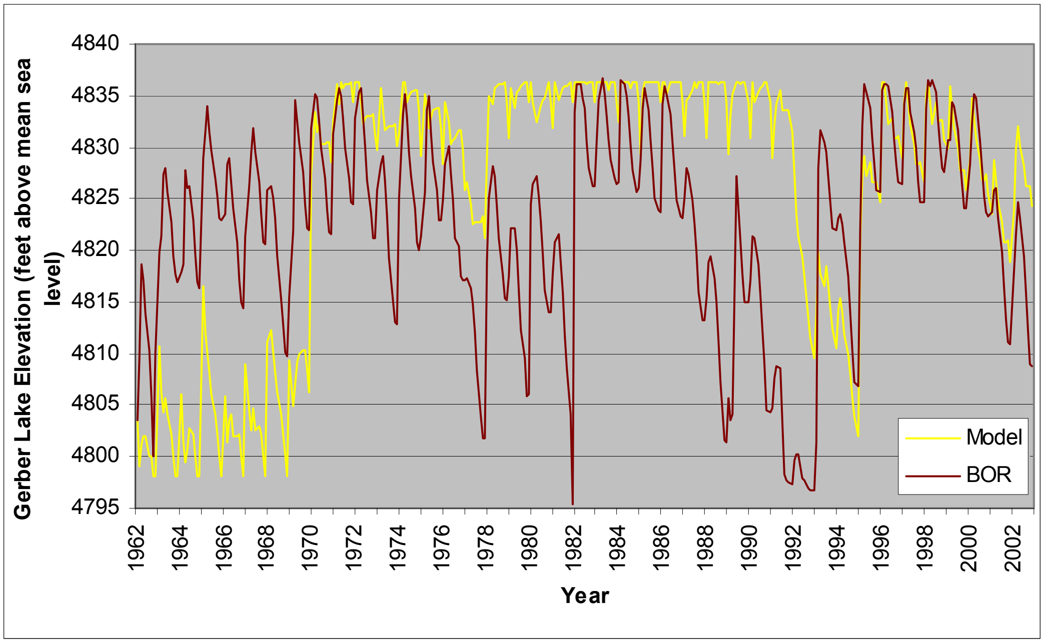
As can be seen from Figure 21 below, Clear Lake outputs matched up with Reclamation data very well for the latter half of the 41-year period but not the first. Why the earlier model data do not map more closely to historical data are unclear. The R^2 value is 0.7944.

Figure 21: Clear Lake Level Validation



Gerber Reservoir output data were the least similar to their historical counterparts, as seen in Figure 22. The intra-annual trends are very similar, but once the model reached the minimum allowable level, it remained there until 2002. Historically, the Reservoir was managed much more dynamically. This poor relationship is reflected in the R^2 value of 0.0688.

Figure 22: Gerber Reservoir Validation



The volume-elevation relationships between UKL, Clear Lake and Gerber Reservoir are approximately 70,000 acre-feet per foot, 20,000 acre-feet per foot and 2,000 acre-feet per foot, respectively. Due to the relatively minimal impact of Gerber Reservoir management on model outcomes (1 foot of UKL = 3.5 feet of Clear Lake = 35 feet of Gerber Reservoir), it is likely that the hydrological model was too insensitive to replicate historical levels. This minimal impact on model outcomes also implies that the lack of validation shown here will have insignificant impacts on study results.

5.1.2 No-Trade Model Validation

In this section, the no-trade model is analyzed to ensure that water is being distributed according to the artificially imposed priority structure. To test the no-trade model, simulations of 20 years were constructed randomly from historical data and run in the dynamic model. These simulations were reconstructed and run through the model a total of 30 times to develop average outcomes. To tax the model, it was assumed that 2001 requirements were imposed and no groundwater was available. The results of this validation are presented in Table 17 below. In this analysis, even the highest priority areas experienced years with low production. The Lost Basin values are lower than the upper basin values because their water supply is less certain. Note that there is a substantial drop in land in production between priority levels B and C. There also appears to be a drop between Malin and Shasta Irrigation Districts. Given that there is no priority structure to differentiate between these areas, seasonal per acre crop water use was expected to explain these observed differences. For the majority of areas, this creates the ordering structure within the priority group – but for Poe Valley this is not the case. Poe Valley consumes significantly more water per acre than Lower Klamath Lake in California (roughly 2.3 versus 1.9 acre-feet), but that area is in production more regularly than Lower Klamath Lake in California. This issue has not been resolved.

Each of the percentages shown in Table 17 also represents the percentages of land in all soil classes within these areas. In other words, in Fort Klamath, 94.7 percent of lands in soil class III and V are irrigated. In the absence of economic criteria to drive water allocation, this requirement was imposed to restrict random water allocations within each area from occurring. This is discussed in more depth in the model section above.

Table 17: Average Share of Irrigated Land in Each Assessor Area

Sub-Region	Assessor Area	Priority Level	Land Irrigated
Upper Basins	North Country (Williamson)	A	94.8%
	Fort Klamath (Wood)	A	94.7%
	Modoc Pt. to Chiloquin	A	94.7%
	Sprague	A	94.7%
Lost Basin	Bonanza/Dairy/Hildebrand	A	93.2%
	Langell Valley	A	92.9%
Project	Merrill/Malin	B	88.9%
	Midland/Henley/Olene	B	80.2%
	Tulelake	B	90.1%
	Poe Valley	C	63.7%
	Lower Klamath Lake (OR)	C	61.5%
	Malin Irrigation District	C	55.2%
	Shasta Irrigation District	C	48.7%
	Lower Klamath Lake (CA)	C	48.5%
	West of Hwy. 97 to Keno	C	48.7%

5.2 Results and Implications

The main objectives of this study are 1) to assess the impact of increased IGD flow requirements on net farm revenues and land idling in the basin in the presence and absence of water trading, 2) to evaluate the impact of increased energy rates on land idling and irrigation technology distribution, 3) to estimate the changes in net revenues and land idling due to incremental changes to ESA requirements, and 4) to assess how groundwater availability impacts net farm revenues and land idling in the presence of other constraints. Chapter four presented the framework for performing this assessment; here the results and implications for water management in the basin are presented.

This section of the chapter is broken into six subsections. Section one provides a roadmap to the analyses that follow, describing how six key parameters were adjusted in the model to address the individual objectives. The second section provides descriptive statistics generated by the model on how farm profits would be distributed if the hydrological conditions for 1962 to 2002 were to occur today. Section three contains the results and implications of the IGD and trading assessment, where average annual impacts of increased IGD flow requirements are presented in the presence and absence of water trading. This analysis allows us to compare the potential benefits from trading to those previously forecasted and to compare the losses experienced in 2001 to those expected in future dry years with higher IGD flow requirements. The forth section presents and discusses how farm profits, land idling, and the distribution of irrigation technologies change in response to increasing energy prices. The magnitude of average losses and land idling is compared to the magnitude of those incurred through increases in IGD flow requirements. Section five presents the results of the ESA analysis, where the relationship between incremental changes in ESA requirements and farm profits is developed. This relationship allows us to investigate how sensitive farm profits are to changes in IGD and UKL requirements. Finally, section six presents the results of the groundwater availability investigation. In this analysis, other parameters are allowed to co-vary with changing groundwater availability, allowing us to observe the significance of groundwater given a range of scenarios. Additionally, a simple dynamic groundwater analysis of declines over randomly generated 20 year periods is presented.

5.2.1 Analytical Roadmap

The above objectives are addressed by varying particular model parameters given the hydrological conditions of years between 1962 and 2002. The parameters that are varied include IGD flow requirements, UKL level requirements, trading flexibility, energy prices, groundwater availability, and subirrigation. Broadly, objective one involves co-varying ESA requirements and trading flexibility; objective two involves the variation of energy rates; objective three allows ESA requirements to vary incrementally to develop marginal relationships; and groundwater availability is varied to address objective four. Table 18 contains a textual overview of the different combinations of parameters used in these analyses, and is included below.

Table 18: Model Scenarios

Scenario	UKL Reqs	IGD Reqs	Trading Flexibility	Energy Prices (per kWh)	Groundwater Availability (acre-feet per month)	Sub-irrigation
Baseline						
Base Case	current	current	none	$0.006	20,000	BOR
IGD and Trading Objective						
Future IGD	current	future	none&high	$0.006	20,000	BOR
Current IGD	current	future	none&high	$0.006	20,000	BOR
2001 ESA	2001	2001	none&high	$0.006	20,000	BOR
2001 ESA no GW	2001	2001	none&high	$0.006	0	BOR
2001 ESA no GW zero SI	2001	2001	none&high	$0.006	0	none
Energy Objective						
Future Energy	current	current	none	$0.006-$0.069	20,000	BOR
Future Energy with IGD	current	future	none	$0.006-$0.069	20,000	BOR
ESA Objective						
Flexible UKL	flexible	future	none	$0.006	20,000	BOR
Flexible IGD	current	flexible	none	$0.006	20,000	BOR
Groundwater Objective						
Zero GW availability	current	future	none	$0.006	0	BOR
Low GW availability	current	future	none	$0.006	10,000	BOR
Medium GW availability	current	future	none	$0.006	20,000	BOR
High GW availability	current	future	none	$0.006	40,000	BOR

The scenario referred to as "baseline" in this table represents a best attempt at replicating conditions in the hydrological and institutional system which have existed after 2002 and prior to court-required increased ESA requirements. These include 2002 ESA requirements, no trading flexibility (due to institutional and physical restrictions), historic energy prices (0.6 cents per kWh), 20,000 acre-feet of additional groundwater availability per month[72], and Reclamation subirrigation estimates. Many of the analyses use this as the starting point from which changes are measured. Farm profits, land idled, groundwater pumped, and other model outputs in the results below are generated based on the hydrological conditions between 1962 and 2002 subject to different combinations of the above parameters. For example, in the coming sections, "average farm profits" are continually referenced. To calculate these, the hydrological conditions of each year were run subject to a particular set of specified parameters and averaged the outputs.

5.2.2 Distribution of Farm Profits

The distribution of annual farm profits is heavily dependent upon both monthly ESA requirements and the availability of groundwater. The following histograms show how farm profits each year would be distributed if the hydrological conditions for 1962 to 2002 were to occur today, varying ESA requirements and groundwater availability. Figure 23 shows their distribution when ESA requirements vary and 20,000 acre-feet of groundwater are available per month. Note that when short-term requirements are imposed, only one of the 41 years registers a profit lower than $20 million. When the long-term requirements are imposed, five years are below $20 million, and in the presence of 2001 requirements this number increases to 12 years.

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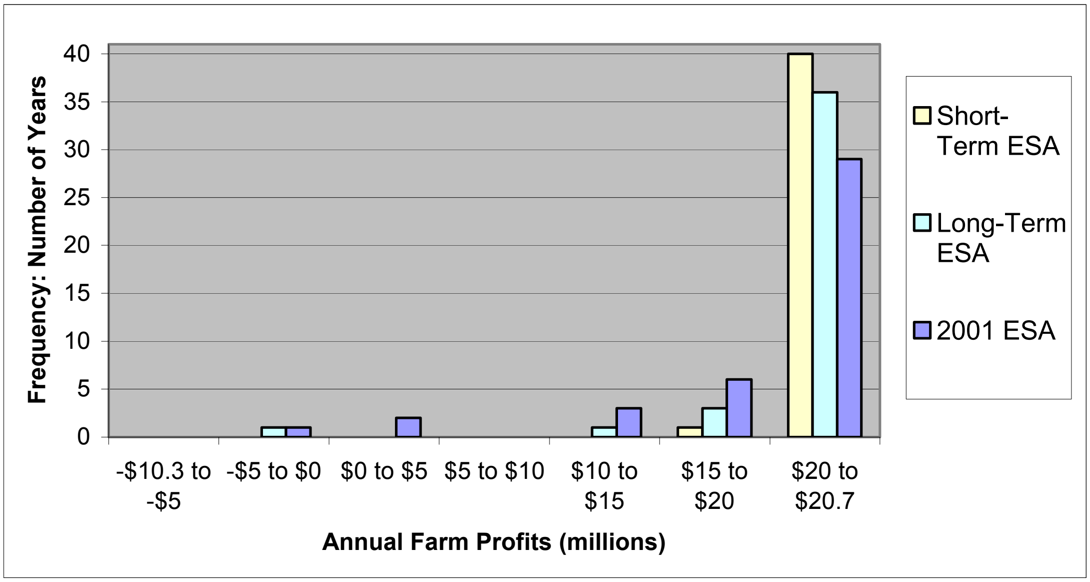
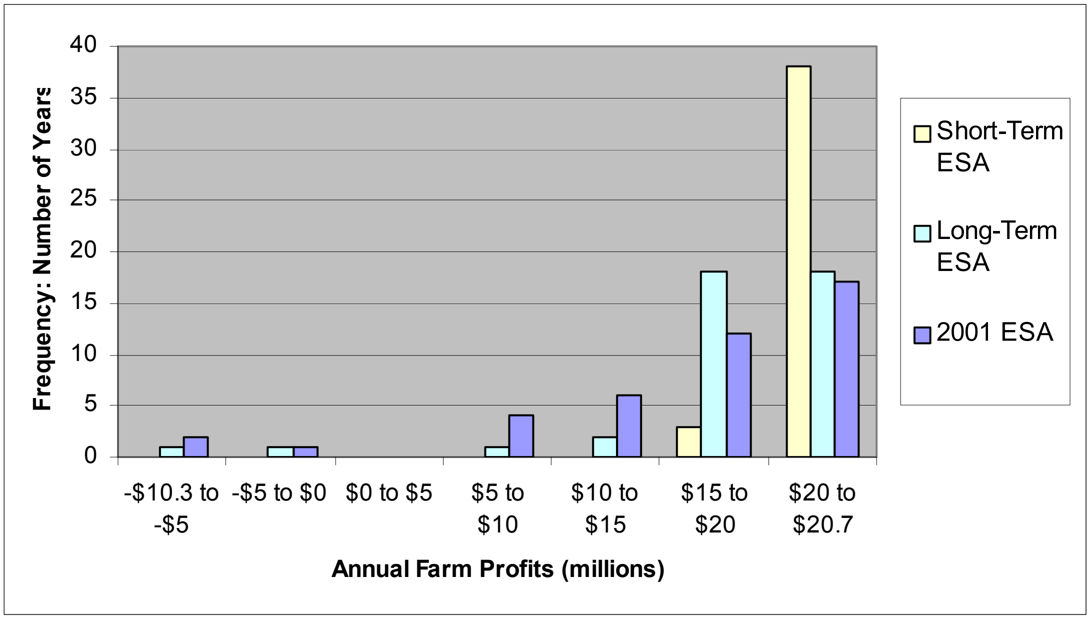
[72] According to the USGS, historical groundwater pumping in the basin was approximately 150,000 acre-feet per season. Here, an additional 160,000 acre-feet of pumping is allowed per season, bringing the total to up to 300,000 acre-feet. This is approximately twice the quantity of groundwater pumped for the water bank in 2004, when water levels were observed to decline significantly over the season.

Figure 23: Histogram of Annual Farm Profits Given Medium Groundwater Availability



When no groundwater pumping is allowed, profits decline significantly, particularly during years where more stringent ESA requirements are imposed. Figure 24 is identical to Figure 23 except that no groundwater pumping is allowed. Under this harsh and somewhat unrealistic condition, greater than 50 percent of years are impacted when future and 2001 ESA requirements are imposed.

Figure 24: Histogram of Annual Farm Profits Given No Additional Groundwater Availability



Already, it is apparent that both groundwater and ESA requirements affect profits (and by proxy, land idling) significantly. In particular, the transition from future ESA requirements to 2001 requirements has a much larger impact than anticipated. These impacts on both farm profits and land idling will be explored more fully in the following sections.

5.2.3 Results of Iron Gate Dam Requirements and Trading Analysis

The first objective is to assess the change in net farm revenues and land idling caused by the transition from short-term to long-term NOAA flow requirements in the presence of both flexible and inflexible water trading. The general approach of this section of this analysis is to investigate historical water supply data to identify whether the supplies of previous years would be adequate to meet both ESA (monthly UKL levels and IGD flows) and agricultural requirements in the basin. It is important to note that the perception of water scarcity in the basin has been heavily influenced by the occurrences of 2001, a year where agriculture was devastated by a combination of both physical (i.e., drought and limited groundwater pumping infrastructure) and institutional (i.e., ESA and trading inflexibility) factors. Consequently, some time was spent investigating 2001. This section starts with a description of how circumstances during 2001 were different than those anticipated in future years, then moves onto an assessment of farm profits given varied ESA requirements and levels of trading flexibility, and finally explores how the differences between circumstances in 2001 and future years may have affected farm profits during that year.

5.2.3.1 Differences between 2001 and Future Years

There are two major differences between the conditions present in 2001 and expected future conditions: ESA requirements and groundwater pumping capacity. These differences are described below.

Flow and Lake Level Requirements

Lake level and flow requirements in 2001 were higher than the proposed long-term requirements in the NOAA and FWS BiOPs. Based on the criteria NOAA and FWS set forth for hydrological year designations, 2001 should have been categorized as both a NOAA and FWS “dry” year. This is NOAA’s lowest flow category (and thus has the most relaxed requirements), but not FWS’, which is “critically dry”.

However, 2001 was anticipated to be an exceptionally dry year, leading us to believe that these requirements were intended as “critically dry” as opposed to “dry” lake levels. In the analyses involving comparisons with 2001 requirements, the FWS “critically dry” lake levels have been replaced with those of 2001. The differences in lake level requirements are shown in Table 19 below. The first month where there is a difference in requirements is July, which has a requirement over one foot higher than the “critically dry” year type in the 2002 BiOP. These differences peak in September at 2.4 feet higher. Keep in mind that each foot of UKL contains roughly 70,000 acre-feet (at these elevations), so 2001 requirements mandated that approximately 77,000 acre-feet of additional water remain in UKL at the end of July than under 2002 requirements. By the end of September, this difference has increased to 168,000 additional acre-feet. Yet lake volumes carry over from one month to the next, making volumes in the “diff” row somewhat misleading. Of more interest is the cumulative additional storage requirement each month, initially 77,000 acre-feet in July and then only the additional water to meet August requirements once the July requirement had been met (56,000 acre-feet). These numbers are given in the difference of differences (DD) row of the table below. In total, an additional 154,000 acre-feet are required over the course of the season (the sum of the values in row DD).

Table 19: FWS Upper Klamath Lake Level Requirements for "Critically Dry" Year Types (feet above mean sea level)

FWS Requirement	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
2002 BO	4142.0	4141.9	4141.4	4140.1	4138.9	4137.6	4137.1	4137.3
2001[1]	4142.0	4141.9	4141.4	4140.1	4140.0	4139.5	4139.5	4139.5
Difference (feet)	0.0	0.0	0.0	0.0	1.1	1.9	2.4	2.2
Diff. (acre-feet)	0	0	0	0	77,000	133,000	168,000	154,000
DD (acre-feet)	0	0	0	0	77,000	56,000	35,000	-14,000

Notes:

1. The stated requirement during 2001 was that lake levels could not fall below 4140 feet above mean sea level. The late-season levels shown here are the rounded lake levels which occurred during 2001.

The specific impact of these higher requirements will be dependent upon the distribution of monthly inflows and more specifically which month is the pinch-point for the year, but the impact will unquestionably be negative. As seen in Table 20 below, April, May and June flow requirements in 2001 were between 200 and 500 cfs higher than in a 2002 NOAA "dry" year. One cfs over the course of a month is equal to approximately 60 acre-feet of accumulated water. An additional 500 cfs by the end of June translates to roughly 30,000 acre-feet of additional flows.

Table 20: NOAA Flow Requirements at Iron Gate Dam for "Dry" Year-Types (cfs)

NOAA Requirement	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Short-Term	691.5	780.5	703.5	629	515.5	560	731	907
Long-Term	1450	1500	1500	1400	1000	1000	1000	1300
2001	1450	1700	1700	1900	1000	1000	1000	1300
Difference (cfs)	0	200	200	500	0	0	0	0
Diff. (acre-feet)	0	12,000	12,000	30,000	0	0	0	0

These additional early season additional flow requirements unquestionably had a substantial impact on farm profits in 2001. Coupled with the higher late season UKL requirements, these brought the additional ESA demands to approximately 222,000 acre-feet between April and September, enough water to supply roughly 100,000 acres with water. Greater pressure would have been placed on Reclamation water planners in their attempts to simultaneously meet these requirements and those of agriculture. Additionally, note that the long term instead of short term IGD requirements are being compared to those of 2001. Were short term requirements compared to 2001, these differences would be much more dramatic.

Groundwater Pumping Capacity

Next, the groundwater-pumping infrastructure available today was not available in 2001. Although nearly 70,000 acre-feet of groundwater were pumped during the 2001 season to supplement surface water flows, much of it was later in the irrigation season after additional high-volume wells had been installed (McFarland, et al. 2005). However, without the appropriate data, it is simply assumed that these 70,000 acre-feet are spread evenly across the eight months (into approximately 9,000 acre-foot segments). Since groundwater can be flexibly delivered when it is most needed, it can be used to alleviate scarcity during critically dry months. The basin model assumes that approximately 20,000 acre-feet are available per month, adding to a total of 160,000 acre-feet for the season. Had this pumping capacity been in place early in the season, perhaps Reclamation would have adjusted their anticipated water availability for the season and allowed the majority of acres to remain in production.

5.2.3.2 Average Farm Profits and the Benefits of Trading

The average estimated impact on net farm revenues and land in production due to increased IGD flow requirements is relatively minor compared to the impacts observed in 2001. Although the magnitude of benefits from trading is therefore limited[73], a meaningful fraction of economic losses are avoided by allowing flexible markets. Table 21 shows the average net revenues and land in production for years with biological conditions similar to those between 1962 and 2002 assuming that 20,000 acre-feet of groundwater can be pumped each month. Here, two models were used – one which allows flexible trading from the upper basins and Lost Basin to the project, and one which approximates the institutional constraints and the irrigation infrastructure within the basin (as discussed in the model section above). This latter version of the model prioritizes the irrigation of certain Klamath Assessor areas over others according to the arrangement of water rights in the basin[74], and further requires

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[73] Without substantial impacts on profits, little demand for water exists.

[74] The priority structure of water rights in the project is delineated by irrigation district rather than the geographic arrangement used in this study. Based on personal communication with individuals from Reclamation and CH2M Hill, the existing arrangement of priority rights was mapped onto the

that water be applied to soil classes within each area in even proportions (i.e., if 50 percent of Bonanza acres are irrigated, 50 percent of each soil class within Bonanza must be irrigated). This version of the model is intended to represent the current structure for water allocation (limited trading) in the basin rather than an economically or socially optimal arrangement. The optimal arrangement (which yields more socially optimal outcomes) is represented by the trade model.

According to the model results, long-term ESA requirements bring the average annual farm profits down from \$20.6 million to \$19.7 million (four percent decline) and the idling of approximately 6,400 of the 323,000 acres (two percent of acres). These numbers are not significantly larger even in the presence of 2001 requirements. Trading reduces the impact of this transition by an average of \$0.4 million (or just under half), although approximately 2,800 additional acres are idled in the trading scenario. This somewhat counterintuitive latter result is due to subirrigation – during trading, water moves from upper basin acres to the more valuable project acres, and nearly two acres in the upper basins must be idled to provide enough water for one project acre. This is because of subirrigation; an idled acre in the upper basins evapotranspires nearly half the water that it would if irrigated, whereas an idled acre in the project evapotranspires very little. This result indicates that 2,800 additional upper basin acres were idled in the process of moving water to the project.

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geographic delineations used here. Three priority levels (A, B, and C) exist in the project. See the model section for more details.

Table 21: Average Annual Net Revenues and Land in Production (All Years)

Annual Net Revenues (millions)	No Trade	Trade
Short-Term ESA	$20.6	$20.6
Long-Term ESA	$19.7	$20.1
2001 ESA	*$18.2*	*$19.4*
Short-to-Long Impact	$0.9	$0.5
Benefits of Trade		$0.4 (44%)

Land in Production (thousands of acres)	No Trade	Trade
Short-Term ESA	322.8	318.8
Long-Term ESA	316.4	309.5
2001 ESA	*305.1*	*295.0*
Short-to-Long Impact	6.4	9.3
Benefits of Trade		-2.9 (-45%)

Average impacts on both net farm revenues and land in production during dry years are found to be much more significant than those reported above. As can be observed in the histograms of farm profits in Figures 23 and 24, the impacts on farm profits are largely concentrated in a few years. NOAA categorizes many (but not all) of the heavily impacted years, such as 1992, 1994 or 2001, as “dry” year based on April through September inflows to the basin. The complete set of these years in the period of interest is 1981, 1991, 1992, 1994 and 2001. The average NOAA “dry” year farm profits and land in production are provided in Table 22, below. In these five years, the average annual impact on farm profits in the transition from short- to long-term ESA requirements is approximately $3.1 million and land idling increases to approximately 23,700 acres. Benefits of trading are about $1.8 million, which implies that trading reduces the average annual impact during dry years by approximately 58 percent, although land idling (due to the process described above) increases by 9,000 acres. Note that if 2001 ESA requirements were imposed, this impact would be over $10 million and the benefits of trading increase to $5 million. This dramatic increase demonstrates the relative stringency of 2001 ESA requirements.

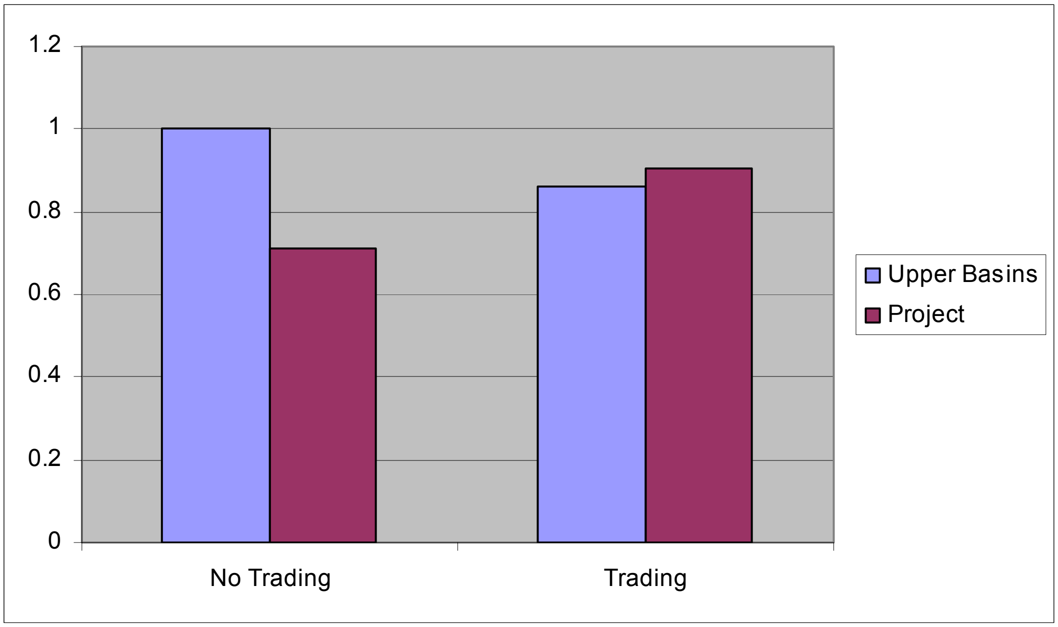
Table 22: Average Annual Net Revenues and Land in Production (NOAA "Dry" Years)

Annual Net Revenues (millions)	No Trade	Trade
Short-Term ESA	$20.7	$20.7
Long-Term ESA	$17.6	$19.4
2001 ESA	*$9.5*	*$15.3*
Short-to-Long Impact	$3.1	$1.3
Benefits of Trade		$1.8 (58%)

Land in Production (thousands of acres)	No Trade	Trade
Short-Term ESA	323.9	323.8
Long-Term ESA	300.2	291.2
2001 ESA	*244.2*	*208.0*
Short-to-Long Impact	23.7	32.6
Benefits of Trade		-8.9 (-38%)

One of the postulations in this research is that trading will allow the redistribution of lands from the lower value upper basins to the project. The average fraction of upper basin and project areas during NOAA "dry" years and given medium groundwater availability is shown in Figure 25. Observe that in the no trading scenario, 100 percent of upper basin land is irrigated (we expect this since there is no way to prohibit those acres from receiving water), whereas only 70 percent of the more valuable project lands are irrigated. As anticipated, this pattern reverses when trading is allowed. Notice that if subirrigation were assumed to be zero or if groundwater pumping were prohibited, this effect would be magnified considerably.

Figure 25: Fraction of Land in Production During NOAA "Dry" Years



Although the dry year impacts are more substantial than observed in the average year, they are still insignificant in comparison to the impacts due to irrigation curtailment during 2001. Next, the model used above is applied to some of the parameters present during 2001 and the results are compared to a previous study.

5.2.3.3 Economic Impacts and Benefits of Trading in 2001

Next, the variation in 2001 farm profits is explored given adjustable ESA requirements and groundwater availability and the outcomes are compared to results obtained by Jaeger (2004) in his retrospective analysis of the potential benefits of water trading in the basin during 2001. Prior to reporting these outcomes, it is important to note that Jaeger does not consider subirrigation in his model, likely overstating the hydrological benefits of trading, especially outside the project[75]. This issue is discussed, then the divergences between Jaeger's results and those of this study are explored.

Subirrigation

When one acre of land is idled, the Reclamation water bank will pay for the following quantities of water in each area:

Table 23: Quantity of Water Paid for by Reclamation per Acre Idled

Area	**Acre-feet per Acre Idled (acre-feet)**
Wood, Williamson[76]	1.04
Sprague	1.5
Project, Lost Basin	~2.25[77]

The compensation varies widely due to the assumed quantity of subirrigation in the different areas in the basin. In the Wood and Williamson, idling an acre of land will only supply enough water for less than half an acre elsewhere. This greatly reduces the benefits of idling these lands, previously the most logical target due to their low land value and high water security.

2001 Analysis

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[75] It is also important to recognize that estimates of trading benefits presented here and by Jaeger may be low. In both models, we assume that each acre in an assessor area earn the average profits over the crop rotation. In a real world situation, some of these acres would be high profit crops and others would be low profit crops. These differences would provide additional potential to gain from trade. Major annual variations in prices between crops would provide additional potential benefits as well.

[76] No contracts have been established between Reclamation and irrigators within the Williamson basin. Due to similarities of topography and hydrology, the subirrigation in the Williamson is assumed to follow that in the Wood basin.

[77] Here, Reclamation compensates irrigators based on the evapotranspiration of the particular crop planted. This value represents an estimated average.

The following analysis compares the post-2001 model conditions where groundwater is available, long-term ESA requirements are imposed and subirrigation is included, to the 2001 conditions in Jaeger's model. For 2001, Jaeger estimates economic losses due to water delivery curtailment at approximately $33 million (this includes fixed cost impacts) and benefits of trading of approximately $25 million (or 75 percent reduction of impacts through trading). Here, replicating the conditions modeled in Jaeger's study (discussed below), impacts on farm profits are found to be approximately $19 million and benefits of trade approximately $11 million (or 60 percent of impacts - see Figure 26, scenario 4). The differences and similarities between these results are explained in more detail in the following paragraphs.

Jaeger's study, which was intended to investigate the benefits of water trading given the land in production, restricts water deliveries by attempting to replicate the magnitude and geographic distribution of land actually idled in 2001. The current study instead restricts water availability based on 2001 hydrological conditions, allowing the model to choose how much land is irrigated in a given year[78]. As described above, the no-trade model simply imposes a priority structure upon this choice and further requires that the share of land irrigated in each soil class within each area is the same. Given a set of parameters which replicates those implicit in Jaeger's model (including his assumptions about irrigation), results from this study's

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[78] The hydrological conditions of 2001 are dictated in part by the assumptions made in calculating inferred inflow that year. This year, it was assumed that 75 percent of land was idled in the project and a total of 70,000 acre-feet of groundwater was pumped. This reduces overall outflows and increases overall inflows, and since inferred inflows equal outflows minus inflows, it has the effect of greatly reducing the inferred inflows for that year. Jaeger (2004) indicates that the vast majority of acres were idled in the project that year, so this estimate of 75 percent may be low. If that were the case, the impacts reported in this section would increase considerably.

2001 analysis are observed to diverge from Jaeger’s for three reasons: 1) that greater flexibility is built into this model, allowing the model to reach higher levels of profits than in a relatively exact replication of 2001 conditions; 2) that more land (and idled land) is included in Jaeger’s model (roughly 420,000 acres versus 320,000 acres); and 3) that a hydrological balance of outflows and inflows for 2001 may not result in a water deficit equal to that implicit in Jaeger’s land restrictions.

Five scenarios are presented, within each of which results of both the trading and no trading model are assessed. These are compared in Table 24 below. The first scenario is the base case model described, except that long-term flow requirements are imposed. Scenario two is identical to scenario one, save that no additional groundwater is available beyond the 70,000 acre-feet of additional water pumped that year. The third scenario is the same as scenario two, except instead of long-term NOAA and FWS requirements, the more stringent 2001 NOAA and FWS requirements are imposed. In scenario four, scenario three is modified to assume zero subirrigation, replicating the assumptions of Jaeger’s model. Finally, in scenario five, scenario three is repeated except that nearly unlimited quantities of groundwater are available (here, 49,000 additional acre-feet per month or nearly 400,000 acre-feet per year). Scenario five is intended to show how the model responds when the groundwater constraint is no longer binding; this is not considered to be a realistic situation.

Table 24: 2001 Scenarios

Scenario	UKL Reqs	IGD Reqs	Trading Flexibility	Energy Prices (per kWh)	Groundwater Availability (acre-feet per month)	Sub-irrigation
1: Future base case	**long-term**	**long-term**	**none&high**	**$0.006**	**20,000**	**BOR**
2: 2001 GW	**long-term**	**long-term**	**none&high**	**$0.006**	**~9,000**	**BOR**
3: 2001 base case	**2001**	**2001**	**none&high**	**$0.006**	**~9,000**	**BOR**
4: Jaeger's model parameters	**2001**	**2001**	**none&high**	**$0.006**	**~9,000**	**zero**
5: Max GW	**2001**	**2001**	**none&high**	**$0.006**	**~49,000**	**BOR**

In the set of "no-trade" scenarios, model results indicate that profits in 2001 are highly responsive to the above parameters, and that increased groundwater availability would have alleviated much of the loss experienced that year. The results of these analyses are displayed graphically in Figure 26 below. Reducing groundwater availability from the future base case scenario to the 2001 groundwater conditions (scenario one to two) increases losses from $12 million to $15 million (these values represent maximum profit per season of $20.7 million less the no-trading profits in Figure 26). As the more stringent 2001 ESA requirements are added (from scenario two to the 2001 base case), profits losses increase further to roughly $17 million, and the subsequent removal of subirrigation (2001 base case to Jaeger's model parameters) increases losses to $19 million[79]. If the 2001 base case model is provided with large quantities of groundwater (scenario five), losses in 2001 are only approximately $6 million. This progression indicates that although hydrological circumstances are a

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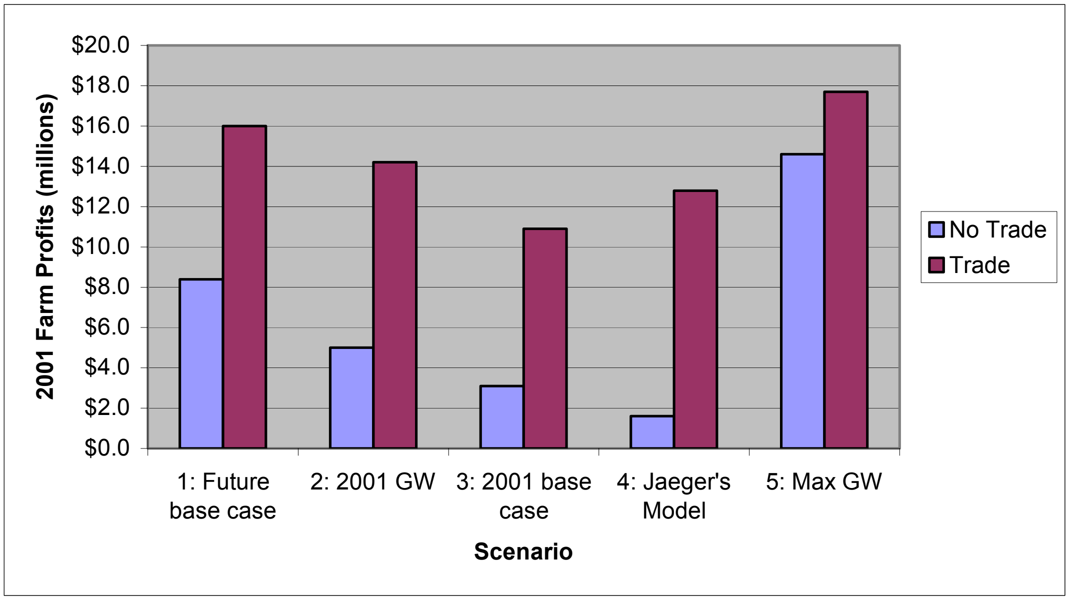
[79] Recall that idled land produces profits in proportion to its subirrigation coefficient (i.e., an acre idled where subirrigation is 50 percent of normal evapotranspiration will receive 50 percent of the profits of a normal year less the fixed costs for idling the other half acre).

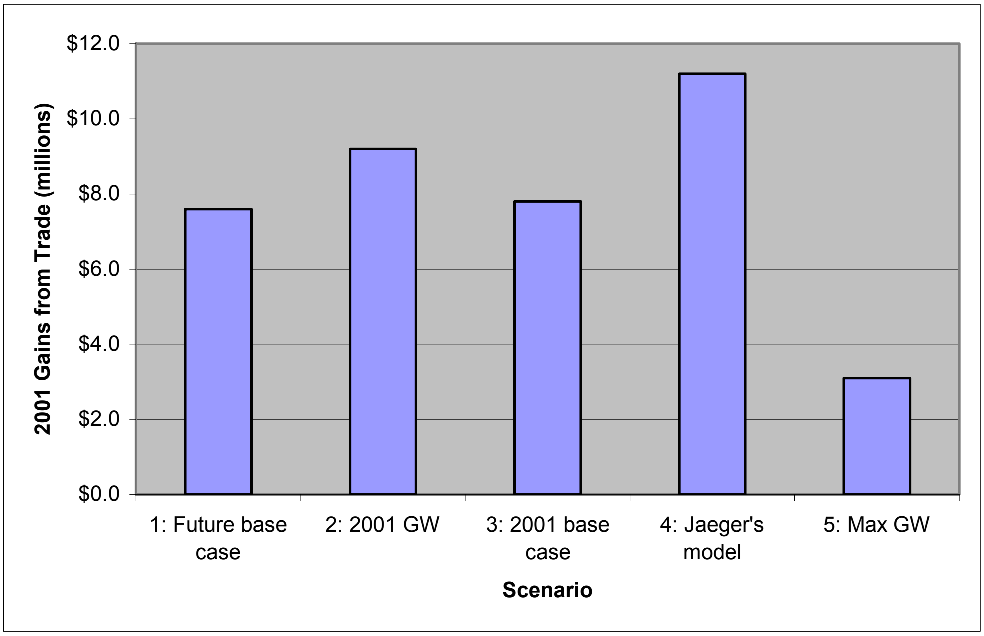
major driver for the losses experienced in 2001, so too are some of the more malleable institutional and infrastructural circumstances present that year.

Figure 26: Profits of a Range of Scenarios Given 2001 Flows



In "trade" scenarios, profits decline through scenarios two and three and then rebound as subirrigation values are zeroed. The results of these analyses are displayed graphically in Figures 26 and 27, above and below. As groundwater is withheld and ESA requirements are made more stringent, the benefits of trading remain at approximately $7.5 million and $9 million. However, as zero subirrigation is introduced (scenario four), these benefits increase to $11 million, which is a 40 percent increase over the scenario where Reclamation subirrigation values are assumed (scenario three). The explanation follows the argument presented in the beginning of this section – subirrigation greatly reduces the hydrological contribution of idled upper sub-basin acres; zero subirrigation means that fewer upper basin acres are idled to supply each project acre with water. As plentiful groundwater supplies are introduced, losses are observed to be only $3 million. Thus, from greatest impact (no-trade scenario four) to least impact (trade scenario five), there is a $16 million difference, once again pointing to the importance of these institutional and infrastructural parameters during dry years such as 2001.

Figure 27: 2001 Farm Profit Gains from Flexible Water Trading in 2001



Overall, similarities are encountered between the benefits of trade in each category. Table 25, below, provides a summary of the results presented in this section. The percent reduction in profit reductions due to the introduction of flexible water trading ranges between 44 and 62 percent, which is a fairly narrow range considering the parametric differences between these scenarios. Whether the no-trade impact is significant (such as when 2001 flows encounter 2001 ESA requirements without the buffer of subirrigation: $19.1 million) or insignificant (such as when average flows face long-term ESA requirements: $1.0 million), the percent recovery due to trading is very similar (59 and 44 percent). Although the magnitude of trading benefits estimated by Jaeger (2004) is much higher than is estimated here, percent reductions in losses are similar.

Table 25: Summary of Objective 1 Results

ESA Requirement	Net Farm Revenues No Trade	 Trade	Gain from Trade	Percent Loss Reduction
Average Flows				
Short-Term ESA	$20.6	$20.6	$0.0	-
Long-Term ESA	$19.7	$20.1	$0.4	44%
2001 ESA	$18.2	$19.4	$1.2	50%
Average NOAA "Dry" Year Flows				
Short-Term ESA	$20.7	$20.7	$0.0	-
Long-Term ESA	$17.6	$19.4	$1.8	58%
2001 ESA	$9.5	$15.3	$5.8	52%
2001 Flows				
Long-Term ESA w/ GW	$8.4	$16.0	$7.6	62%
Long-Term ESA w/o GW	$5.0	$14.2	$9.2	59%
2001 ESA w/ subirrigation	$3.1	$10.9	$7.8	44%
2001 ESA w/ no subirrigation	$1.6	$12.8	$11.2	59%
2001 ESA w/ max groundwater	$14.6	$17.7	$3.1	51%
Jaeger 2004 (assume $25 million max profit)	$-8.4	$16.7	$25.1	75%

5.2.4 Results of Energy Price Analysis

The second objective is to evaluate the impact of the energy price contract expiration on agriculture in the basin. Note that this analysis considers only the direct impact of energy price increases on irrigation costs, and does not consider the impacts of demand increases[80] or those on irrigation district pumping costs[81]. It is also important to be aware of the sensitivity of these results to certain assumptions made about parameters in the energy model[82]. The impacts of increased energy prices on farm profits and overall land idling are discussed, and then changes in the distribution of flood acres and fixed and convertible sprinkler acres across the basin are investigated.

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[80] The model focuses on costs incurred through on-farm water application and does not consider any impacts on the energy costs borne by irrigation districts (from pumping and distribution). Accordingly, this assessment may result in a reasonable replication of impacts in the upper sub-basins, but may not accurately represent the impacts in irrigation districts such as Tulelake, where increases in district level pumping costs may be as significant in magnitude as aggregate increases in Tulelake irrigation energy costs (based on personal communication with Harry Carlson, Director of the Intermountain Research and Extension Service (U.C. Davis) on July 26, 2006).

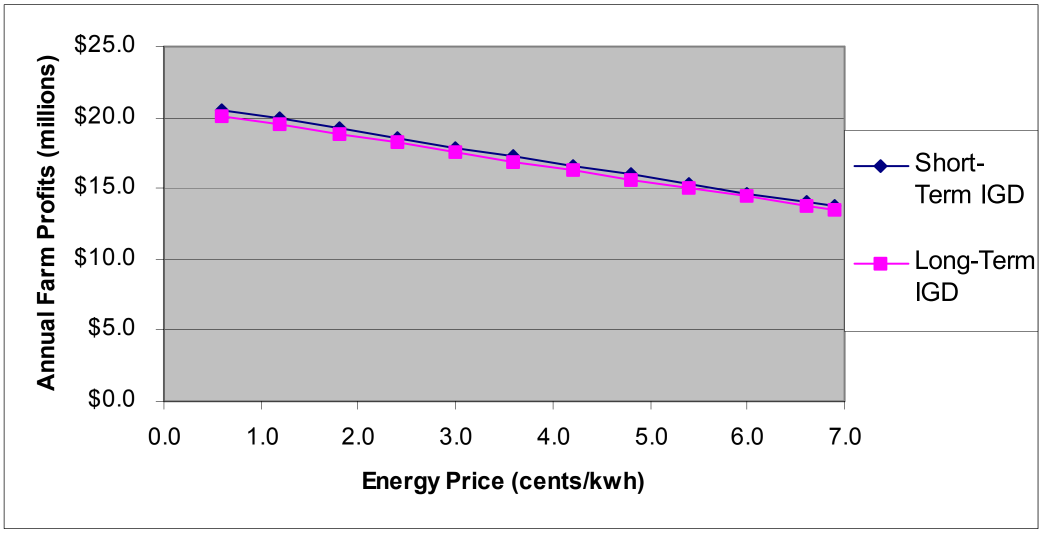
[81] No attempt is made to project how PacifiCorp will adjust energy demand charge increases. In addition, the energy analysis is conducted using the trade model as opposed to the no-trade model. This is necessary because transitions from sprinkler to flood occur based upon the profitability of each acre, and profitability is specifically excluded from the no-trade model so that water allocation decisions are made based upon the imposed priority structure. Although the trade model is a less realistic representation of the current institutional and physical system in the basin, using it for this purpose will have little ill effect, as individual landowner decisions are of primary interest. Aggregate profits will be lower than those represented here, as increased flexibility will allow the redistribution of water from low to high profit lands.

[82] Due to the unverifiable nature of many of these assumptions, the results presented in this section should not be interpreted as more than suggestive.

5.2.4.1 Impact on Net Farm Revenues and Land Idling

As energy prices increase, net farm revenues would be expected to decline because each irrigator in the basin uses electricity to deliver water to their crops. Increases in idled acres would also be expected due to the inability of certain low-profit irrigators to bear the dramatic increase in electricity costs. The question in this section is how substantially farm profits and land in production are impacted by these price increases. Figure 28, below, displays the relationship between energy price and annual farm profits in the basin. Here, assumptions in the model follow scenario one above (20,000 acre-feet of groundwater available per month) save for the fact that ESA requirements are broken up into short-term and long-term requirements. Energy prices vary from the current price ($0.006 per kWh) to the anticipated future energy price ($0.069 per kWh).

Figure 28: Response of Average Annual Farm Profits to Energy Price



In the presence of current ESA requirements, average annual farm profits fall in a predictably smooth arc from full levels of $20.6 million to the final level of approximately $13.7 million when the energy price hits the projected maximum. This is a decline in profits of $6.9 million, or approximately 33 percent of total profits (see Table 26 below), which is not surprising considering that the cost of irrigating one acre with sprinkler irrigation increases from roughly $4 to over $40 (see Table 12 in the model data section). Long-term IGD flow requirements demonstrate a nearly identical pattern save a consistently lower profit level. Referring to the previous section, profits due to long-term IGD requirements given flexible water trading were $0.4 million lower than profits given short-term requirements.

Table 26: Average Annual Farm Profits and Land in Production (All Years)

Annual Net Revenues (millions)	Short-Term IGD	Long-Term IGD	Net Loss due to ESA
$0.006 per kWh	$20.6	$20.2	$0.4
$0.069 per kWh	$13.7	$13.5	$0.2
Net Loss due to Energy Prices	$6.9	$6.7	
Difference		$0.2 (50%)	

Land in Production (thousands of acres)	Short-Term IGD	Long-Term IGD	Net Loss due to ESA
$0.006 per kWh	319.1	309.6	9.5
$0.069 per kWh	312.2	303.4	8.8
Net Loss due to Energy Prices	6.9	6.2	
Difference			0.7 (7%)

To a small extent, overlapping impacts of increased IGD flow requirements and energy prices can be observed, where the sum of the two independent impacts is greater than the combination. As can be seen in the above table, although the short-term and long-term IGD profit reductions are very similar, the net loss in the presence of long-term requirements is slightly lower (by roughly $200,000). Additionally, approximately seven percent of the land idled would have been idled with or without changes in ESA requirements. The pattern is similar during NOAA "dry" years, where just under 50 percent of profit reductions and roughly 15 percent of acres idled are shared between these two institutional changes (see Table 27 below).

Table 27: Average Annual Farm Profits and Land in Production (NOAA "Dry" Years)

Annual Net Revenues (millions)	Short-Term IGD	Long-Term IGD	Net Loss due to ESA
$0.006 per kWh	$20.7	$19.4	$1.3
$0.069 per kWh	$13.9	$13.2	$0.7
Net Loss due to Energy Prices	$6.8	$6.2	
Difference			$0.6 (46%)

Land in Production (thousands of acres)	Short-Term IGD	Long-Term IGD	Net Loss due to ESA
$0.006 per kWh	323.8	291.2	32.6
$0.069 per kWh	317.3	289.7	27.6
Net Loss due to Energy Prices	6.5	1.5	
Difference			5.0 (15%)

Looking at this issue more carefully, the majority of the difference in profit differences occurs because greater land is in production in the presence of short-term requirements, and more land in production means higher energy costs. The model is constructed such that initial energy expenditures (based on $0.006 per kWh) are built into the net revenues that accrue to each acre. Accordingly, initial energy costs are zero and energy costs after the price increase are a direct reflection of the mix of irrigation technologies (i.e., sprinkler requires much more energy than flood) and quantity of land in production. Increases in energy prices cause costs to increase in three ways: (1) direct increases in expenditures on energy, (2) costs associated with land taken out of production (variable plus fixed costs), and (3) conversion costs from sprinkler to flood irrigation (reduced crop yields and additional initial investment in infrastructure). In Table 28, the breakdown of the overall cost increases due to energy price changes in the presence of short and long term IGD requirements is presented. Note that increases in energy expenditures alone ($5.4 million and $5.3 million for short- and long-term requirements) account for roughly 79 percent of the overall impact ($6.9 million and $6.7 million) of increased energy prices under both sets of requirements. Increased curtailment costs account for 6 percent (approximately $400,000) of increases under both sets of requirements, and the remaining 15 percent (roughly $1.1 million) is attributable to expenses on conversions from sprinkler to flood irrigation. The total lands in production at $0.069 per kWh are 312,200 acres and 303,400 acres given short and long term IGD requirements. This difference, of approximately 8,800 acres, accounts for the majority of the difference in cost increases ($150,000). The remaining change is attributable to the differences in the number of acres curtailed as energy prices increase. This is the difference between the "increase in idling" rows, or roughly 700 acres. The model was used to calculate the curtailment cost of these additional acres, which was found to be approximately $11,000[83]. These together provide the total difference between the impacts of energy price increases given short-term IGD requirements versus long-term requirements.

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[83] Dividing $11,000 by 700 acres yields roughly $16 per acre, which is impossible given that the minimum curtailment cost is $40 per acre. This apparent inconsistency is due to differences in the composition of irrigation technologies in the 6,900 acres and 6,200 acres of short and long-term land idling increases. Although fewer additional acres are idled under the long-term requirements, each acre (on average) is more expensive to idle because the cheapest opportunities have already been taken advantage of due to increases in IGD flow requirements.

Table 28: Breakdown of Average Cost Increases due to Increased Electricity Prices

Short-Term IGD (thousands of acres)	Flood	Sprinker	Long-Term IGD (thousands of acres)	Flood	Sprinkler
$0.006 per kWh	183.3	135.8	$0.006 per kWh	176.0	133.6
$0.069 per kWh	214.1	98.1	$0.069 per kWh	208.1	95.3
Difference	-30.8	37.7	Difference	-32.1	38.3
Increase in Idling		6.9	Increase in Idling		6.2
Total Land @ $0.069		312.2	Total Land @ $0.069		303.4

Electricity Cost Increase	$5.43 million	Electricity Cost Increase	$5.27 million
Difference in Electricity Cost Increases			**$150,000**
Curtailment Cost Increase	$406,000	Curtailment Cost Increase	$395,000
Difference in Curtailment Cost Increases			**$11,000**
Total Difference between Short and Long Term Increases			**$161,000**

How changes in the price charged for a good affect the quantity demanded is captured by the concept of elasticity. The price elasticity of demand for electricity is the percentage change in quantity consumed divided by the percentage change in price charged. The fact that this is a proportional measure – where an elasticity of -1 implies that a 5 percent increase in price will prompt a 5 percent decrease in demand – allows elasticity measures to be compared independent of the scale of the change and the magnitudes of price and quantity. In this analysis, the price of electricity is expected to increase by 1,150%, as it increases from 0.6 cents per kWh to 6.9 cents per kWh. The demand for electricity from flood and sprinkler irrigation given short-term and long-term energy prices can be approximated based on the quantity of land irrigated by sprinkler and flood technologies (given in Table 28 above), the amount of water applied to each acre (roughly 3 to 4 acre feet), and the electricity required for sprinkler and flood irrigation defined in Appendix C (232.69 kWh and 29.42 kWh). These values of electricity demand are provided in Table 29 below. Notice the considerable decrease in demand under both short- and long-term NOAA flow scenarios as price increases. However, these percentage decreases (both roughly 20 percent) are two orders of magnitude lower than the proportional increases in electricity price (1,150 percent). This yields an inferred price elasticity of demand for electricity of approximately -0.02 under both short- and long-term NOAA flow conditions, indicating that the demand for electricity is extremely inelastic with respect to its price (i.e., a 100 percent increase in price would yield only a 2 percent decline in electricity use).

Inelastic demand for a good is often expected when: (1) that good is considered to be essential, (2) it has few or no substitutes, or (3) it is a relatively small part of the consumer's budget constraint. Electricity as applied to agriculture in the basin is essential to the production process and has few substitutes (perhaps diesel fuel or natural gas), but depending on the value of crops being irrigated, energy costs may represent a relatively large fraction of the irrigator's production costs. This latter factor is largely negated by the fact that even small reductions in electricity consumption may have devastating effects on crop yields, forcing irrigators to maintain relatively steady demand as price increases over certain ranges. It is worth noting, however, that elasticities are dependent upon the ranges of prices over which the change occurs. The demand for electricity in the Klamath would likely be much more elastic as the price increased past 6.9 cents per kWh because those higher prices would make farming unprofitable for an increasing share of irrigators.

Table 29: Price Elasticities of Demand for Electricity Given Short- and Long-Term NOAA Flow Requirements

Short Term IGD	Energy Demand (kWh)		
Energy Price (per kWh)	Flood	Sprinkler	Total
$0.006	16,852,144	98,866,644	115,718,788
$0.069	19,683,819	71,419,866	91,103,684
		Elasticity	**-0.020**

Long Term IGD	Energy Demand (kWh)		
Energy Price (per kWh)	Flood	Sprinkler	Total
$0.006	16,181,000	97,264,975	113,445,975
$0.069	19,132,194	69,381,378	88,513,572
		Elasticity	**-0.021**

As mentioned in section 4.2.5.2, these results are dependent upon the assumed quantity of land that can switch from energy-intensive sprinkler irrigation to flood irrigation if necessary. "Fixed" sprinkler acres are those that have slopes greater than four percent (calculated using a GIS analysis), implying that these acres cannot be converted to flood irrigation. "Convertible" acres are then those sprinkler-irrigated acres with slopes less than four percent. If this criterion was adjusted (i.e., to three percent or five percent), or if a more complex metric were employed involving other important criteria such as land undulation or soil texture, the resulting "fixed" sprinkler acres could be substantially lower. This could potentially result in much greater (or much less) land idling, as those fixed acres that previously switched to flood would likely be idled. A sensitivity analysis was not conducted on this criterion.

In the next section changes in the distribution of irrigation technologies due to energy price increases are investigated more closely.

5.2.4.2 Distributional Impacts on Irrigation Technologies

Next, changes in the distribution of flood acres and fixed and convertible sprinkler acres across the basin in response to increasing energy prices are described. Subject to assumptions about the conversion slope (described above) and key parameters[84], fairly substantial quantities of fixed sprinkler acres fall out of production and convertible sprinkler acres move over to flood.

Fixed Acres

As seen in Table 30 below, the distribution of fixed sprinkler acres generally leans toward the higher soil classes. Due to the high profitability of these soil classes, it is not surprising that comparatively few of the fixed sprinkler acres are found to fall out of production[85].

Table 30: Distribution of Flood Acres and Fixed and Convertible Sprinkler Acres

	Soil Class II	Soil Class III	Soil Class IV	Soil Class V
		(acres)		
Fixed Sprinkler	8,200	23,900	18,100	1,800
Convertible Sprinkler	3,900	26,300	48,600	5,100
Flood	3,800	39,000	109,000	36,000

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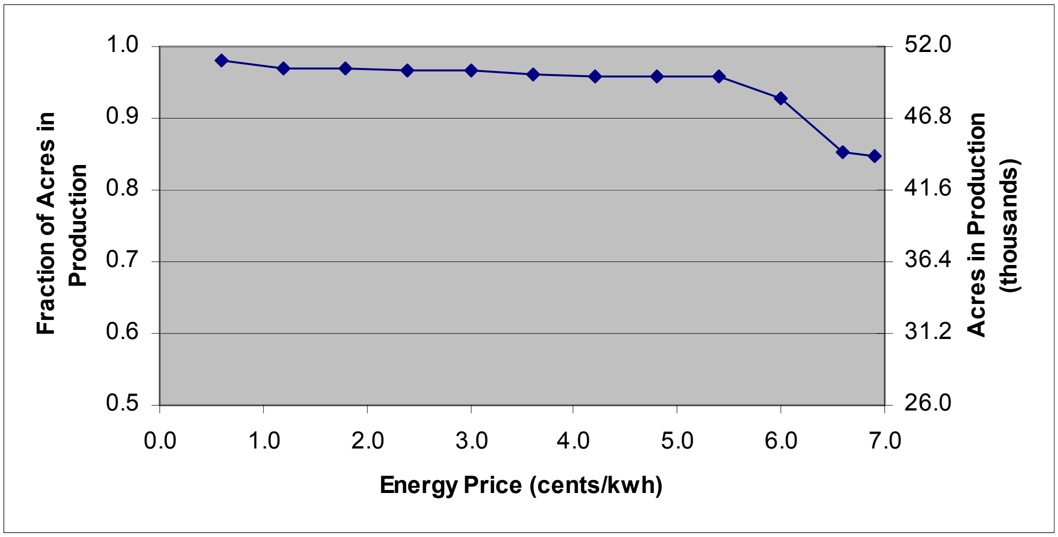
[84] This analysis relies on fairly strong assumptions about conversion parameters, and that the model is fairly sensitive to the values of these parameters. These assumptions are described in detail at the end of this section.

[85] See Jaeger 2004a, where the analysis suggested that much greater quantities of sprinkler acres would be idled in response to increased energy rates. In that model, Jaeger assumes that roughly 153,000 acres are sprinkler irrigated on class IV and V in the basin (all of which are assumed to be fixed), whereas only 19,900 acres are assumed to be fixed in this study's model after removing convertibles.

The relationship between fixed sprinkler acreage in production and energy price is shown in Figure 29 below. Notice that approximately 13 percent of fixed sprinkler acreage falls out of production in response to rising energy prices[86]. The impact of these rising prices is nonlinear with respect to energy rate, where the transition from $0.06 per kWh to $0.066 per kWh triggers the largest wave of land idling. The increase in per acre energy costs in this interval corresponds to a seven percent decrease in irrigated acreage. This would imply an inferred energy price elasticity of demand for sprinkler irrigated acres over this narrow interval of -0.7.

Figure 29: Fraction of Fixed Sprinkler Acreage in Production in Response to Energy Price



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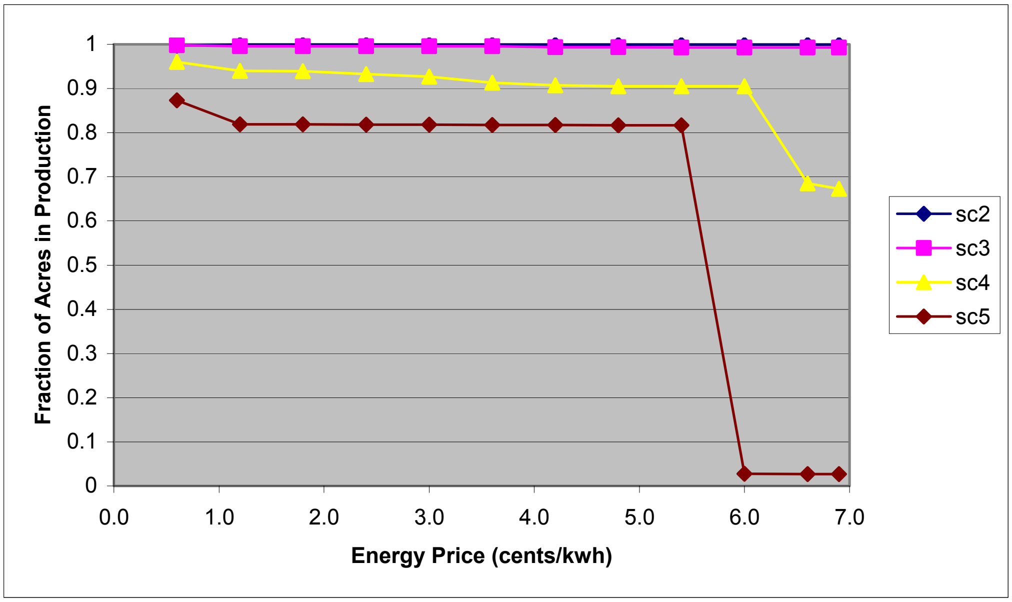
[86] Since the model constructed is a short-run model, acres that have negative profits may remain in production due to the presence of fixed costs. Assuming that these irrigators were not able to shift to more energy-efficient technologies, it is more reasonable to expect they would go out of business in the long run. Making the necessary adjustments in the model would have the effect of increasing idled acres.

Figure 30 below shows this impact broken into soil classes. Notice that soil class V acres fall out of production first[87], followed by a fraction of soil class IV acres. No soil class II or III acres fall out of production due to their high land value. The seven percent reduction in fixed acres mentioned above comes from soil class IV acres, which decline from 90 percent to 69 percent of acres in production in the transition from $0.06 per kWh to $0.066 per kWh.

Figure 30: Fraction of Fixed Sprinkler Acreage in each Soil Class in Production in Response to Energy Price



Convertible Acres

The conversion of certain sprinkler acres to flood irrigation is anticipated in response to increasing energy rates; in this study, the magnitude of these conversions is of interest. The first step in this process was described above: choosing the criteria

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[87] Notice the small quantity of acreage (~2.5 percent) remaining in Class V at the highest three energy prices. This is an unresolved issue, as no class V acreage (which has universally lower value) should go out of production prior to class IV acreage.

to delineate convertible from fixed acres (here, a four percent slope). Once this determination has been made, the next step is choosing the criteria by which the conversions from sprinkler to flood acres are restricted[88]; here crop yield reductions and annualized cost increases were chosen. The assumptions made about these are important and are discussed in both the model chapter and at the end of this section. Figure 31 shows the fraction of convertible sprinkler acres that remain in sprinkler and the fraction that convert to flood given a range of energy prices. At $0.069 per kWh, the final percentages in sprinkler and flood are 61 percent and 36 percent, respectively. Note that flexibility allows the majority of these convertible acres to stay in production – only approximately 1.5 percent of these acres fall out of production due to energy cost increases. This minor decrease largely occurs before conversion to flood begins, and can be attributed to acres where the conversion costs and yield losses exceed the idling costs (variable plus fixed costs of irrigation delivery curtailment).

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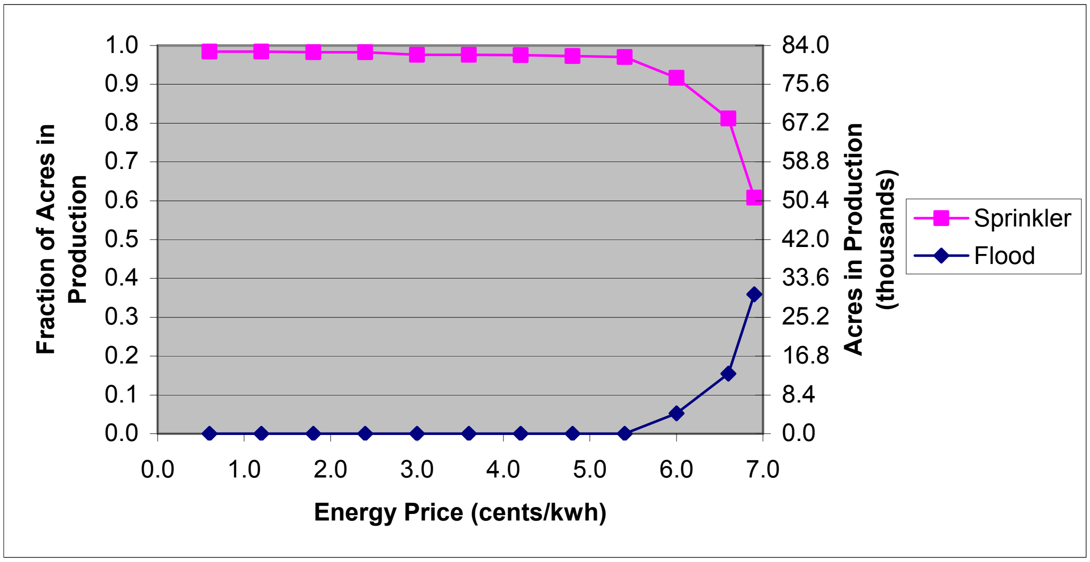
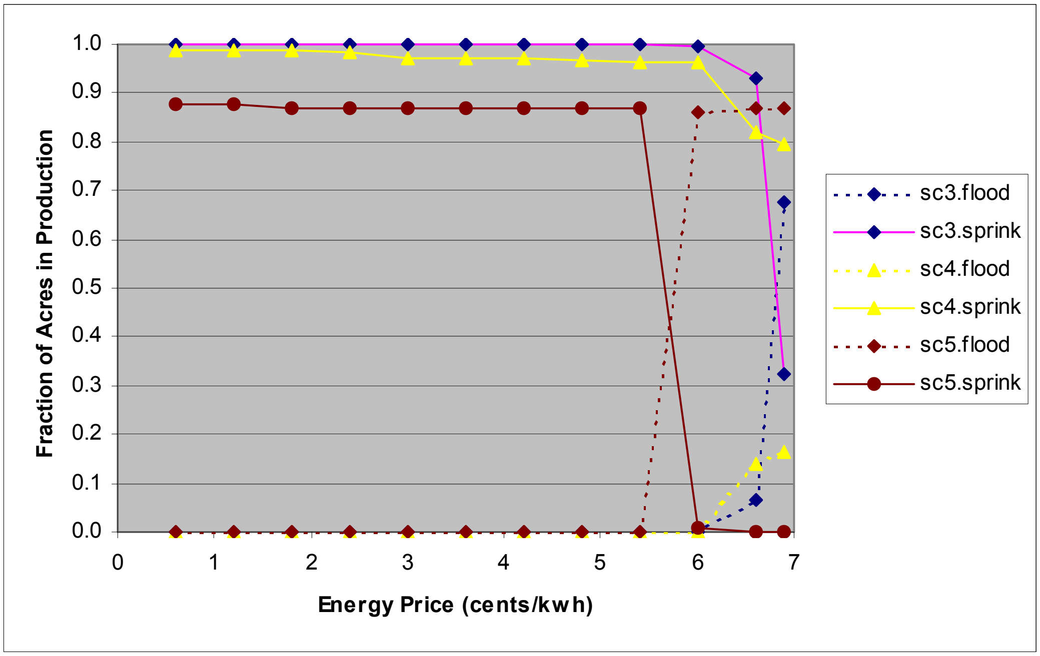
[88] Sprinkler irrigation occurs for an economically valid reason, so conversion to flood irrigation is assumed to carry with it penalties.

Figure 31: Fraction of Convertible Sprinkler Acreage in Flood and Sprinkler Technologies



This can be more easily observed in Figure 32, which demonstrates the same relationships for soil classes. All of the data in this figure exhibit expected behavior except for the soil class III data. Here, at the transition between $0.066 per kWh and $0.069 per kWh, flood soil class III acres suddenly increase from approximately 8 percent to 68 percent of all convertible acres, surpassing the percentage of flood conversion on class IV acres by over 40 percent. This is counterintuitive because soil class III acres are uniformly more valuable than soil class IV acres. The model decides whether or not to convert from sprinkler to flood for each acre based on a comparison of profits from sprinkler irrigating (no conversion costs or yield losses but large energy costs) and flood irrigating (conversion cost and yield losses but no energy costs). Irrigation energy costs are very sensitive to the quantity of water applied to the crops. On average, soil class III acres evapotranspired 29.2 inches of water as compared to 26.9 inches of water evapotranspired by class IV acres. Collectively, Merrill/Malin and Midland/Henley/Olene contain approximately 57 percent of the convertible class III acres in the basin, and their trigger points for conversion (based on land value and water use) both occur between \$0.066 per kWh and \$0.069 per kWh. This accounts for the increase described above.

Figure 32: Fraction of Convertible Sprinkler Acreage in Each Technology by Soil Class



Appendix D provides assumptions made in the sprinkler conversion model. This exposition makes it apparent how sensitive sprinkler conversion is to the value chosen for η_k and χ_k, which were arrived at through limited data collection and estimation as opposed to more thorough data collection and analysis; these were beyond the scope of this project. Given the roughness of these estimates and the sensitivity of the conversion results to their magnitudes, results in this section are primarily intended to provide a general idea of what could occur in response to increased energy rates in the Upper Klamath Basin.

5.2.5 Results of ESA Sensitivity Analysis

The third objective is to evaluate how annual farm profits respond to changes in the future monthly ESA flow and lake level requirements. By modifying these requirements incrementally, their marginal impact on farm profits can be estimated based on the hydrological conditions of years between 1962 and 2002. If the best available alternative to ESA water use is assumed to be irrigation, this establishes an estimate of the opportunity cost[89] of these requirements. Although decisions about resource allocation for threatened and endangered species are made based upon biological requirements rather economic impacts, estimation of these opportunity costs may help shed light on the anticipated impact of ESA requirements in the basin. The following paragraphs describe the approach and results of this analysis.

For the analysis of the response to changing FWS and NOAA requirements, the monthly UKL level requirements of all year types were raised and lowered in one-inch increments and the IGD flow requirements in 50 cfs intervals, then average annual profits were calculated between 1962 and 2002[90]. Figure 33 provides a

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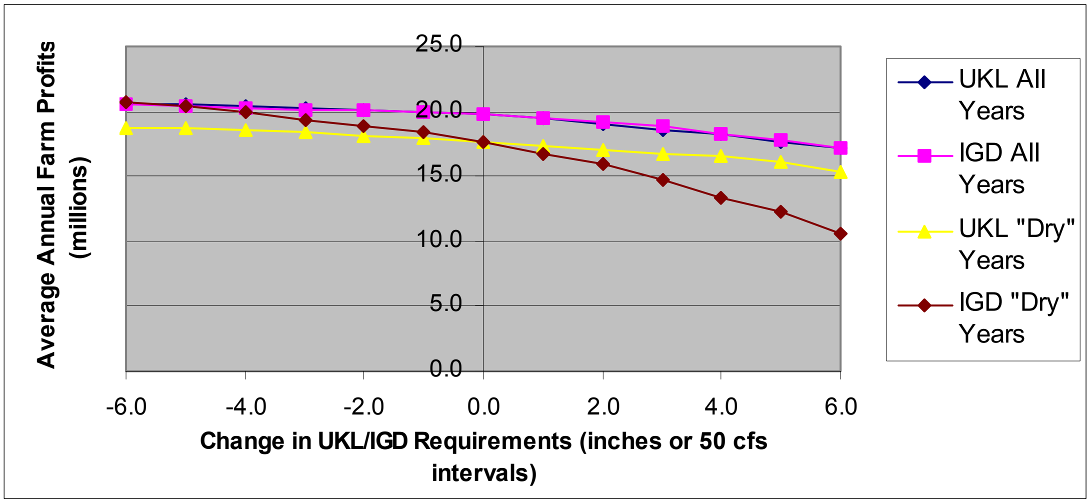
[89] *Opportunity cost*, a fundamental concept to economics, is the cost of foregoing the next best choice when making a decision.

[90] The IGD and UKL numbers cannot be directly compared because the chosen units (one inch and 50 cfs) were only chosen for their algebraic convenience. 50 cfs is approximately 3000 acre-feet, and 1 inch of UKL holds approximately 6,000 acre-feet. An increase in the lake level requirements results in one inch being lost for use that year, whereas increasing IGD flow requirements by 50 cfs results in a flow loss over the entire eight-month period, or approximately 24,000 cfs. These numbers are also

graphical view of the results. This graph depicts average annual profits increasing and decreasing in response to changing ESA requirements for all years and only NOAA “dry” years. The points along the central vertical axis represent the status quo profits, which has been identified as $19.8 million and $17.6 million, for all years and dry years. As the ESA requirements increase (rising lake levels and flow requirements), profits fall as anticipated, dropping as much as $7 million as flow requirements are increased 300 cfs. As they are relaxed, profits rise – the most apparent example being the increase to full profits from $17.6 million in dry years as IGD requirements slacken.

Figure 33: Impact of Changing ESA Requirements on Annual Net Revenues



A simpler way of approaching this type of analysis may be to look at the change in profits at one increment away from status quo (the central axis) in order to investigate the “marginal” value of one inch of lake level requirement or 50 cfs of

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difficult to compare, however, because profits are typically restricted by a binding constraint in one month of the year.

flow requirement. Table 30, below, shows the average marginal values for both the lake level and flow requirements occurring between 1962 and 2002 and during dry years only. The average annual change in profits from increasing or decreasing UKL levels[91] by one inch is $240,000 for all years and $308,000 for dry years, both of which are between one percent and two percent of basin profits. The average change from increasing or decreasing IGD flows by 50 cfs is $194,000 for all years and $813,000 for dry years, or less than one percent and roughly four percent of basin profits. These results are similar to those of Adams and Cho (1998), who find that adjusting UKL requirements (in the range of ESA requirements) by six inches could cause project profits to change by between $600,000 and $1.7 million (converting roughly to $100,000 to $300,000 per inch).

Comparing these outcomes points to the dependence of the marginal impact of these requirements on hydrological conditions; 50 cfs of IGD flows have a lower impact than one inch of UKL levels when all years are considered, but a substantially higher impact when only dry years are considered. The sensitivity of particular years to the arrangement of flow or lake level requirements may warrant greater flexibility in the construction of these requirements.

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[91] The impacts of increasing the requirements by one "unit" (inch or 50 cfs) and decreasing the requirements by one "unit" were averaged.

Table 31: Average Annual Marginal Costs to Irrigators of Increased ESA Requirements

	Years Evaluated	
	1962 to 2002	NOAA "Dry"
Iron Gate Dam (each 50 cfs)	$194,000	$813,000
Upper Klamath L. (each inch)	$240,000	$308,000

Another approach to this analysis would have included non-uniform changes in lake level and flow requirements, identifying the marginal impacts of each particular year designation. Alternatively, investigation of the economic ramifications of more flexible dynamic flow and lake level requirements would have been interesting. With sufficient biological expertise, this could eventually lead to a bio-economic model, where the biological consequences of adjusted flow and lake level requirements could be evaluated with the impacts on the basin economy. Based on such a model, monthly flow and lake level requirements could be constructed and coordinated on a yearly basis and updated periodically throughout the year.

5.2.6 Results of Groundwater Sensitivity Analysis

Model results are highly sensitive to groundwater availability, although the majority of years do not require significant groundwater to satisfy the needs of both fish and farmers. There is uncertainty with respect to the groundwater resource capability because the relations between the locations, timing, and volume of pumping and the resulting water level declines and potential impacts to streams have not been quantified. In the following subsections, the lower and upper bounds of groundwater availability used in the analysis are first discussed, then the results of the single-year analysis are reviewed, and finally the results of the more speculative multi-year groundwater analysis are investigated.

5.2.6.1 Groundwater Availability and Pumping Capacity

Variation of the allowable groundwater pumping in the basin has an understandably significant impact on farm profits. Historically, groundwater has been used at relatively consistent levels to irrigate certain acres within the basin, but those acres are not included in the model since they are assumed to be unaffected by the changes under investigation; all groundwater pumping referenced here is over and above current pumping. The model allows a monthly quantity of water that can be pumped if needed. It is unrealistic to assume that zero additional groundwater would be available to the basin over a long period of time, but this was included to represent how the system would respond in the absence of any additional pumping. It is also fairly unrealistic to assume that 40,000 acre-feet could be pumped each month, as the necessary hourly pumping rate over that month would require a pumping infrastructure likely not available in the near future (see Table 32). Moreover, it is unlikely such a rate could be maintained without undesirable consequences with respect to water level declines and impact on springs. This quantity of pumping, (nearly a third of pumping for the entire season prior to 2001), would require approximately 45 pumps capable of pumping 6,700 gallons per minute (gpm) running 24 hours per day at 100 percent effiency for the entire month (or many more smaller pumps). An uncertain number of pumps this size were installed along the California-Oregon border in 2001, but not nearly enough to meet this need. Furthermore, declines in groundwater levels from recent pumping indicate that substantially exceeding 2004 withdrawals (80,000 acre-feet for the season) may result in unacceptable consequences.

Table 32: Pumping Requirements at Various Basin-Wide Groundwater Demands

Monthly Groundwater Demand (acre-feet)	Pumping Rate Required (gallons per minute)	Number of 6,700 gpm Pumps Required[1]
5,000	37,813	5.6
10,000	75,625	11.3
20,000	151,250	22.6
40,000	302,500	45.1

Notes:

1. During the 2001 drought, an uncertain number of roughly 6,700 gpm wells were drilled along the Oregon-California border. This provides a reference value.
2. Maximum additional pumping in the project area occurred in 2004 at approximately 80,000 acre-feet over four months

5.2.6.2 Single-Year Groundwater Analysis

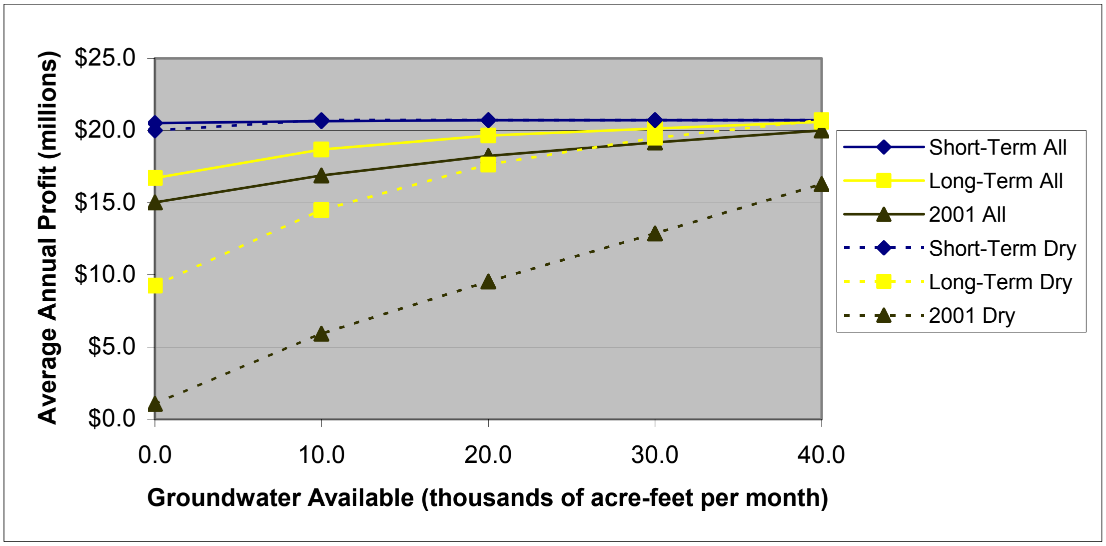
This analysis seeks to develop a better understanding of how varied levels of groundwater availability would affect pumping volumes and farm profits in the presence of hydrological conditions similar to those of past years. This issue is investigated from a static perspective – each year is run independently of each other, whereas in the next section the issue is investigated dynamically. This analysis assumes that the groundwater level begins at one foot bgs – since groundwater pumping costs are calculated based on the depth on March 1st, this restrains the model from unlimited pumping by attaching a nominal cost to each acre-foot pumped.

Sensitivity of Average Annual Farm Profits to Groundwater Availability

The first analysis involves estimation of the average marginal value of groundwater, similar to the analysis of average marginal ESA requirements above.

Monthly groundwater availability was varied in 10,000 acre-foot increments between zero and 40,000 acre-feet per month. These marginal values were developed for the short-term, long-term and 2001 ESA requirements. Figure 34 shows the average and dry year farm profits in response to changing availabilities of groundwater. Results are summarized in Table 33. The center point of each graph, at 20,000 acre-feet of availability per month, is the assumed availability in future years. In the presence of short-term ESA requirements, variation in groundwater availability has little effect on the average profits for all or only dry years, implying that water supply under those requirements is not a major constraint. Long-term requirements have a more pronounced impact, with average profits ranging from $16 million to $20 million for all years and $9 million to $20 million for dry years. Not surprisingly, average and dry year profits given 2001 ESA requirements are even more sensitive to groundwater availability.

Figure 34: Average Annual Farm Profits Given Varied Groundwater Availability



Values in Table 33 are averages of the profit reductions when availability is reduced from 20,000 acre-feet to 10,000 acre-feet and the profit gains when it is increased to 30,000 acre-feet. These values place the graphical analysis above in a better perspective. Given short-term ESA requirements, there is an average profit response of $30,000 to 10,000 additional acre-feet per month for all years, and no response for dry years. This counterintuitive result occurs because the single year that is impacted given short-term requirements is not in the set of dry years. As long-term requirements are imposed, average profits change by over $700,000 per additional 10,000 acre-feet per month for all years, and by over $2.5 million for dry years. These profit responses increase to over $1.1 million for all years and nearly $3.5 million for dry years given 2001 requirements. In other words, if 20,000 acre-feet per month were available and an additional 6,700 gpm pump were installed and run 24 hours per day (providing roughly 1,000 acre-feet per month at its maximum– see Table 31 above), average gains of roughly $70,000 per year for all years and $250,000 for dry years would be expected given long-term ESA requirements. The net benefits of such an installation depend on basin groundwater availability; supply well construction, maintenance, and energy costs; and the value of surplus pumping capacity to (or level of risk aversion of) water managers and planners.

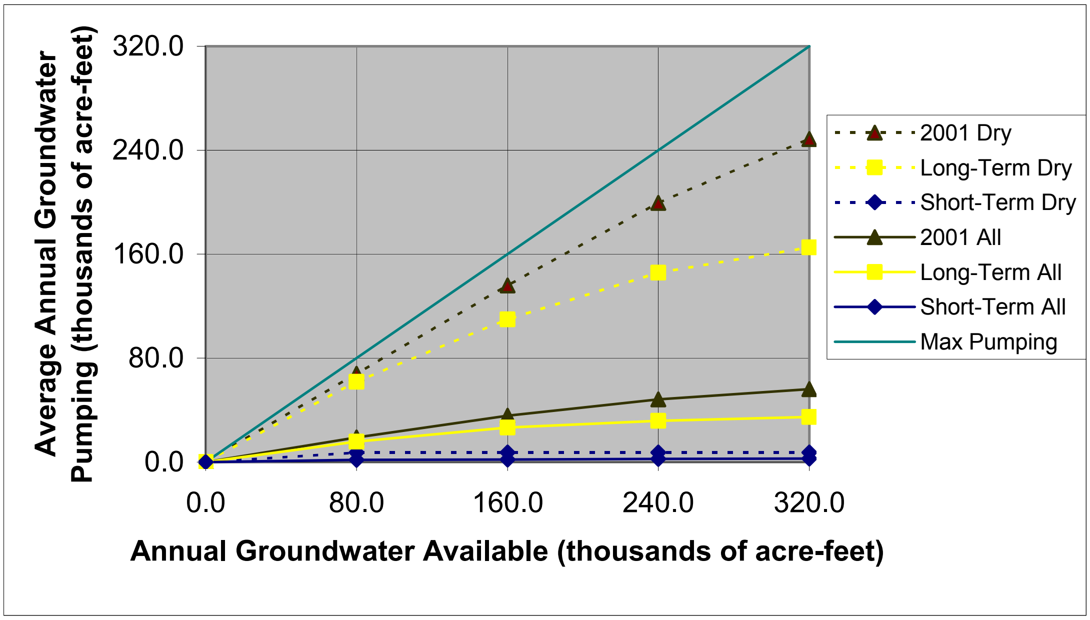
Table 33: Average Annual Change in Farm Profits as Groundwater Availability Rises/Declines by 10,000 Acre-Feet

	Years Evaluated	
	1962 to 2002	NOAA "Dry"
Short-Term Requirements	$30,000	$0
Long-Term Requirements	$733,000	$2,510,000
2001 Requirements	$1,146,000	$3,477,000

Sensitivity of Average Annual Groundwater Pumping to Availability

Of additional interest was how much water would be pumped given varied levels of groundwater availability. Recall that the single-year analysis assumes that water managers have perfect foresight of inflows for the entire season. Thus, they are capable of planning their water needs for August in March, and can use UKL as a storage vehicle for needed groundwater from early in the season. Only groundwater actually needed to meet basin needs is pumped, as the value of water for inter-annual storage is not high enough to justify the energy costs of pumping. Figure 35 shows the average annual basin-wide groundwater pumping given varied groundwater availability and adjusted ESA requirements. Model results indicate that the extent of groundwater pumping relies heavily on both. The “max pumping” line at a 45-degree angle shows the quantity of water that would be pumped if all of the available water were used each year (i.e., if 160,000 acre-feet were available per year, this quantity would be pumped each year). The solid lines represent the response of average annual pumping to varied availability in all modeled years given different ESA requirements, whereas the dashed line represents this response during dry years. As seen in this figure, average groundwater pumping is a relatively small fraction of groundwater available when all years are considered, but is substantially higher for dry years only. Additionally, as ESA requirements grow more stringent, groundwater pumping increases. Finally, observe that as availability is increased, pumping increases at a decreasing rate; this pattern was expected, as certain years will have fixed groundwater requirements and additional supplies will not be utilized, whereas others (such as 1992 or 2001) will use all additional water made available. This pattern is furthered because each month has its own demand (and constraints: 80,000 acre-feet per year converts to 10,000 acre-feet per month, far more restrictive than allowing the annual quantity to be flexibly pumped) that will be fulfilled by different levels of groundwater availability. As demands are met for each month, the slope of the curve diminishes. Note that the “short-term dry” curve is flat after 80,000 acre-feet per year, indicating that all monthly demands were met by that level of groundwater availability.

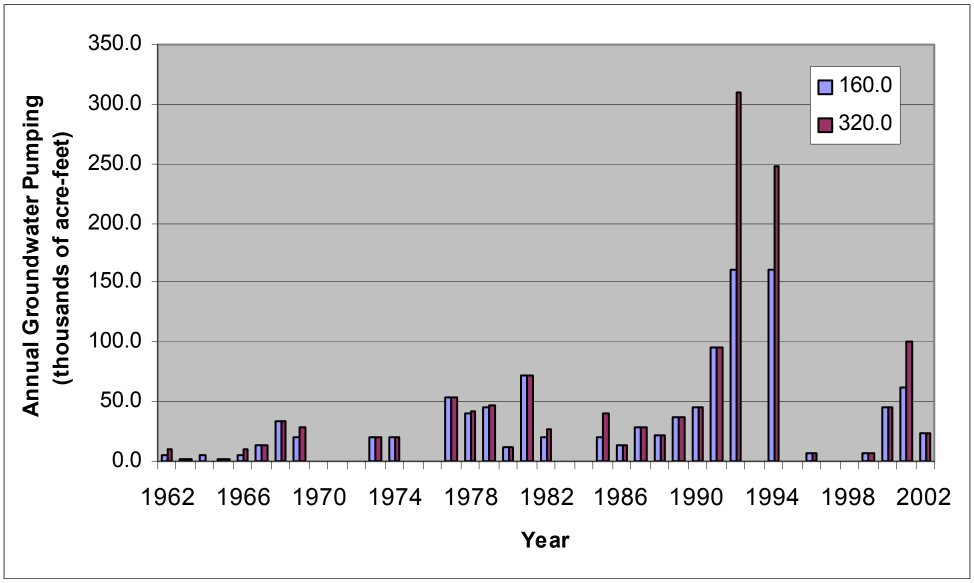
Figure 35: Average Annual Groundwater Pumping Given Varied Availability and ESA Requirements



This pattern of increasing pumping at a decreasing rate can be observed in Figure 36 below. This figure shows the groundwater pumping each modeled year between 1962 and 2002 given 160,000 and 320,000 acre-feet of annual availability and long-term ESA requirements. Now the majority of the increase in pumping from greater availability is observed to be driven by only a few years (here, 1992, 1994, 2001). Investigating the profit distribution under medium groundwater availability in section 5.2.2 above confirms that there is no need for greater pumping in the vast majority of years, where profits have already been maximized. Notice that in certain years (such as 1985 or 2001), total pumping varies widely between availability levels even though the constraint (i.e., 160,000 or 320,000 acre-feet) has not been met. Constraints on monthly groundwater pumping explain these differences – certain months used their full share of 20,000 and 40,000 acre-feet per month, whereas others did not. In sum, this led to annual pumping levels that differed but were considerably below the total pumping restriction for the year.

Concern has been expressed over groundwater declines observed in the period between 2001 and 2004, where significant pumping (between 25,000 and 80,000 acre-feet per year) took place for the water bank. The model indicates that given hydrological conditions observed between 1962 and 2002, continuous annual pumping at these levels may be unnecessary. Furthermore, this also indicates that additional installations (beyond 160,000 acre-feet per month) of groundwater pumping capacity may be idle the majority of the time. Depending on the profit reductions during years where this extra capacity could be used, installation of such capacity may cost more than farm reductions could justify. Furthermore, the source of funding for such installations is uncertain.

Figure 36: Annual Groundwater Pumping Given Varied Availability per Year



5.2.6.3 Groundwater Energy Costs

Energy costs associated with pumping groundwater are dependent upon two factors: pumping depth and the price of energy. As the latter rises, each additional foot of groundwater pumping becomes more costly[92]. If groundwater were to be an important part of the long-term solution to water issues in the basin, average groundwater levels would decline in response to increased pumping. Insufficient information was available at the time of this analysis to model how groundwater depths would change over multiple years[93], so this section instead focuses on how start-of-year groundwater levels affect annual pumping behavior, land idling, and farm profits assuming long-run energy prices.

First, land idling and farm profit responses are explored. The model uses the trade model to investigate initial pumping depths between zero and 160 feet bgs, and assumes that up to 20,000 acre-feet of pumping can occur each month.[94] At these depths and long-run energy prices, this translates to $0 and $32.46 per acre-foot of pumping given model assumptions about energy costs (see Appendix C). Table 34 displays estimated profits at selected initial groundwater depths for average and dry year hydrological conditions. Since little groundwater is needed during the typical

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[92] Assuming that it takes 2.94 kWh of electricity to pump an acre-foot up a single foot (calculations are in Appendix C), the 2005 and 2012 energy prices of $0.006 and $0.069 per kWh translate to 1.7 cents and 20.3 cents per foot. This analysis assumes that these energy requirements remain constant as depth increases, which may substantially underestimate overall costs.

[93] As described in Chapter 4, the model is set up to run dynamically. Although a dynamic analysis would have been an interesting and useful contribution to this research, too little was known about the groundwater system when this research was conducted to reliably predict how water levels would respond to pumping in the long-term.

[94] The hydrological feasibility of these pumping depths has not been investigated.

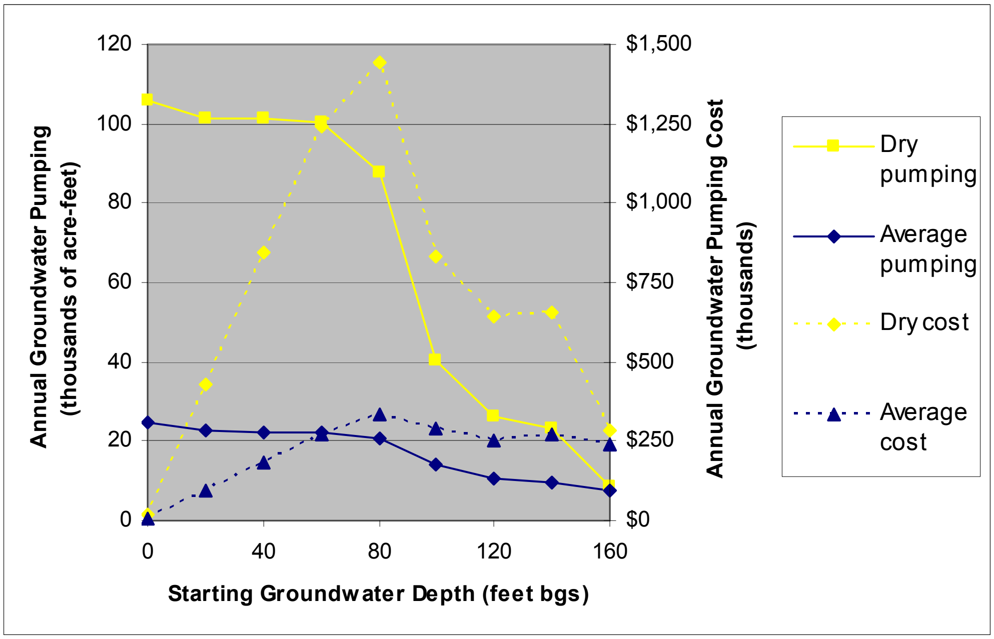
year, average annual profits decline only $300,000 as initial groundwater depth decreases to 80 feet bgs. During dry years only, this same change has an average impact of $1.6 million due to the much greater dependence of dry year profits on groundwater. The losses incurred between depths of zero and 80 feet bgs are caused by both increased energy costs and lost net revenues from additional acres idled, observed in Table 34 to be 3,600 and 9,000 acres in average and dry years. Interestingly, roughly 43,000 acres are idled in dry years as initial groundwater depths fall from 80 to 120 feet bgs, yet profits only decline by $400,000. This is because the marginal value of groundwater-fed irrigation on these 43,000 acres approaches zero somewhere in this interval. As a result, the lost revenues from taking these acres out of production are largely balanced by the savings from not pumping groundwater for irrigation. Groundwater pumping costs are covered in greater detail next.

Table 34: Annual Farm Profits Given Various Initial Groundwater Depths

Initial Groundwater Depth	**Average Farm Profits (millions)**		**Average Land in Production (thousands)**	
(feet bgs)	**1962 to 2002**	**NOAA “Dry”**	**1962 to 2002**	**NOAA “Dry”**
0	$13.4	$13.1	303.4	289.7
40	$13.3	$12.3	300.9	287.2
80	$13.1	$11.5	299.8	280.7
120	$13.0	$11.1	292.7	237.3
160	$12.9	$10.9	290.9	228.0

Initial groundwater depths play a large role in determining the magnitudes of annual groundwater pumping volumes and energy costs. As can be seen in Figure 37 below, average groundwater pumping in both average and dry years continuously falls as initial groundwater depth increases. Energy costs, on the other hand, peak at pumping depths of 80 feet bgs, and then fall as savings from avoiding energy costs exceed the effect of increasing marginal pumping costs. During dry years, groundwater pumping costs are estimated to be nearly $1.5 million per year at 80 feet bgs, or roughly 7.5 percent of the maximum annual basin farm profits. The idling of 43,000 seen in Table 34 above can be observed in the same transition between 80 and 120 feet bgs, when groundwater pumping decreases roughly 70,000 acre-feet during dry years. Similar abrupt transitions were observed in the energy analysis (Section 5.2.4) as particular energy price levels in the model triggered the conversion of large acreages from sprinkler to flood irrigation.

Figure 37: Initial Groundwater Depth versus Annual Pumping Volume and Cost



Next, these results are summarized and the conclusions and extensions from this work are discussed.

6 CONCLUSIONS AND EXTENSIONS

The objective of this research is to assess the impact of changes in ESA flow requirements and energy prices on the Upper Klamath basin farm economy in the presence of variable levels of water trading flexibility and groundwater availability. Accomplishing this objective involved: 1) the construction of a dynamic monthly model of the basin's agricultural economy; 2) multiple simulation model runs using combinations of parameters representing various expected institutional, agricultural, and hydrological conditions; and 3) estimation of impacts due to increases in flow requirements and energy prices subject to groundwater availability and trade flexibility.

A mathematical programming framework is used in which farm decisions are assumed to maximize net revenue subject to hydrological, institutional, economic, and agronomic constraints. Expected water inflows in future years are characterized based on historical data between 1962 and 2002. The model was also calibrated based on these historical data

6.1 Summary of Results

There are four specific objectives of this study: 1) evaluate the costs of an abrupt increase in ESA flow requirements given different levels of water trading flexibility; 2) evaluate the impact of anticipated energy cost increases on water availability and the resulting redistribution of irrigation technologies in the basin; 3) assess the sensitivity of farm profit reductions to changes in lake level and flow requirements, especially focusing on potential multi-year strategies; and 4) investigate the potential economic importance of groundwater in future basin water supplies. The results of these objectives are reviewed below.

Perceptions of both the risk of water shortfalls and their resulting impact have been heavily influenced by the events of 2001. Looking more closely at historical data reveals that the impacts of 2001 were partially the result of exceptionally restrictive ESA requirements combined with low levels of groundwater pumping infrastructure (Table 25). Results indicate that with modest amounts of groundwater available annually, average long-term impacts on farm profits due to the imposition of long-term IGD flow requirements would be -\$1.0 million (Table 21). For dry years, the impact would be -\$3.1 million (Table 22). Looking more closely, minor impacts on profits occur in the majority of years and a few years with heavy impacts are responsible for these averages reported above (Figure 23). Greater groundwater allowances would yield much lower impacts during these years (Table 25). Consistent with previous results (Jaeger 2004), water trading is shown to alleviate roughly 50 percent of basin net revenue reductions that would otherwise occur (Table 25). During the majority of years this benefit is insignificant in magnitude, but during dry years greater trading flexibility may provide considerable relief. Finally, this study demonstrates that if trading were to occur, it would likely redistribute idled lands from the project (as occurred in 2001) to the upper basins (Figure 25).

Model results suggest that the 10-fold increase in energy rates due to the PacifiCorp contract expiration will have a much more pronounced impact on irrigators than changes in ESA requirements ($6.9 million versus $1.0 million per year – Table 21 and Figure 28), and also indicate that the demand for electricity over this price increase is extremely inelastic (roughly -0.02: a 100 percent increase in electricity price results in a 2 percent decrease in kilowatt-hours demanded). As energy prices increase, "convertible" sprinkler irrigators may switch to flood (with fixed cost increases and yield declines) assuming that their land has an average slope of less than four percent. Model results indicate that of the 52,000 "fixed" sprinkler acres, roughly 13 percent would be retired as energy prices rise to their long-term levels (Figure 29), although this low number may be reflected in the "fixed" acreage criterion that average slope be greater than four percent. Given the same increases, 36 percent of the 83,900 convertible sprinkler acres would switch to flood irrigation (Figure 31). Considering these results, recent government spending to stimulate switches from flood to sprinkler irrigation (under the EQIP program) may not be in the best interest of the agricultural economy.

Previous studies have demonstrated that minor adjustments to ESA requirements in the basin could have major impacts on farm profits (Adams and Cho 1998). This analysis confirms these findings, indicating that changing UKL requirements by one inch will impact profits by an average of $240,000 when all years are considered, and $308,000 when only dry years are included (Figure 32 and Table 31). Within the relevant range of UKL elevations, Adams and Cho approximate this marginal impact at between $100,000 and $300,000 per inch. Results suggest that IGD flow requirements have a less pronounced average impact when all model years are included ($194,000 for a 50 cfs adjustment), and an exacerbated effect when only dry years are considered ($813,000 for 50 cfs – see Figure 32 and Table 31). Decision-makers should be aware of these costs when weighing the marginal biological costs or benefits of adjusted lake levels.

Confirming the outcomes observed in Objective 1, the groundwater sensitivity analysis indicates that farm profits are highly responsive to the availability of groundwater. In the presence of long-term requirements, results suggest that profits change an average of $700,000 when all years are considered and $2.5 million when only dry years are considered (Figure 33 and Table 33). Both of these values increase by roughly 50 percent in the presence of the more stringent 2001 requirements. An average of roughly 25 percent of available groundwater is pumped during the 1962 to 2002 period based on the model, far lower than expected. Given more stringent ESA requirements, this pumping fraction increases considerably during dry years (see Figure 34). Figure 35 emphasizes this point – during the majority of model years between 1962 and 2002, less than 5,000 acre-feet of groundwater are pumped per month (excluding historically groundwater-dependent acres). Results of the groundwater energy analysis suggest that if increased pumping in the basin depresses groundwater levels considerably, increased pumping costs (due to higher energy rates and greater pumping depths) may prompt increased land idling, and paradoxically, decreased groundwater pumping (Table 34 and Figure 37).

6.2 Conclusions

This research suggests several reasons why the economic impacts due to water supply shortfalls in future years may not be as substantial as those of 2001. First, between April and September of that year, ESA lake level and flow requirements demanded an additional 222,000 acre-feet of water relative to long-term future requirements, enough to irrigate roughly 100,000 acres of the 200,000-acre Reclamation project. Had additional early season outflows been stored in UKL and extra required storage been made available, this water could have been used for irrigation throughout the season. Second, both groundwater pumping capacity and delivery throughout the basin in 2001 was inadequately developed – these have since been improved considerably. Third, although institutional and physical barriers to water markets may prohibit their full introduction, the 2002 to 2006 Reclamation water bank indicates that some drought mitigation mechanism may be in place in future years. Finally, although costly for irrigators in the basin, dramatic increases in energy prices (for both irrigation and groundwater pumping) may cause greater water conservation and land retirement (with corresponding increases in water availability).

Greater development of basin groundwater resources and the institution of a flexible water bank may be sufficient to mitigate the majority of costs related to increased ESA flow requirements in future years. Between 2002 and 2006, the groundwater system in the basin has shown promising resilience in response to substantial water bank pumping. Absent the water bank requirements, the model suggests that the farm economy may only occasionally demand large volumes of groundwater, resulting in aggregate long-term demands that may not be large enough to meaningfully affect regional groundwater levels. If groundwater levels decline below institutionally acceptable levels during a given year, a short term market mechanism could be used to efficiently redistribute water to its highest value uses (largely from the upper basins to the project), minimizing regional economic impacts. Such a mechanism would require the installation of a more advanced metering infrastructure to track and quantify trades between irrigators, but the benefits of trading could greatly outweigh the installation costs. Increased groundwater resource development and short-term trading would obviate the need for an expensive and inefficient set of permanent water bank volume requirements, or for more expensive supply augmentation alternatives such as surface water storage.

6.3 Extensions

Additional research would substantially improve both the reliability and the applicability of the results presented in this study. The hydrological model assumed perfect knowledge of seasonal water availability in March; a modeling effort that incorporated intraseasonal hydrological uncertainty would be more appropriate, as late season irrigation curtailments can be especially damaging to crops. Incorporation of alternative irrigator water management strategies (e.g., deficit irrigation or transition to less water-intensive crops) would provide better insight into the potential impact of on-farm management decisions on basin water availability. A better understanding of the groundwater system and the benefits of conjunctive use (joint management of surface water and groundwater as a single supply) would also provide considerable benefits to basin water managers, although the forthcoming USGS/OWRD study partially addresses these uncertainties. A broader analysis of hydrological uncertainty could also consider the role of climate change in the timing and magnitude of future years' water availability.

Additional research on economic and institutional issues in the basin is also warranted. Using multiobjective programming to jointly maximize farm profits and biological benefits would extend the results presented in this study considerably (see Cohon 1978). This would require collaboration between biologists, policymakers, and economists to create a bioeconomic model of the basin, allowing for a more thorough analysis of the implications of various sets of ESA requirements. Researching the conveyance losses and third party effects in water trades from the upper basins to the project would provide greater information on the hydrological benefits of these trades, as would a benefit-cost analysis of installing an irrigation metering infrastructure. Although water trading has been used historically in both Oregon and California to manage potential water conflicts, further research on the institutional feasibility of a drought mitigation water bank in the basin is warranted. Furthermore, more concentrated research on Oregon and California groundwater law would provide a better understanding of the institutional constraints on groundwater management in the basin.

For the analysis of increased energy price impacts, a more pointed study of both the economic and physical criteria by which sprinkler acres can switch to flood would provide greater insight into the likelihood of these conversions. More accurate estimation of the basin-scale water savings or loss of sprinkler irrigation systems in the Upper Klamath basin would provide useful insights into the water supply implications of conversions and retirement. Additionally, a more precise, ground-truthed definition of “fixed” versus “convertible” sprinkler irrigation would provide a more reliable estimate of these acreages, and therefore of the extent of land retirement in response to energy price increases.

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ACRONYM REFERENCE LIST

Acronym	Explanation
bgs	Below ground surface
BiOP	FWS or NOAA Biological Opinion
CADFG	California Department of Fish and Game
CDWR	California Department of Water Resources
cfs	Cubic feet per second
DEM	Digital Elevation Model
EPA	Environmental Protection Agency
EQIP	NRCS Environmental Quality Incentives Program
ESA	Endangered Species Act
ET	Evapotranspiration
FWS	U.S. Fish and Wildlife Service
GAMS	Generalized Algebraic Modeling System
GIS	Geographic Information System
IE	Irrigation Efficiency
IGD	Iron Gate Dam
ITRC	Irrigation Training and Research Center
kWh	Kilowatt-hour
LP	Linear Programming
NAS	National Academy of Sciences
NOAA	National Oceanographic and Atmospheric Agency
NRCS	Natural Resources Conservation Service
OSU	Oregon State University
OWRD	Oregon Water Resources Department
OWT	Oregon Water Trust
UKL	Upper Klamath Lake
USGS	U.S. Geological Survey

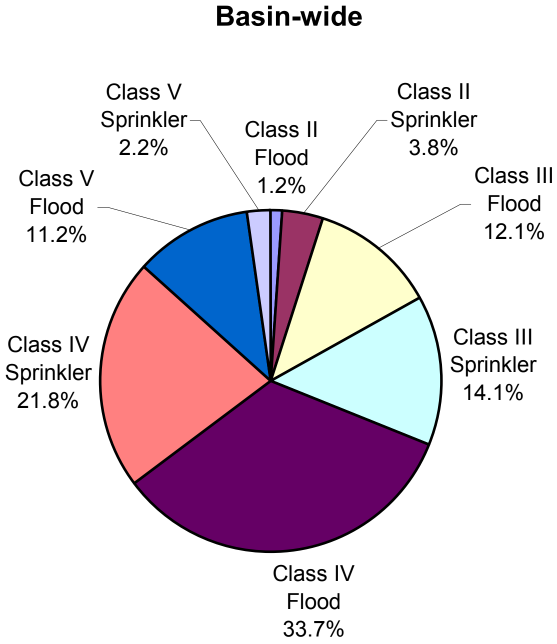
APPENDICES

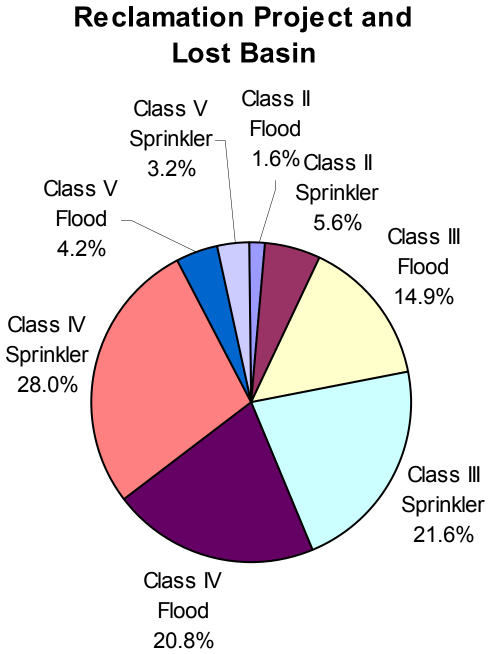
Appendix A: Fraction of Each Crop in Area Rotations

	Crop Type (measured in acres)								
Area and Soil Class	Potatoes	Grain	Alfalfa Hay	Onions	Mint	Strawberries	Beets	Other Hay	Pasture
Upper Basins									
Fort Klamath Valley									
Class III	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Class IV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Class V	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Total	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**1.00**
Modoc Point to Chiloquin									
Class II	0.15	0.20	0.65	0.00	0.00	0.00	0.00	0.00	0.00
Class III	0.00	0.09	0.67	0.00	0.00	0.00	0.00	0.14	0.10
Class IV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Class V	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Total	**0.01**	**0.06**	**0.38**	**0.00**	**0.00**	**0.00**	**0.00**	**0.07**	**0.48**
Sprague River Valley									
Class III	0.00	0.32	0.68	0.00	0.00	0.00	0.00	0.00	0.00
Class IV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Class V	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**0.00**	**0.00**	**0.01**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.98**
North County									
Class III	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Class IV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Class V	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Total	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**1.00**
Lost Basin									
Langell Valley									
Class II	0.00	0.05	0.65	0.00	0.00	0.00	0.00	0.20	0.10
Class III	0.00	0.03	0.08	0.00	0.00	0.00	0.00	0.38	0.51
Class IV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Class V	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Total	**0.00**	**0.02**	**0.16**	**0.00**	**0.00**	**0.00**	**0.00**	**0.21**	**0.61**
Bonanza/Dairy/Hildebrand									
Class II	0.08	0.03	0.77	0.00	0.00	0.13	0.00	0.00	0.00
Class III	0.00	0.04	0.92	0.00	0.00	0.00	0.00	0.04	0.00
Class IV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Total	**0.02**	**0.02**	**0.56**	**0.00**	**0.00**	**0.04**	**0.00**	**0.02**	**0.34**
Reclamation Project									
Poe Valley									
Class II	0.02	0.12	0.77	0.00	0.00	0.00	0.00	0.09	0.00
Class III	0.00	0.14	0.43	0.00	0.00	0.00	0.00	0.12	0.32
Class IV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Total	**0.00**	**0.07**	**0.34**	**0.00**	**0.00**	**0.00**	**0.00**	**0.09**	**0.49**

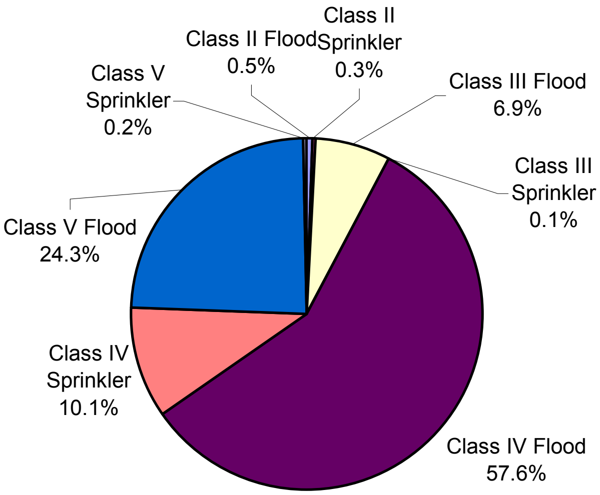
	Crop Type (measured in acres)								
Area and Soil Class	Potatoes	Grain	Alfalfa Hay	Onions	Mint	Strawberries	Beets	Other Hay	Pasture
Merrill/Malin									
Class II	0.20	0.10	0.70	0.00	0.00	0.00	0.00	0.00	0.00
Class III	0.11	0.14	0.58	0.00	0.01	0.00	0.00	0.09	0.07
Class IV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Total	**0.09**	**0.10**	**0.43**	**0.00**	**0.00**	**0.00**	**0.00**	**0.06**	**0.32**
Midland/Henley/Olene									
Class II	0.15	0.15	0.70	0.00	0.00	0.00	0.00	0.00	0.00
Class III	0.04	0.05	0.46	0.00	0.00	0.00	0.00	0.18	0.27
Class IV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Total	**0.05**	**0.06**	**0.38**	**0.00**	**0.00**	**0.00**	**0.00**	**0.09**	**0.42**
Lower Klamath Lake									
Class II	0.25	0.25	0.50	0.00	0.00	0.00	0.00	0.00	0.00
Class III	0.02	0.54	0.01	0.00	0.00	0.00	0.00	0.12	0.31
Class IV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Class V	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**0.02**	**0.51**	**0.02**	**0.00**	**0.00**	**0.00**	**0.00**	**0.11**	**0.34**
Malin Irrigation District									
Class II	0.24	0.20	0.50	0.00	0.00	0.00	0.00	0.06	0.00
Class III[2]	0.06	0.14	0.60	0.00	0.00	0.00	0.00	0.10	0.10
Class IV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Total	**0.07**	**0.14**	**0.57**	**0.00**	**0.00**	**0.00**	**0.00**	**0.09**	**0.12**
Shasta View/Malin									
Class II	0.15	0.15	0.50	0.00	0.00	0.20	0.00	0.00	0.00
Class III	0.09	0.16	0.66	0.00	0.00	0.09	0.00	0.00	0.00
Class IV	0.00	0.00	0.70	0.00	0.00	0.00	0.00	0.00	0.30
Total	**0.08**	**0.12**	**0.64**	**0.00**	**0.00**	**0.09**	**0.00**	**0.00**	**0.07**
West of Hwy 97/Keno									
Class II	0.00	0.30	0.70	0.00	0.00	0.00	0.00	0.00	0.00
Class III	0.00	0.17	0.27	0.00	0.00	0.00	0.00	0.19	0.38
Class IV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Class V	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Total	**0.00**	**0.10**	**0.18**	**0.00**	**0.00**	**0.00**	**0.00**	**0.07**	**0.65**
Tule Lake									
Class II	0.24	0.12	0.24	0.16	0.16	0.08	0.00	0.00	0.00
Class III	0.16	0.41	0.44	0.00	0.00	0.00	0.00	0.00	0.00
Class IV	0.00	0.79	0.00	0.00	0.00	0.00	0.00	0.12	0.09
Total	**0.13**	**0.46**	**0.28**	**0.03**	**0.03**	**0.02**	**0.00**	**0.03**	**0.02**
CA Lower Klamath Lake									
Class II	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Class III	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Class IV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Total	**0.00**	**0.70**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.30**

Appendix B: Distribution of Basin-Wide Soil Classes and Irrigation Technologies





Sprague, Williamson and Wood Basins



Appendix C: Calculation of Irrigation and Groundwater Pumping Costs

Pumping costs:

$\mathbf{c = p*E}$

where E is the energy consumed

Energy consumed:

$\mathbf{E = t*kw}$

where t is the time of pumping and kw is kilowatts (kilojoules per second)

Rate of energy consumption:

$\mathbf{kw = (q*tdh)/(3960*e_{pp})}$

where q is the pumping rate in gallons per minute and tdh is the total dynamic head – the sum of lift, head loss, lateral head loss, mainline head loss and the pressure at the pump in pounds per square inch (psi) multiplied by 2.306 feet per psi. The pressure required at the pump varies from 45 to 70 psi. Lift, head loss, lateral head loss and mainline head loss are assumed to add up to 15 feet of pressure. e_{pp} is the combined efficiencies of the motor and pump, assumed to be 0.7. These numbers are based on typical values for technologies in the region.

Hours of pumping:

$\mathbf{t = (d*27{,}180)/(q*60)}$

where d is the required acre-inches of water, and 27,180 is the number of gallons in an acre-inch of water.

Energy consumed (combined formulas):

$$E = (27{,}180*d*tdh)/(60*3{,}960*e_{pp})$$

d is 12 acre-inches per acre-foot

tdh is 15 for flood and 118.8 for sprinkler

Total energy consumed per acre-foot of water from pump to field is thus 232.97 kWh for sprinkler irrigation (conservatively assuming 45 psi of pump pressure) and 29.42 kWh for flood irrigation.

At the typical market energy price of $0.06 per kWh, this is approximately $14 per acre-foot of water applied to the field. Given that irrigation efficiency is never 100 percent, if sprinkler irrigation efficiency is assumed to be around 80 percent, then for each foot of water consumed by the crops, 1.25 feet must be applied. Annual crop water application requirements range from 2 to 3 feet (or 2.5 to 3.75 feet pumped), bringing the per acre sprinkler irrigation cost to between $35 and $52.50 (once again, assuming 45 psi of pump pressure – up to 70 psi may actually be applied). The U.S. Department of Agriculture Economic Research Service (USDA/ERS) estimates western U.S. irrigation energy costs for pumping and pressurization to average $44 per acre, and the Oregon State University Extension Service has estimated that alfalfa grown in central Oregon costs $25 in pumping costs per acre (Jaeger 2004a).

It is assumed here that the irrigators are not capable of reducing their energy costs through any means other than shifting to flood irrigation (if possible given their land). It may be possible for irrigators to switch to other sprinkler methods that consume less energy or have higher irrigation efficiency. However, irrigator options are restricted to conversion to flood irrigation for simplicity – an exhaustive analysis of the optimal mix of irrigation technologies in the basin is beyond the scope of this study.

To deliver groundwater to the surface (either to supplement Klamath flows or to use as irrigation water), head loss and frictional losses are assumed to depend on depth to groundwater. For each foot of depth to groundwater, an additional 0.5-foot of head loss and frictional losses are assumed to occur. Accordingly, to pump one acre-foot of water up one foot, the total energy consumed is estimated at 2.94 kWh.

Sources: Jaeger 2004a and personal communication with Marshall English, Professor of Bioresource Engineering at Oregon State University, on March 15, 2006.

Appendix D: Sprinkler Conversion Assumptions

The results of this analysis heavily depend on the yield and annualized cost penalties for conversion of convertible sprinkler acres to flood irrigation. These are discussed in the model section (4.3.2.1) above, but will be elaborated on here. Assuming a particular acre of land is capable of switching to flood irrigation, that acre will convert if the benefits of conversion exceed the conversion cost. Recall that the profit of one acre that converts is equal to $(1-\frac{\pi_{ij}}{\pi_{\max}}\eta_k)\pi_{ij}-\chi_k$, where π_{ij} is the profits accruing to one acre in area i and soil class j, $\pi_{\max}$ is the maximum profit of any acre in the model, η_k is the yield cost for each irrigation technology (0.25 for flood and 0 for sprinkler), and χ_k is the annualized conversion cost for each technology ($30 for flood and $0 for sprinkler). The profit of one acre that does not convert is simply π_{ij}. The cost of conversion is then the profits of not converting minus the profits from converting, which reduces to $\frac{\pi_{ij}^2}{\pi_{\max}}\eta_k+\chi_k$. The benefits of conversion (or the energy savings of converting) is the energy cost to sprinkler irrigate minus the energy cost to flood irrigate. To simplify, a convertible sprinkler acre will switch to flood if: $\Delta e_{iy}^I > \frac{\pi_{ij}^2}{\pi_{\max}}\eta_k+\chi_k$. Where Δe_{iy}^I is the change in irrigation energy costs in a given area and during a given year.

Appendix E: Inferred Inflow Values for Each Month and Year

Year	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
1962	46,898	14,241	53,152	46,096	46,472	34,567	6,064	44,206	291,696
1963	15,942	48,035	56,830	34,216	55,012	31,052	20,579	-9,419	252,247
1964	49,671	9,287	38,357	100,578	65,442	52,024	16,117	-10,723	320,754
1965	40,603	44,347	56,152	64,286	75,076	65,610	96,805	-75,189	367,690
1966	19,059	-17,032	26,443	90,263	49,715	31,281	24,799	-5,404	219,125
1967	28,754	34,876	48,800	54,118	43,217	19,851	14,330	4,308	248,254
1968	9,828	-7,179	47,768	56,894	59,497	76,789	25,231	-3,167	265,662
1969	44,334	-9,103	34,524	59,598	55,533	24,539	13,378	18,213	241,016
1970	34,913	30,901	63,992	64,981	73,757	34,312	23,589	-2,105	324,340
1971	25,531	54,819	62,139	43,110	41,867	17,635	17,096	19,574	281,772
1972	69,426	34,960	35,540	36,776	49,102	39,282	26,566	-1,978	289,673
1973	5,783	-2,406	19,613	45,761	45,907	30,959	32,171	198	177,986
1974	6,273	31,156	8,424	11,801	34,422	25,323	1,744	-4,142	115,001
1975	39,227	27,717	7,778	13,830	48,123	28,151	14,588	3,927	183,339
1976	19,506	6,357	6,648	47,048	47,667	96,530	23,740	11,571	259,066
1977	18,220	-9,376	84,823	79,229	61,138	32,873	10,500	12,213	289,620
1978	16,401	36,511	53,303	44,720	54,235	31,735	26,014	-3,063	259,855
1979	14,281	34,394	32,727	42,823	52,796	44,326	16,518	-4,410	233,456
1980	34,971	32,233	44,695	71,736	63,947	37,369	12,152	23,617	320,721
1981	22,194	28,321	57,489	59,265	57,822	19,325	-6,714	8,705	246,407
1982	94,112	46,043	11,169	45,537	64,524	27,978	23,583	5,778	318,724
1983	60,651	41,643	46,142	31,855	40,998	33,596	20,227	4,624	279,735
1984	41,717	41,471	36,188	46,404	36,172	14,781	52,950	30,112	299,795
1985	24,080	14,550	26,384	52,305	38,881	58,918	46,447	13,830	275,394
1986	68,746	30,580	49,346	41,862	50,514	29,036	31,923	9,220	311,227
1987	8,199	12,453	32,183	66,150	90,587	44,005	15,755	-5,198	264,133
1988	20,473	24,317	57,176	74,355	51,293	36,293	-2,382	-10,971	250,553
1989	42,452	52,294	84,466	39,834	44,561	22,982	23,088	17,662	327,339
1990	14,165	16,651	53,278	75,310	66,663	31,460	6,930	-2,768	261,689
1991	36,116	25,269	75,869	52,114	61,416	33,419	1,047	-23,303	261,947
1992	17,475	13,121	12,960	83,149	111,654	50,830	23,545	1,029	313,762
1993	101,153	69,449	37,089	69,528	48,987	33,079	-2,397	2,437	359,324
1994	-791	2,446	82,898	60,427	50,381	23,866	13,114	8,697	241,039
1995	29,898	41,330	72,370	74,853	53,703	19,786	-3,103	-7,677	281,160
1996	58,205	38,644	53,756	50,005	56,654	26,834	-362	-9,913	273,822
1997	9,295	14,470	33,893	72,321	70,035	25,611	14,660	8,565	248,850
1998	31,225	73,930	121,058	102,817	44,257	16,036	-2,026	17,269	404,567
1999	98,865	62,657	29,330	40,505	36,550	44,239	9,997	-1,395	320,747
2000	27,005	20,374	50,168	53,403	68,074	14,025	42,440	3,722	279,211
2001	14,341	33,736	36,548	47,613	42,941	-37,977	13,816	-36,377	114,640
2002	15,823	7,905	40,548	52,478	45,026	33,150	12,188	-5,216	201,902
Average	**34,861**	**31,743**	**54,290**	**62,160**	**58,429**	**26,275**	**11,661**	**-2,013**	**270,177**