AN ABSTRACT OF THE THESIS OF

Brenda P. Turner for the degree of Master of Science in Agricultural and Resource Economics presented on September 18, 1995. Title: A Farm-Level Economic Analysis of Water-Conserving Irrigation Systems and Commercial Agricultural Water Transfers to Instream Flows in Central Oregon.

Redacted for privacy

Abstract approved: ______________________________

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The middle Deschutes River between Bend, Oregon and Lake Billy Chinook typically experiences critically low flows during the irrigation season. Commercial agriculture in the North Unit Irrigation District and Central Oregon Irrigation District is one major user of Deschutes River water. The overall objective of this research was to estimate the cost to transfer water from commercial agriculture operations to instream flow use assuming a water market existed. Two methods of providing water within commercial agriculture were considered; 1) lining irrigation district canals that supply water to farms and 2) changing on-farm water use. On-farm practices include adopting water conserving irrigation technologies and involvement in Oregon's water conservation program. Supply curves were generated for these alternatives assuming expected and alternative streamflow levels. Results indicated that changing crop rotations, adopting water conserving technologies and participating in Oregon's conservation program were used, depending on the market price for water. Canal lining, however, was generally the most cost-effective means of providing water to enhance flows in the middle Deschutes River.

A Farm-Level Economic Analysis of Water-Conserving Irrigation Systems and Commercial Agricultural Water Transfers to Instream Flows in Central Oregon

by

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A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for
the degree of

Master of Science

Completed September 18, 1995
Commencement June 1996

Master of Science thesis of Brenda P. Turner presented on September 18, 1995

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ACKNOWLEDGEMENT

I would like to express my sincere gratitude to my major professor, Dr. Greg Perry, for the advice, enthusiasm, and professional assistance he provided while guiding me to complete a thesis "worth waiting for". I would like to thank Dr. Joe Stevens for his guidance, support and practical advice which (almost) kept me sane throughout the thesis process. I am grateful to Dr. Alan Mitchell for accepting a position on my committee from off-campus and always providing input and information whenever needed.

I would like to thank the United States Department of Agriculture's Cooperative State Research Service who provided funds used to complete this research under the National Research Initiative Competitive Grants Program.

This thesis would not have been possible without the extraordinary support offered by the Extension Agents, Irrigation Districts, agri-businesses and farmers who participated. Thank you for your efforts.

A special thanks to my fellow graduate students, especially Tove Christensen and Siân Mooney, who were always there to lessen my utmost confusion about this research and life in general and help me to overcome computer jinxes.

Without Tjodie Templeton, my "personal secretary", this thesis would still not be completed. Her professional skills were a blessing and the full candy bowl provided a great stress remedy.

Finally I would like to thank my family for their patience, encouragement and understanding of my late nights and missed events throughout my education. I will always be appreciative of you all.

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LIST OF ABBREVIATIONS

Abbreviation	Definition
EF	every furrow irrigation
AF	alternate furrow irrigation
AGF	alternating furrow irrigation
SF	surge furrow irrigation
SP	sprinkler irrigation
PV	center pivot irrigation
FL	flood irrigation (without deep furrows, used for pasture irrigation)
S	siphon tube
G	gated pipe
PB	pumpback system
IS	irrigation scheduling
LL	laser levelling

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1. INTRODUCTION

1.1 Background and Setting

Conflicts among water users are inevitable in the western United States, given that the number of users continues to increase while most streams and rivers are already fully appropriated. In the past, increased water demand was satisfied by developing new water sources. Today the most physically and economically optimal locations have been developed, leaving little prospect that water shortage problems can be solved by developing new supplies. Therefore, it becomes imperative that society identify other methods to efficiently meet this demand, including evaluating how water is allocated among users as well as eliminating waste and implementing conservation technologies and policies.

The major water user in the West is irrigated agriculture. Although agriculture accounts for nearly 90 percent of all water consumption in the western U.S. (Rosen and Sexton, 1993), supplies in many areas are inadequate for irrigators to water all of their land with appurtenant[1] water rights. Given short supplies, irrigators either produce non-irrigated crops (which tend to be less profitable) or fallow their land. Annual water supply levels and the seniority of individual rights determine how

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[1] Water rights are incidental rights attached to land.

much water is initially available each growing season but climate and soil conditions, crop rotations, irrigation technology, and irrigation system management define how much land can actually be irrigated.

Agriculture is not the only water use affected by scarce supplies and fully appropriated streams. Diverting water out of streams disrupts non-consumptive uses such as aquatic and wildlife habitats, recreation, and pollution abatement. Historically, instream water uses have not had a legitimate water right status. In recent years several states, including Colorado, Idaho, Montana, Washington, Alaska, Arizona, Hawaii, Nevada, and Oregon, have passed legislation identifying instream flows as a beneficial use (Livingston and Miller, 1986; McKinney and Taylor, 1988). The recognition of non-consumptive instream uses is meaningless unless water is available to be left instream. Given the large proportion of water in the Western agricultural sector, agricultural withdrawals could potentially be a source for streams experiencing low water supplies.

One area where water conflicts exist between agricultural and non-agricultural users is the Deschutes River Basin of Central Oregon. Annual rainfall averages only 9 to 12 inches making irrigation mandatory for crop production. Groundwater resources are limited and too deep to be economically-viable for agricultural uses. To increase irrigation water supplies, government and private entities have developed surface water storage and distribution systems throughout the Deschutes River Basin. Irrigation districts manage the reservoirs and divert available supplies during the growing season, thus impacting natural streamflows. The eight irrigation districts operating in the Deschutes Basin (Squaw Creek, Tumalo, Swalley, Arnold, Central Oregon, Ochoco, Lone Pine and the North Unit) provide water to 151,000 acres (Bureau of Reclamation, 1994b). Irrigators within district boundaries can be divided into two groups; (1) those who use water primarily for non-commercial farms (also known as hobby farms, urban-farming or urban-agriculture) and (2) those producing commercial crops and livestock. Hobby farmers raise a variety of livestock including llamas, emus, horses, cattle or buffalo on small land parcels, often less than 10 acres. They are not as concerned about profits as they are about lifestyle since it is alleged that they do not need a farm income to survive. In general, the majority of hobby farmers' income is derived from off-farm employment while commercial farmers generate most or all of their income with agriculture.

Table 1 outlines central Oregon irrigation district characteristics. Several of the irrigation districts contain primarily hobby farms. Most districts hold either a natural flow right to Deschutes River water or a right to water stored in reservoirs located near the source of the Deschutes River. Squaw Creek and Ochoco are exceptions. The Squaw Creek District diverts water from Squaw Creek into its main canal just south of Sisters, Oregon. Ochoco maintains Prineville Reservoir located southeast of Prineville, Oregon. This district is characterized by commercial agriculture whereas Squaw Creek distributes water to a combination of commercial producers and hobby farming. The remaining districts have rights to divert Deschutes River natural flow and(or) stored water at or near Bend, Oregon.

Tumalo, Lone Pine, Swalley, and Arnold irrigation districts comprise about 13 percent of the total central Oregon irrigation district acreage. All four of these districts distribute water primarily to hobby farms. The remaining two districts, the

Table 1. Summary of Central Oregon Irrigation Districts

District	Date of Water Right	Nature of Water Right	Acreage	Primary Uses
Ochoco	1914, 1916 and 1917	4 acre feet storage at Ochoco and Prineville Reservoir	20,100	Commercial
Squaw Creek	1885-1895	>200 cfs[a] natural flow from Squaw Creek	8,000	1) Urban 2) Commercial
Tumalo	1905, 1911	9.5 cfs Deschutes River natural flow, 110 cfs stored at Crescent Lake	8,100	Urban
Lone Pine	1900	≈ 38 cfs Deschutes River natural flow	2,400	Urban
Swalley	1899	120 cfs from natural Deschutes River flow	4,560	Urban
Arnold	1905	125 cfs from natural Deschutes River flow	4,400	Urban
North Unit	1913	430 cfs from Wickiup Reservoir and secondary 200 cfs from Crooked River natural flow	59,000	Commercial
Central Oregon	1900	300 cfs from natural flow and 200 cfs from 1907 water right from Crane Prairie Reservoir	45,000	1) Urban 2) Commercial
Total			151,560	

[a]cubic feet per second

Source: Central Oregon Watermaster, 1995 and Irrigation Districts

North Unit Irrigation District (NUID) and Central Oregon Irrigation District (COID), are the largest in the basin. Together they make up over two-thirds of the total irrigation district acreage in the region. COID contains a mix of commercial agriculture, primarily hay/cattle operations and hobby farms. NUID is dominated by commercial crop production.

The irrigation distribution systems in the Deschutes River Basin provide the means to irrigate tens of thousand of acres that would otherwise be dryland farmed or not farmed at all. Because water was plentiful in earlier years, fields were designed to accommodate relatively inefficient flood irrigation systems. Open, unlined canals were built to carry water from rivers and streams to farms. Today most canals remain unlined and flood irrigation is still widely used in the basin. In addition, the more water-efficient (but capital-intensive) sprinkler systems tend to be more common on hobby operations.

1.2 Problem Statement

The diversion of water to satisfy over 120,000 acres of crop production has a major impact on the Deschutes River's natural flow, especially in the middle Deschutes River (defined as the river stretch from the irrigation diversion points in Bend, Oregon to Lake Billy Chinook located approximately 50 miles downstream). As a result of these irrigation diversions, the aquatic environment, recreation uses, and water quality of the Deschutes River are affected.

A recent study of the upper Deschutes River quality revealed that temperature and pH levels were high during summer months (Bureau of Reclamation, 1993b).

Poor water quality is believed the result of low river flows, high ambient air temperatures, lack of riparian vegetation, the existence of agricultural return flow, and excessive growth of aquatic vegetation during summer. Reservoir releases keep flows high for river portions above the city of Bend, which helps alleviate some of the problems, but beyond the irrigation district diversions in Bend the reservoir releases are not enough to meet environmental needs in the middle Deschutes River. It is the area below Bend that has significant water quality problems.

One way to alleviate low flow problems in this area is to reallocate water from agriculture to instream uses. Water is diverted near Bend for both commercial and hobby farms, either of which could provide water for instream flows in the Deschutes River. Particular focus here is on potential shifts from commercial farms, recognizing that hobby farmers receive substantial utility from being involved in agricultural activities and would likely have a higher reservation price for their water rights. Testing this proposition is beyond the scope of this thesis.

In addition to direct transfers from agricultural use, another potential source of water for instream flows is to reduce seepage losses in unlined canals. The Deschutes Basin is dominated by old lava flows and other porous rock structures. Canals that cross these areas can experience substantial seepage losses. Canal lining or piping would significantly reduce seepage, thereby making water available for direct transfer to instream flows.

1.2.1 Agricultural Water Transfers to Instream Uses

Because the Deschutes Basin often experiences low annual water supplies and because water is a very vital input to crop production and farm profitability in this region, a combination of on-farm water conservation and transfer agreements is one possible option for increasing streamflows.

In central Oregon most agricultural water market transfers are between irrigators within an irrigation district. Few transfers for instream flows have occurred. Oregon law states three ways water transfers can occur. Rights can be leased, sold, or gifted. Transfers through lease agreements as opposed to gifting or selling rights is advantageous because leasing water rights does not break the appurtenance between the right and the land. Gifting does not provide monetary compensation to the rights holder and selling rights eliminates the possibility of future water use on the original right holders' land.

Before any lease agreements can be made, water must be available for transfer. Because irrigators in this region generally use most of their annual allotment (and must use all of it once every five years under the prior appropriation doctrine), water could be freed either by 1) fallowing land or producing non-irrigated crops and transferring the associated right, 2) switching to crops that require less water or 3) conserving water by increasing production and(or) delivery efficiency and thus complying with Oregon's allocation of conserved water program (ACWP) (ORS 537.455-.500)[2]. The ACWP allows land to be maintained in irrigated production while

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[2]All Oregon Revised Statutes are located in State of Oregon Legislative Counsel Committee, 1993.

transferring a portion of conserved water to another use. In return for retaining possession of the irrigator's portion of the conserved water, the state gains the right to at least 25% of the conserved water to be used for instream flows. The state and right holders' share of conserved water are partially determined by the conservation project funding source. If more than 25% is subsidized by the federal or state government, the percent of water delegated to the state is set equal to the percent subsidized.

Because water is vital to agricultural production in central Oregon, irrigators considering water leases should first familiarize themselves with alternative irrigation technologies and associated water requirements for individual crops, soils, and slopes. Transactions costs limit the ability of individual farmers to gain the type of information necessary to make completely informed decisions, however. As the greatest water user of the Deschutes River, agriculture could also be the greatest supplier of instream flows but the two keys to moving water away from agriculture are the price paid for the lease and water availability. Irrigation water values are the basis for lease agreements. They can be either marginal values based on the value of each additional unit of water, or average values based on the total value of a quantity of water. Water can be valued on a crop-specific basis or calculated for a particular crop mix. Also, short or long term values can be determined (Gibbons, 1986). If economic values are available to NUID and COID irrigators, they will have essential information needed to negotiate lease prices.

1.2.2 Oregon Stream Protection

That the State of Oregon adopted the conservation program demonstrates how important managing stream and river flows is to the state's citizens. But passing stream related legislation is not the only way Oregon has shown concern for streamflows. Several agencies or groups have focused attention on the Deschutes River Basin in particular because of low river flows. The Bureau of Reclamation has developed a series of studies related to its Upper Deschutes River Basin Water Conservation Project (Bureau of Reclamation, 1993a; Bureau of Reclamation, 1993b; Bureau of Reclamation, 1993c). The Warm Springs Indians and the Environmental Defense Fund are studying ecosystem management in the Deschutes River Basin (The Confederated Tribes of the Warm Springs Reservation and The Environmental Defense Fund, 1994). The formation of the Oregon Water Trust, a nonprofit organization established to acquire and hold water rights for instream flows in the public trust, illustrates the public's interest in streamflow enhancement. This group as well as environmental groups, individuals or government agencies could potentially sign lease agreements that transfer agricultural water to instream uses.

1.3 Thesis Objectives

Economic factors will certainly influence irrigator's willingness to adopt water-conserving practices and lease their water. Irrigation systems, crop value, and initial water allotments will influence the value of irrigation water to irrigators and consequently the price lessors will need to pay. In addition to individual water rights, another potential source of water for instream flows is to capture the water lost in off-farm distribution systems (irrigation district canals). This research will estimate the value of water to commercial farmers with Deschutes River water rights and estimate the quantity of water irrigators would be willing to lease when faced with different lease rates. These issues are addressed by estimating the water supply curve for commercial farms in the Deschutes River Basin and comparing the cost of on and off-farm measures to conserve water.

1.4 Procedures

To complete the research objectives, the economics of producing commercial agriculture in central Oregon will be evaluated including production with traditional and water-conserving irrigation technologies. The value of water will be studied with farm budget analysis and mathematical programming. The following procedures will be used to achieve the research objectives:

a) Enterprise budgets for traditional and alternate irrigation management practices (those which demonstrate potential for water conservation and feasibility on major central Oregon crops) will be developed using MBMS, a budget generating software, based on information from irrigators, local agribusinesses and existing research.

b) The water management practices and crop rotations that maximize profit will be estimated for various annual allotment assumptions representing low, medium and high water years. GAMS, a mathematical programming software, will be used to solve the model. Water supply curves will be identified based on linear programming results.

c) The cost to lease water from farmers will be compared to the cost resulting from canal lining and piping based on previous projects in the Deschutes River Basin.

1.5 Specific Study Region

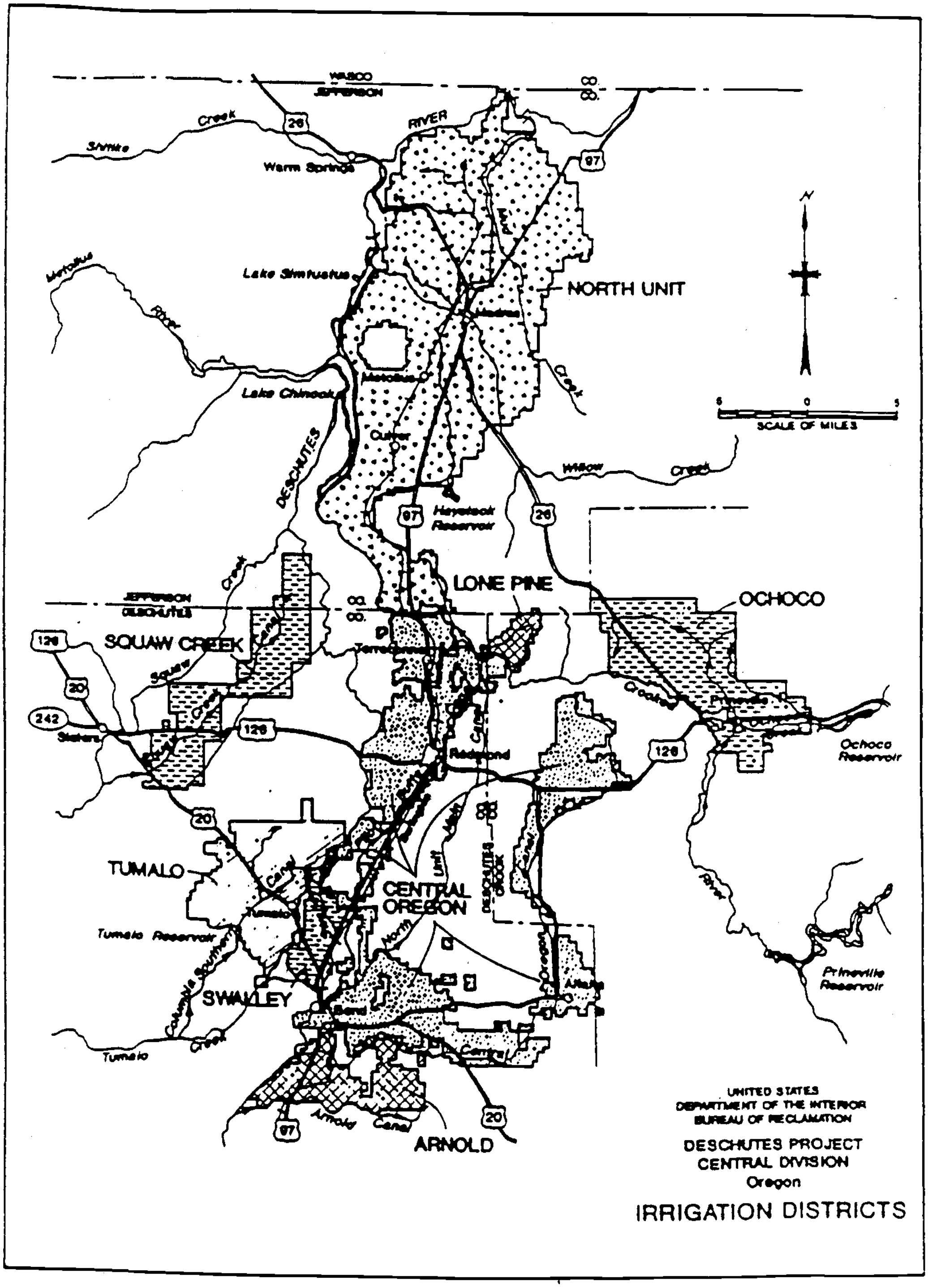
The NUID and COID contain most of the commercial agriculture irrigated from Deschutes River natural flow or storage near the head of the river. Because the Bureau of Reclamation (Bureau) built the NUID's storage and distribution infrastructure and the NUID is still repaying the cost, the district must operate under certain Bureau regulations. COID is not currently mandated by the Bureau because repayment has been completed for Crane Prairie Reservoir, a Bureau project. A number of small independent districts merged in the early 1900's to form COID. COID and the NUID hold unique water rights and function with different operational guidelines.

1.5.1 The North Unit Irrigation District

The most junior water rights among the Deschutes Basin irrigation districts are held by the NUID. That is, all other districts have priority to available stream water, leaving the junior right holder to the water that remains after the senior rights are filled. In addition to having junior rights, the NUID has also been affected by the ongoing drought in the region. The 1994-1995 reservoir storage level is one of the lowest the NUID has experienced (Schonneker, 1995). Even in high supply years some areas of the North Unit are fallowed and water is applied to less than the 60,000 acres for which the NUID holds rights.

The NUID diverts water out of Wickiup Reservoir to the Deschutes River, then out of the Deschutes River into its main canal at the city of Bend, Oregon. Figure 1 shows the main canal, reservoirs, Deschutes River and the NUID boundary. The natural river flow is altered year round as water is stored upstream, then released and diverted for irrigation during the growing season.

When first settled in the 1800's, most of the North Unit area was devoted to sheep grazing (Fisher, 1936). Grazing was gradually replaced by dryland wheat production (Van Winkle, 1950). In 1913, the State of Oregon and the Bureau of Reclamation began the first serious irrigation study in the North Unit area. Construction actually began on the North Unit project in 1938 and deliveries began in 1946 (Van Winkle, 1950). By 1949, full service to approximately 50,000 acres was available in NUID for Deschutes right holders. A pumping station on the Crooked River was built in the late 1960's to provide water during peak periods. The pumps also provide water for the Crooked River right holders to approximately 9,000 additional acres (Bureau of Reclamation, 1972). Today NUID manages Wickiup Reservoir (located southwest of Bend, Oregon) and Haystack Regulating Reservoir (operating south of Madras in Jefferson County, Oregon). In addition to the reservoirs, NUID also operates the pumping plant on the Crooked River, 66 miles of main canal, and 233 miles of laterals (Bureau of Reclamation, 1983). A number of



Source: Bureau of Reclamation, 1994b

Figure 1. General Map of Central Oregon Irrigation Districts

high value crops are produced in the NUID, including grass seed, peppermint, and specialty seed crops such as garlic and carrot seed. Wheat is also produced as a rotation crop. Irrigators in NUID have one of two water rights, either a Deschutes River water right or a Crooked River water right. All water rights held by irrigators with Deschutes River rights have identical origination dates with a more junior right assigned to all Crooked River right holders (NUID, no date). The water may be used on any portion of land with an individual water right but cannot be spread to other land or other uses without following the legal transfer procedures. Transfers must be approved by the NUID and the Oregon Water Resources Department (OWRD) (Oregon Water Resources Department, 1991b; NUID, no date).

1.5.2 Central Oregon Irrigation District

The Central Oregon Irrigation District distributes water to approximately 45,000 acres scattered in Deschutes and Crook Counties north and east of Bend, Oregon (Figure 1). The more southerly portions of the district near Bend are characterized by hobby farms. COID's commercial agriculture is concentrated in the northern sections of the district near Terrebonne, Oregon and Powell Butte, Oregon. The commercial farms consist mainly of grass and alfalfa hay operations with limited field crop production.

COID grew from the merging of several independent irrigation companies around the turn of the century. The district delivers water for two water rights, one dated in 1900 for 300 cubic feet per second (cfs) of natural flow from the Deschutes

River and another dated 1907 for 200 cfs of storage releases from Crane Prairie Reservoir.

Two main canals deliver water to COID farms. The Central Oregon Canal diversion is located a few miles above Bend on the Deschutes. It carries water northeast into Crook County. The Pilot Butte Canal begins at the North Canal Dam in Bend and runs northeast, terminating in the Lone Pine Irrigation District. Lone Pine receives its water through the Pilot Butte Canal (The Deschutes County Historical Society, 1985).

COID and NUID irrigators receive an initial allotment in the early spring of each year based on water availability in the region. The allotment is adjusted over the growing season as necessary. Irrigators must decide where their water will be the most beneficially applied and then adjust irrigation practices and crop rotations (when possible) based on the water allotment, projected yields, crop prices, soil moisture, weather conditions and a host of other factors. When adequate water is available, growers in the region apply on average 2 to 4 acre-feet of water per acre in agricultural production. In recent years, only about 1.5-2.0 acre-feet per acre was available to NUID growers (NUID, 1993). The 1995 allotment was initially only 1.4 acre-feet but was adjusted to 1.6 acre-feet per acre in June, 1995 (Schonneker, 1995). COID has a greater annual allotment than the NUID. In recent years, COID commercial irrigators have received approximately 2.5 to 3 acre-feet per acre (COID, 1994).

1.5.3 Water Distribution Systems

Irrigation District main canals pass through portions of the Deschutes River Basin that are characterized by volcanic origins. The region's lava plateau and areas of pumice and volcanic ash lose high volumes of water through seepage losses in unlined canals (Bureau of Reclamation, 1994b). Transportation losses significantly reduce the amount of water distributed to irrigators. Between 1989 and 1993, approximately 50% of the net supply available in NUID was lost to operational spills and transportation losses (NUID, 1993). Most of the loss was the result of canal seepage between the river diversion point and the farms. The net supply or total water diverted into COID's Central Oregon and Pilot Butte canals was 321,000 acre-feet with 71 percent delivered to the farms (COID, 1992). Piping or lining reduces transportation losses. Several canal lining and piping demonstration projects are ongoing in central Oregon (Bureau of Reclamation, 1993C). Widespread construction will probably not occur for several years or until additional research is completed and funding secured. During the construction of the irrigation systems, plentiful water supplies led to the construction of wasteful open canals and inefficient on-farm irrigation systems. Also, sprinkler and other technologies were not available because they were just-emerging technologies and (or) rural areas did not have electricity.

Until the recent introduction of sideroll sprinklers, gravity-fed flood irrigation dominated the relatively flat crop-producing areas of central Oregon. The traditional flood system utilizes an every-furrow technology to carry water during each irrigation set. Furrow irrigation is inherently inefficient[3]. Water must be overapplied to facilitate the movement of water over the entire furrow length because water will not progress from the top to the bottom of the field unless the infiltration rate is exceeded. Sprinklers can be operated more efficiently than the traditional furrow-irrigation, but sprinklers require substantial capital investment in pumps, mainline, and sprinkler line, as well as energy costs not included in furrow irrigation. Additional labor may also be necessary to operate sprinklers. Furrow irrigation is uncommon for pasture, grass hay and grain hay but can be used on all other crops in central Oregon given that the appropriate field characteristics, including slope and soil type, exist.

At the Oregon State University Central Oregon Agricultural Research Center (COARC) studies have been conducted to assess the water usage and environmental impacts of water-conserving irrigation technologies (Mitchell, Light and Page, 1993; Mitchell and Stevenson, 1994; Schattin, Farris and Mitchell, 1994). An economic analysis of the COARC research has not been performed to date.

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[3]Irrigation system efficiency is defined here as the percent of water applied that is available for crop uptake, or

$$\text{Efficiency} = \frac{G - DP - R}{G} \tag{1}$$

where G = Gross water applied,
DP = Deep percolation, and
R = Runoff.

1.6 Summary of Relevant Literature

A thorough examination and understanding of the issues relating to water flows in the Deschutes River requires reviewing three bodies of literature. The first involves Oregon's existing instream flow protection. A second important issue is Oregon's network of regulations involved in transferring water rights. This information establishes the legal basis and procedure for water transfers to instream flows in the Deschutes River. The third topic area pertains to farm-level economic analysis. Previous studies utilized various techniques to model farm-level economics and allocate water among crops, a task required for the completion of this project.

1.6.1 Instream Flow Literature

Oregon was one of the first western states to recognize the beneficial qualities of instream flows.. Oregon's first legislative acknowledgement occurred in 1955 with the passing of the State's minimum streamflow law (ORS 536.235, 536.310(7), and 536.325; Brandes, 1985). A minimum streamflow is a flow level adopted by the state following application by the Department of Environmental Quality or the state Department of Fish and Wildlife to support aquatic life, maintain recreation or minimize pollution (ORS 536.310(7), and 536.325). It is not a water right but an administrative device to maintain streamflows. The establishment of minimum perennial stream flows is a high priority of both the Water Resources Commission[4]

[4]The Water Resources Commission is a seven member citizen board appointed by the Governor. The Commission oversees the Oregon Water Resources Department (OWRD, 1994b).

(WRC) and OWRD (ORS 536.235). Instream flows may be reserved as minimum streamflows on any unappropriated stream flow (McKinney and Taylor, 1988).

In 1988, a specific type of minimum flow, a "Diack flow", was established based on the Oregon Supreme Court ruling in Diack vs. City of Portland (Oregon Water Resources Department, 1992). Diack flows are minimum water levels designated to support recreation, fish, and wildlife in state scenic waterways. OWRD may not issue permits for new water uses that would reduce flows below the Diack flow level in scenic waterways. These flow requirements are limited to state scenic waterways and are not required for federally-designated wild and scenic rivers. In some instances such as the Deschutes River, water was already appropriated below the Diack flow level. Not enough water remains to meet designated Diack flows. During the irrigation season, (mid-April to mid-October) the Diack flow in scenic waterways between Bend and Lake Billy Chinook is 250 cubic feet per second (cfs) and 500 cfs the remainder of the year (Central Oregon Watermaster, 1991). Although a minimum perennial streamflow level necessary to support these non-consumptive uses has been acknowledged, actual streamflow in the middle Deschutes River is about 30 to 50 cfs during the irrigation season[5]. Closer to Lake Billy Chinook, large springs and irrigation return flows enhance the river flow.

In 1987, the legal concept of an instream water right was created (ORS 537.332-537.360; OWRD, 1994a). An instream water right is a water right held in trust by the OWRD to maintain water instream for public use. It is regulated and

[5]Appendix A illustrates graphically the relationship between natural, current and recommended mean monthly flows for the Deschutes River from Bend to Lake Billy Chinook (data from OWRD, 1991a)

enforced like all other water rights except it does not require control or diversion of the water. There are three ways that instream water rights can be granted. For new rights, only the Department of Fish and Wildlife, the Department of Environmental Quality and Department of Parks and Recreation may apply to OWRD to establish an instream water right (OWRD, 1994a). Any individual may apply to the OWRD to convert an existing water right to an instream water right. In addition, a minimum streamflow may be converted to an instream water right subject to an involved application and review process. All rights converted to instream rights will maintain their priority date and may be owned by the applicant, purchased, leased or acquired by gift. Instream right application are subject to a technical review including an analysis of the application by OWRD and a public interest review.

The allocation of conserved water program (ACWP) statutes were also adopted in 1987 (ORS 537.455 to 537.500; Parrow, 1994). This legislation was enacted to modify the prior appropriation doctrine (which dominates water law in western states). Prior to the conservation law, there were no incentives for conservation because conserved water was forfeited if not used once every five years. The ACWP allows water users to conserve water without losing the seniority of their rights and designates a portion of the conserved water right to the state for instream flows. ORS 537.465 specifies that rights holders with certificates are allowed to participate in the conservation program, implying that holders of decreed water rights, or pre-1909 rights, are not allowed to participate. Some legislative effort is now ongoing to make pre-and post-1909 rights the same for a variety of purposes. Conserved water is considered "the reduction of the amount of water consumed or irretrievably lost in the process of satisfying an existing beneficial use achieved either by improving the technology or method for diverting, transporting, applying or recovering water or by implementing other approved conservation measures" (ORS 537.455(1)). The applicant must prove that water will be conserved and the OWRD must approve the project. Most right holders can use the conserved water on other land, or give, lease or sell it. Irrigators operating on a Bureau of Reclamation irrigation district such as the North Unit may not irrigate land that does not already have a water right, however. The NUID irrigators' portion of the conserved water could be leased or sold to other irrigators to be used on land with an existing water right within the district or, with the irrigation district and Bureau's approval, transferred to other uses inside or outside the NUID such as instream flows.

The conservation program has not been active. As of July, 1994, the OWRD had received only two requests for allocation of conserved water. Both were withdrawn prior to completion of the review process (OWRD, 1994a). The inactivity of the program may be partially credited both to the program design and interpretation by rights holders. The program is designed such that a portion of a water right is permanently given to the state. This may be viewed by rights holders as a loss of a property right, a right which they may not be willing to surrender. Also, the application process for this program requires that water rights be reviewed and water uses monitored to determine the amount of conserved water applicable to the program. This could result in some discrepancies between rights holders and the State of Oregon.

1.6.2 Water Transfers in Oregon

In Oregon, certificated[6] water right holders may change the use, point of diversion or place of use without losing their water rights' priority date as long as the OWRD grants permission (Kraynick, et.al, 1983; ORS 540.520 to 540.578). An application must be filed in accordance with ORS 540.520 and ORS 540.530. Upon receipt of a transfer application, the OWRD is required to inform the public of the proposed transfer by publishing the request in a local newspaper. If a protest against the transfer is filed, or if the OWRD believes the transfer may injure other rights holders, a hearing is held to discuss the application. The law currently states that both certificated rights and post-1909 water rights may be transferred. Rights dated before the 1909 Water Code was enacted are a right to use water but they do not have a certificate and are therefore not a "water right" (Kraynick et al., 1983). Efforts to change ORS 540.510 to give all rights the same transfer status surfaced during the 68th Oregon Legislative Assembly in 1995 with HB 2184. This bill waives the notification and waiting requirements of ORS Chapter 540 for temporary transfers of the place of use for short periods (less than five years).

The OWRD recently initiated a simplified process for temporarily converting existing water rights to instream use by developing a "Short-Term Water Right Lease Agreement" (OWRD, 1995B). Certified or decreed surface and stored water rights may be leased up to two years. The lease is renewable. Also, stored water rights

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[6]Since 1909, a certificate has been issued with each new water right granted. Rights prior to 1909 can be decreed or declared legitimate by a court order. If rights do not have a certificate and are not decreed, they are not legally recognized.

with permit status are permissible. Unlike a long-term lease or lease agreements over two years, this process does not require the issuance of a new certificate. The water right does not change but the temporary change in use of the water is noted by the OWRD. Water conserved under the ACWP program is eligible for the short-term lease agreement.

Transfers within an irrigation district do not involve the lengthy process that out-of-district transfers involve. Intra-district transfers in the COID, for example, require only the notification and approval of the COID. Water right transfers involving Bureau of Reclamation irrigation districts are generally treated the same as other transfers except that in addition to the approval of the OWRD and the district, the Bureau must also approve all transfers. The Bureau constructed the irrigation district infrastructure for the purpose of providing irrigation to the land. Any transfer out of a Bureau district would essentially break the contract. The Bureau must determine if the district needs are satisfied before approving a transfer. As of April 1995, the Bureau office in Bend has not been approached with a proposed transfer from the NUID to Deschutes River flow (Boyer, 1995).

A final important Oregon statute related to water transfers is ORS 537.390. Although its original purpose may have been to discourage speculation (Kraynick et.al., 1983), this statute may impair some water rights transfers because it limits the value recognized for water rights. It states that "...no value shall be recognized or allowed for such rights in excess of the actual cost to the owner of perfecting them..." (ORS 537.390). To date this statute has not hindered transfers because the market aspects of water transfers in Oregon are not monitored and no provisions exist to enforce this statute.

1.6.3 Previous Research

Related professional literature has focussed on a number of modelling methods to evaluate farm-level production economics and allocation of irrigation water given a particular set of assumptions. Previous studies ranged from a simple one-crop scenario to a complex multi-crop rotation with several technology choices and resource limitations to evaluate optimum crop mixes, resource allocation, and farm returns. The difference between each method is associated with the data available and the research objectives. Previous research has commonly assumed that profit maximization is the producer's goal. While each farmer has a unique set of objectives they wish to accomplish which may or may not include profit maximization, this is arguably a valid objective.

Crop simulation models have been used extensively to study irrigation water allocation. An example of a single crop study using crop simulation is Zavaleta, Lacewell and Taylor (1980). This study addressed irrigation management that maximizes net returns per acre of sorghum on the Texas High Plains by integrating climatic conditions, soil properties, agronomic characteristics, and production decisions. The optimal irrigation technology and rate of water applications were determined using a dynamic model which allows the intra-seasonal reallocation of water based on environmental and economic conditions. Results from deterministic and stochastic weather patterns were compared. If perfect knowledge of all economic, climatic, and institutional conditions are known at the beginning of the simulation (deterministic case), net returns are greater than in the stochastic situation. Water use was greater in the stochastic case. By assuming unlimited water supplies, this study is not directly applicable to crops produced with the limited water supplies found in the West.

In Harris and Mapp (1986), a crop simulation model was designed specifically to analyze water-conserving irrigation systems. Risk-efficient irrigation strategies for grain sorghum producers in the Oklahoma Panhandle were identified by generating a growth simulation model over twenty-three years of uncertain weather conditions and using stochastic dominance. This study also assumed non-limiting water supplies. Six of the water-conserving irrigation strategies result in higher expected net returns than the traditional systems. Results also indicated that risk aversion in itself is not the reason irrigators use the traditional intensive irrigation practices but that low pumping costs are a possible explanation.

Another variation of crop simulation was presented by Talpaz and Mjelde (1988). This study developed optimal irrigation strategies for a fixed water supply by experimenting with corn simulation models to solve for the optimal irrigation timing and application rate for alternate weather years. One weakness of this study was that the acres to be irrigated were predetermined so only the net returns per acre are of concern. This optimization by experimentation study showed that irrigation timing is critical for net returns per acre as the crop required less water in the early growth stages than subsequent periods.

Mathematical programming has been extensively utilized when studying a multi-crop scenario where the reallocation of water among crops is possible. Mathematical programming includes dynamic, linear, and nonlinear programming either employed singly or combined. Mathematical programming not only allows for the determination of optimal (e.g. profit maximizing) resource combinations but also can endogenously generate a value for irrigation water.

Eckert and Wang (1993) used a linear programming model to show the farmer responses to changes in the availability of water supplies on a Conejos county, Colorado crop-livestock operation. Data from a farmer survey was used to approximate resource constraint levels. Resource constraints included pasture and crop acreages, labor, operating and borrowed capital, crop contracts, and water availability. Net returns and shadow prices for water were generated for low, medium and high-priority water rights with and without a groundwater supply. The higher the priority, the greater the water supply. As water availability declined, net returns dropped from $67 per acre with high priority rights and a groundwater supply to $13 per acre for low priority rights with no groundwater source. Shadow prices for surface water varied by month and ranged from $2.25 to $1300 per acre-inch depending on water right priority. Lower priority was associated with high shadow prices.

An example of a combined mathematical programming study is Yaron and Dinar (1982) who used a linear programming model to maximize a farm's income and a dynamic programming model to generate new irrigation scheduling activities based on the shadow prices of water in the linear programming model. The model was applied to cotton farms and demonstrated that altering irrigation management can increase income.

Other studies mix crop simulation with mathematical programming. Bernardo, et al. (1987) concentrated on the distribution of limited water with a two-stage model. First, yield responses to alternate irrigation management were analyzed with crop simulation. Next, the irrigation activities are entered into a nonlinear programming model (with nonlinear harvest and hauling costs) to solve for the maximum net farm returns. The result showed that in the particular study region, Washington State's Columbia River Basin, the opportunity exists for implementing water-conserving irrigation practices.

The previous research summarized here is a sample of the different ways farm production can be modelled. The modelling technique employed depends on the research goals and data available. In chapter two, the theory underlying the modelling techniques used in this research is outlined.

2. ECONOMIC THEORY

Economics can be defined as the allocation of scarce resources among competing uses (Nicholson, 1992). Economic theory helps in understanding how and why individuals make these allocation decisions. Though theory does not always predict actual decision-making, it often provides a close approximation. Economic theory and nonlinear programming are the principal analytical tools used in this thesis. This chapter reviews important aspects of economic theory that pertain to this study namely perfect competition, input substitutability, and water markets, as well as a discussion of mathematical programming.

2.1 Perfect Competition and Profit Maximization

The basic features of a perfectly competitive market are 1) a large number of independent buyers and sellers, 2) all firms producing a homogeneous product, 3) a demand curve that is perfectly elastic (firms are price takers), 4) ability by firms to freely enter and exist the industry, 5) profit maximization as the goal of each firm, 6) perfectly mobile factors of production, and 7) buyers and sellers have complete knowledge of market conditions (Koutsoyiannis, 1979). Real world markets seldom meet all the above conditions. Complete knowledge of market conditions is often impossible or costly to obtain. Also, goals other than profit maximization could be sought. A firm may want to minimize capital investments, minimize operating costs, achieve a constant production rate, maximize total revenue, reduce debt, expand the size of the business, or minimize income fluctuations (Naylor and Vernon, 1969;

Castle et al., 1987). Profit maximization and perfect competition are often used to symbolize firm activity because they make the economic problem much easier to analyze while maintaining the more important factors that influence economic decisions. Perfect competition and profit maximization are used in this study.

A firm's production decisions can be characterized by a production function (Henderson and Quandt, 1980)

$$F(q_1,\ldots,q_s,x_1,\ldots,x_n) = 0 \tag{1}$$

where q_i represents output and $i=1,\ldots,s$,
x_j represents input and $j=1,\ldots,n$.

The production function mathematically represents the efficient technological and physical possibilities available to produce the vector q of outputs. The assumptions underlying this production function are 1) it has continuous first- and second-order partial derivatives unequal to zero for all its nontrivial solutions (a mathematical constraint), 2) it is an increasing function of outputs and a decreasing function of inputs and 3) the function is regular strictly quasi-convex over a relevant domain (which ensures a unique solution).

Profit maximization can be expressed as total revenue less total cost, or

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

where Π is profit,
p_i is the price of q_i $\forall$ i,
r_j is the cost of input x_j $\forall$ j.

Inputs are combined to produce the profit maximizing level q_i based on technological constraints. Only certain combinations of inputs x_j are technologically feasible to produce output. This is illustrated in Figure 2 for one output, q_1, and one input, x_1.

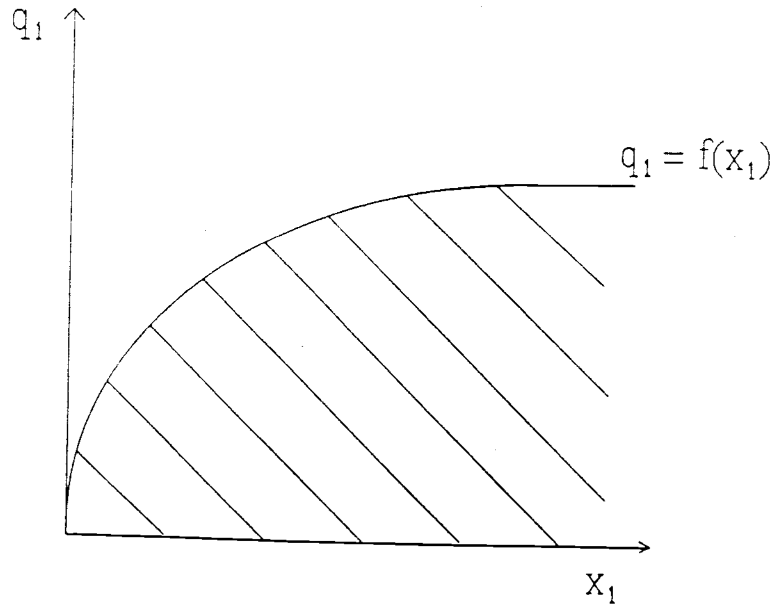

Figure 2. Production Function

The figure 2 shows a possible shape of a production function. All possible technological choices facing a firm are located in the shaded region. The upper boundary of the feasible region, or the maximum technologically possible output level for a given input level, is the firm's production function. Mathematically, profit maximization subject to technological constraints on the production function can be expressed as

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

where J is the constrained maximized profit,
λ is a Lagrange Multiplier, a variable which can be used to solve constrained problems.

The first order conditions required for a maximum are found by taking the partial derivatives of (3) with respect to q_i, x_j and λ $\forall$ i, j:

$$\frac{\partial J}{\partial q_i} = p_i + \lambda F_i = 0 \qquad i = 1,\ldots,s$$
$$\frac{\partial J}{\partial x_j} = -r_j + \lambda F_{s+j} = 0 \qquad j = 1,\ldots,n \tag{4}$$
$$\frac{\partial J}{\partial \lambda} = F(q_1,\ldots,x_n) = 0$$

assuming x_i, $q_j > 0 \; \forall$ i, j.

Manipulating this system of equations results in the optimality conditions for output as

$$\frac{p_i}{p_k} = \frac{F_i}{F_k} = -\frac{\partial q_k}{\partial q_i} \qquad i,k = 1,\ldots,s \tag{5}$$

Thus for every pair of outputs i and k, the rate of product transformation, $\partial q_k / \partial q_i$, must equal the ratio of their prices holding all other inputs and outputs constant. These conditions are characteristic of a profit maximizing firm.

2.2 Returns to Land

The standard profit maximization model outlined above is formulated from the prospective of the farm operator. This study focuses on water value and willingness to sell water in an open market. In the particular study area, farm land has virtually no value unless it has irrigation water rights because of low annual precipitation. The value of the land and hence the land rent is based on irrigation water availability and its value in the production of individual crops. Thus the annual land rent represents the annual productive value of water. The objective function for the landowner is

$$\Pi = LR + WS \tag{6}$$

where LR is returns to land from crop production and
WS is returns from water sales.

Assuming a long-run equilibrium situation, pure profits to the farmer are zero and LR and WS represents the residual return to the land after all other factors of production have been paid. How payments were calculated for the various factors of production is discussed in the next chapter.

2.3 Linear Programming

The first application of linear programming (LP) in farm management was reported by Hildreth in 1948. Since then, the use of LP in farm production has grown from simple, inflexible and deterministic models to more realistic and useful representations of agricultural production which allow nonlinear relationships to be modelled.

LP is a method of determining a maximizing or minimizing combination of activities that are feasible with respect to a set of fixed resource constraints (Hazell and Norton, 1986). LP provides an operational method for quantifying economic relationships. It does not say anything about the implementation of an optimal solution to a problem but simply derives optimal solutions given a particular situation. An LP problem is characterized by an objective function (which maximizes or minimizes a quantity) and resource constraints. In terms of agricultural production, the quantity could be net returns, costs, yields, or capital and the constraints may include limits on input levels, production contract constraints, or rotational constraints.

LP can be used to analyze economic decisions for perfectly competitive firms, given some specific simplifying assumptions. Hazell and Norton (1989) list the following as major assumptions in LP: 1) the objective function being optimized is following as major assumptions in LP: 1) the objective function being optimized is appropriate, 2) at least one constraint must not equal zero, 3) a finite number of activities and constraints is required, 4) all resource endowments, resource requirements, and objective function coefficients must be known constants, 5) fractional resource levels and fractional activity levels are possible, 6) units of the same resource or activity are identical, 7) additivity between activities must exist, meaning that contributions to the objective function or resource use constraints are summed to obtain total quantities, and 8) proportionality in production exists, meaning that resource use and objective function contributions are constant regardless of the level of the activity used. Proportionality presumes the existence of perfectly elastic output demand and supply schedules.

These assumptions represent a somewhat simplified view of the real world, necessitating a cautious interpretation of the results. In particular, the assumption of proportionality is sufficiently limiting that alternatives were needed to overcome this limitation. The specific issues and proposed solutions to the proportionality limitation are discussed later in this chapter. The other LP assumptions demand only a brief explanation to interpret their relationship to farm production.

The first LP assumption concerns the objective function. The objective function in this research is based on the assumption that farmers operate in perfect competition. Perfect competition does not exist in the real world. Some agricultural producers may violate the assumption of complete knowledge or profit maximization, but perfect competition provides a close approximation to farm operations and allows the analysis of important economic influences on a farm. The assumption of known constants. These and other data levels were estimated or set equal to averages based on available data in this research. This does not reduce the accuracy of the results but does mean that the results do not represent all farms in the region. The assumption of fractional activity levels may not be very realistic for farm production. This assumption assumes all farm activities are perfectly divisible thus allowing fractional activity levels. Generally field sizes are defined by a road, fence, tree line or irrigation system design. Farmers normally use field sizes to define the amount of a particular crop to produce. They may produce more than one crop on a large field but will not divide fields into relatively small acreages. Producing on small parcels presents many production related problems including difficulty in performing farming operations with large machinery and many irrigation systems are not designed to accommodate small crop acreages. Because farm size varies significantly from farm to farm, it would be impossible to accurately set field sizes to represent the study region. Therefore, results that suggest subdividing fields into two or more crops may not be practical to implement.

2.4 Substitution Theory and Marginal Analysis

The alternate combinations of inputs that produce a given level output Q are represented by isoquants Q_1, Q_2, and Q_3 in Figure 3 for marginal analysis. The slope of isoquant Q_3 shows the rate at which x_1 can substitute for x_2 in the production of Q while holding output constant at Q_3 along the isoquant (Koutsoyiannis, 1979).

Simplifying the original production function $F(q_1, \ldots, q_s, x_1, \ldots, x_n)$ to a single output Q and two inputs x_1 and x_2 results in a new function $Q = f(x_1, x_2)$.

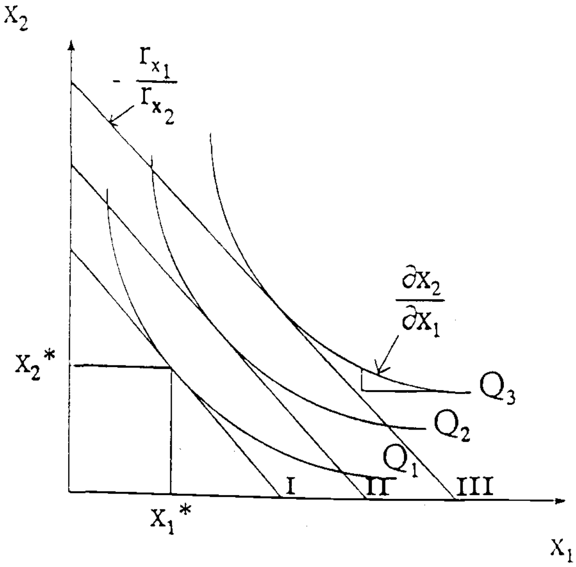

Figure 3. Production Isoquants for Marginal Analysis

Mathematically, the marginal rate of technical substitution (MRS) of x_1 for x_2 is defined as

$$-\frac{\partial x_2}{\partial x_1} = MRS_{x_1x_2} \tag{7}$$

In addition,

$$-\frac{\partial x_2}{\partial x_1} = \frac{\partial Q/\partial x_1}{\partial Q/\partial x_2} = \frac{MP_{x_1}}{MP_{x_2}} \tag{8}$$

Therefore, the ratio of the marginal products of the factors of production depicts the input substitutability. The slope of the budget constraints I, II, and III in Figure 3 is the ratio of input prices (r_x). Inputs x_1 and x_2 will be employed where the ratio of input prices is equal to the $MRS_{X_1X_2}$;

$$-\frac{r_{x_1}}{r_{x_2}} = -\frac{\partial_{x_2}}{\partial_{x_1}} \tag{9}$$

2.5 Substitution Theory and Linear Programming

Substitution of x_1 for x_2 in Figure 3 is continuous, meaning that along a particular isoquant, an infinite number of x_1 and x_2 combinations can be used to produce a constant output. In LP, inputs are not continuously substitutable. Resources required for alternate activities are known and substitutability between inputs is allowed based on predetermined resource requirements. The isoquant Q_1 in Figure 4a is a graphical representation of a classical LP isoquant. The right angled isoquant

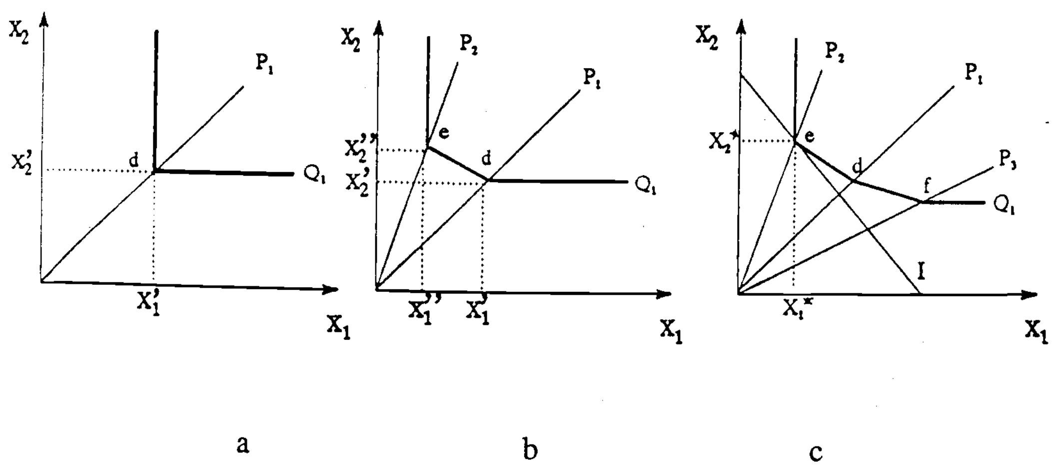

Figure 4. Linear Programming Isoquant and Expansion Paths

shows that no substitution is possible between inputs x_1 and x_2 to produce Q. A firm operating with fixed proportion will always operate along expansion path P_1 where the ratio of x_1 to x_2 is fixed. An expansion path is defined as a particular way of combining inputs in production (Naylor and Vernon, 1969). Any combination of inputs other than d on Q_1 is inefficient because the same output could be produced with fewer inputs by moving along the isoquant toward the vertex of $x_1'x_2'$. While a fixed proportions production function such as that represented by Q_1 in Figure 4a is useful when production processes are strictly performed with fixed proportions, limiting input combinations to a single ratio is not realistic is some instances. Inputs in crop production, for example, are generally not combined in a fixed proportion.

To move closer to a marginal analysis in which inputs are substitutable, alternate production processes can be added to the classic LP. This results in a expansion path, P_2 in Figure 4b, that represents a new independent production process now available to the firm. The isoquant from Figure 4a now has two vertices, d and e in Figure 4b. Two production processes, P_1 and P_2, are now available to produce output level Q_1. Using X_1 in excess of x_1' along Q_1 is again inefficient. The same is true for using X_2 in excess of x_2''.

An example will help to illustrate the addition of alternate input combinations to classic LP. Suppose Q_1 in Figure 4a represents 100 bushels of wheat, x_2 represents the cost of all inputs except water, x_1 represents water, and P_1 represents wheat production with flood irrigation. Point d is the predetermined combination of inputs necessary to produce 100 bushels of wheat using flood irrigation at a cost for all inputs except water of x_2'. If irrigators adopt another system, say sprinkler irrigation, which is less water intensive but requires more capital, they could produce 100 bushels of wheat with input combination $x_1''x_2''$ and production process P_2. In classic

LP, this substitution would not be possible because of the fixed proportionality requirement that forces inputs to be used in a single fixed proportion. By allowing alternate production processes such as P_1 and P_2, irrigators have the opportunity to substitute more irrigation capital investment for water. As more production alternatives are added, the LP isoquant begins to approximate a marginal isoquant (Figure 4c).

At points d, e or f in Figure 4c, a single activity (ie. irrigation technology) must be employed to produce output level Q_1. The budget constraint I is tangent at e, where $x_1^*x_2^*$ would be the optimal input combination to employ because the MRS of x_1 and x_2 is equal to the ratio of the input prices. If the budget constraint is parallel to Q_1 such that it is tangent to a flat segment, say ab, either activity P_1 or P_2 would be the optimal expansion path.

In reality, new technologies (such as more efficient irrigation systems) are not available in a continuous choice set (as depicted in Figure 3) but are discrete or "lumpy" in nature (as in Figure 4c). If P_1, P_2, and P_3 in Figure 4c represent alternate irrigation technologies, substituting inputs while holding output constant will produce a kinked isoquant. By allowing several alternate technologies in an LP model, there is a choice between expansions paths and a choice of limited substitutability. In fact, given the lumpy nature of irrigation technology choices, an approach such as that depicted in Figure 4c more accurately depicts the real world than the neoclassical approach in Figure 3.

2.6 Nonlinear Programming

Another water-conserving alternative for irrigators in central Oregon is to deficit irrigate, or apply an amount of water which is less than that actually required by the plant for maximum yield. This reduces crop yield but allows irrigators to make water available for sale in an open water market. Deficit irrigation could be modelled using the approach described above but the resulting isoquants would only approximate the actual set of substitution choices. For example, a farmer can now produce 100 bushels of wheat using one acre of land and two acre-feet of water, or two acres of land and one acre-foot of water, with many other potential combination available. The continuous set of water application level choices available with deficit irrigation is represented by a smooth isoquant. To accommodate deficit irrigation and the associated violation of the proportionality assumption, farm production can be modelled using nonlinear programming.

When the relationship between resource use and activity levels does not demonstrate proportionality or additivity, the problem becomes nonlinear. Nonlinear programming (NLP) allows the objective function or resource constraints to be nonlinear, permitting the proportionality and additivity assumptions to be relaxed. NLP does not require the proportionality requirements of constant returns to scale, a linear production function, or constant output prices, input prices, marginal cost or average costs. NLP refers to a problem with a nonlinear objective function and(or) nonlinear constraints thus the relationship between variables may be depicted by curves rather than straight lines in LP.

The basic mathematical formulation of nonlinear programming can be depicted as:

$$Z = \phi(X_1,\ldots,X_n) \tag{10}$$

subject to m technical constraints of the form

$$h_i(X_1,\ldots,X_n) \begin{bmatrix} \leq \\ = \\ \geq \end{bmatrix} B_i \qquad i = 1,\ldots,m \tag{11}$$

and to n non-negativity constraints

$$X_j \geq 0 \qquad j = 1,\ldots,n \tag{12}$$

where Z = the objective value,
ϕ = the objective function,
h_i = constraint functions,
B_i = the amount of the *i*th resource available,
X_n = is the level of the *n*th activity,
n = the number of *j* activities, and
m = the number of *i* resources

The objective function, ϕ, can be a linear or nonlinear function of activities X_n. The constraint functions h_i can also be linear or nonlinear. At least one activity must be greater than zero. With the exception of proportionality and additivity, all other LP assumptions must hold for NLP to produce an optimal solution. In this research, a nonlinear water-yield production function is used to allow deficit irrigation of crops. All other constraints are represented as linear relationships. NLP problems can be difficult to solve especially when several nonlinear functions exist. To increase the likelihood of finding an optimal solution with a complex NLP, nonlinear functions can be linearized, or constructed with a series of short linear segments. The function is no longer a smooth function and optimal solutions can only be found at the vertices of two adjoining segments. Given relatively small increments between vertices, linearizing a nonlinear function does not significantly alter the results. Details concerning linearizing a nonlinear function in this research are presented in the next chapter.

2.7 Water Market Theory

As water becomes more scarce, water users may face reallocation and conservation measures. Water markets, or an exchange of water rights in a market place, is one way to reallocate water among users. Increasing interest in water markets stems from the financial, environmental and political barriers blocking the development of new water supplies (Gould, 1988). Water markets can be seen as a special kind of commodity market. Water's unique physical characteristics and the current regulations governing water use can cause water markets to fail, or operate inefficiently.

2.7.1 Property Rights

A market economy is based on the concept of private property. In Oregon, water is owned by the state and water users hold a right to use the state's water. Without an efficient property rights structure, resources are not efficiently allocated in a market economy. Tietenberg outlines four characteristics of property rights that would produce efficient allocations in a well-functioning market economy. They are 1) universality, which implies that resources be privately owned and completely specified; 2) exclusivity, so all rewards and penalties accrue directly to the owner;

3) transferability, so that rights may gravitate to their highest-valued use; and 4) enforceability, which ensures that property rights are protected against encroachment by others. The owner of a well-defined property right has incentive to use the resource efficiently because a decline in the value of that resource will be a direct loss to the owner.

In Oregon, various barriers impede the transfer of water rights. Water does not fit well into the definition of well-defined property rights. In general, common property resources such as air and water can not be exclusive to a single owner and therefore cannot meet the exclusivity or universality criterias. Impacts on other rights holders may obstruct the transfers to higher valued uses because mitigation costs must be incorporated into the transfer. Market participants may have such imperfect information that a market can never develop. Common property, imperfect information, externalities and high transactions costs are all sources of market failure in a competitive market. Water markets are a means of allocating scarce resources but they are not necessarily efficient.

Despite these complexities, some water markets exist in western states. Colby, Crandall and Bush (1993) and Saliba and Bush (1987) both identify the increased use of water markets in the West. Water markets are a means of reallocating water away from those with low marginal net benefits to those with higher marginal net benefits thus increasing social welfare. For an efficient allocation of water, the net marginal benefit of an additional unit of water must be equal for all users and if an efficient allocation exists, net benefits will be maximized (Tietenberg, 1988). Even if an efficient allocation does not exist, moving water to those with higher marginal net benefits would increase society's well-being.

This research serves to alleviate some of the complexities of water markets. Specifically, it will provide information to prospective market participants about the value of commercial agricultural water and how it may change with water availability. The current water rights allocation system in Oregon does not automatically allow water to be used with its highest valued use. Water markets allow water to gravitate to higher valued uses resulting in an increase in social welfare.

2.7.2 Supply and Demand

A profit maximizing firm will continue increasing use of a factor of production so long as it adds more to total revenue than to total cost. Using an input to the point where the value of the marginal product[7] (VMP) is equal to the input price will maximize profit. It follows that the demand curve for a single input of a firm operating in perfect competition is its VMP curve (Koutsoyiannis, 1979). The total demand for an input can be represented by the horizontal summation of demand curves for each firm.

An example of the total demand for a single input X is presented in Figure 5. D_A and D_B represent the individual demand curves for X by A and B respectively.

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[7]The VMP shows the value of the output produced by an additional unit of input employed. The VMP is equal to the marginal physical product (MPP) multiplied by the price of the output (P), or VMP = MPP * P.

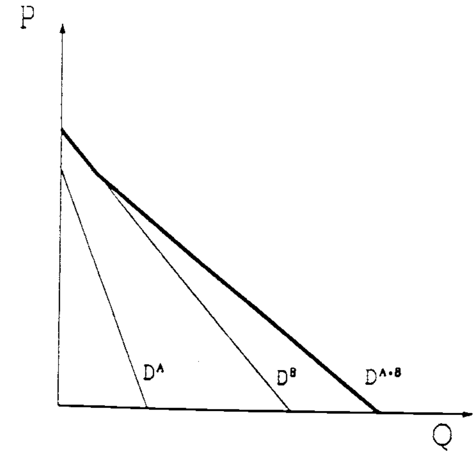
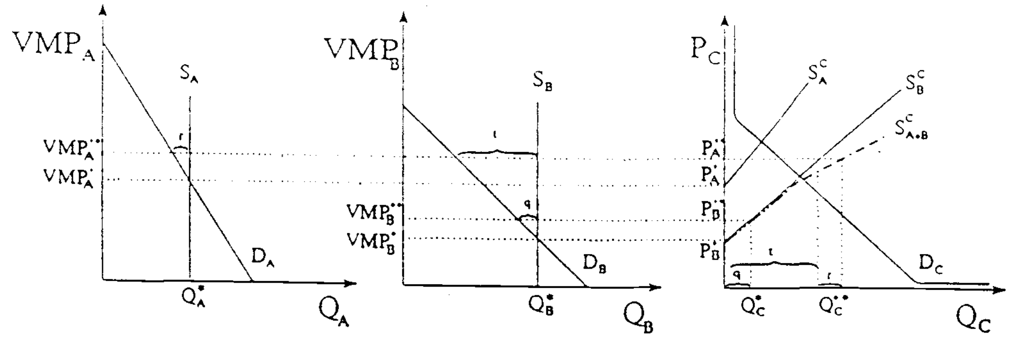


Figure 5. Horizontal Summation of Individual Input Demands

By adding the quantities of X at each price level for D_A and D_B, the total demand D_{A+B} is derived.

Figures 6a and 6b illustrate A's and B's supply and demand relationships for input X. S_A and S_B represent a perfectly elastic supply of X to A and B respectively where S_A is less than S_B. Regardless of price, the quantity of X supplied to A and B is fixed. D_A and D_B are the demands, or VMP's, for A and B, respectively, from Figure 5. Initially at VMP_A*,Q_A*, supply and demand for A are in equilibrium. The same holds for B at VMP_B*,Q_B*.

Firms A and B have a fixed supply of X to use in the production of output or sell to a third firm, firm C. Figure 6c illustrates firm C's supply and demand relationship for X. In this analysis, firms A and B are the only sellers of X and firm C is a single buyer of X. Firm C's demand curve for X is depicted as D_C in Figure 6c. Firm C is supplied by A and B such that S^C_{A+B} is derived from A's and B's supply and demand relationships. Assuming the firms A and B are profit maximizers,



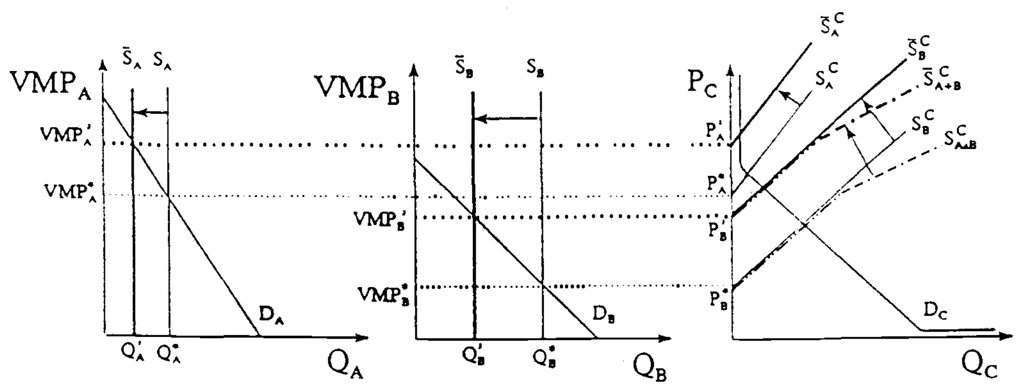
a b c

Figure 6. Demand and Supply Relationships with Two Sellers and One Buyer

they will require compensation to supply their fixed supply of X to firm C such that their profit is maximized. Firm B will begin to supply C with a minimum compensation of P_B* in Figure 6c, which is equivalent to the equilibrium VMP, VMP_B*, for firm B. The same holds for firm A except that the minimum price firm A would require before supplying X to C is higher than that for firm B. Firm C will have to compensate firm A with a minimum of P_A* before A will supply any X. As the supply of X to firm C increases, the amount of X firms A and B has available for production decreases because they are sharing their initial supply with firm C. If firm B sells a unit of X, say q, to firm C, firm B would require compensation of VMP_B**. This is equal to P_B** in Figure 6c. Every additional unit of X sold by B to C would result in an increase in the supply of X to C by one unit and the price required by B for the additional unit would be equal to the new VMP_B for X. Therefore the slope of C's supply curve for firm B is equal to the inverse of the slope of B's VMP curve with the intercept at the equilibrium point where $VMP_B* = P_B*$. C's supply curve for firm A intercepts the y axis at the equilibrium VMP where $VMP_A* = P_A*$ and its slope is equal to the inverse of A's demand curve.

The derived supply curve for firm C is found by summing the individual derived supply curves for A and B horizontally in Figure 6c. The derived supply curve, S^C_{A+B}, is the total quantity firms A and B would be willing to supply to firm C at each price level. At Q_C* all of X supplied to firm C would be supplied by firm B at a price of P_B**. At Q_C**, t would be supplied by firm B at a price of P_A** and r would be supplied by firm A at a price of P_A**.

As illustrated in Figure 6c, the amount of X supplied to firm C is directly related to A and B's supply and demand. In Figures 7a and 7b, the availability of X to A and B is reduced by about 50 percent to $\bar{S}_A$ and $\bar{S}_B$. Shifting A's supply curve



a b c

Figure 7. Adjusted Demand and Supply Relationships with Two Sellers and One Buyer

back to Q_A', the minimum compensation required for A to begin to supply firm C is now P_A'. By shifting firm A's supply curve back, at every quantity that firm A is willing to supply firm C, a higher price is required. The horizontal summation of the new supply curves for A and B shows a shift in firm C's supply curve in Figure 7c. The new supply curve is $\bar{S}^C_{A+B}$. Every point on this supply curve is above S^C_{A+B}. At every quantity supplied, firm C will now have to pay a higher price when the initial supply to firms A and B are relatively low. The opposite would occur if the initial supply of X to A and B was greater than S_A and S_B. The supply curve would shift down and the equilibrium price in Figure 7c would decrease.

This supply and demand relationship illustrated in Figures 6 and 7 is directly related to central Oregon water markets. This is illustrated by letting X be water, firms A and B be the NUID and COID, and firm C be instream water users. Initial water availability has a significant impact on the instream users supply curve for commercial agricultural water and lease price. Irrigator's water supply is directly dependent on natural flow and storage from previous snow-pack. Irrigator demand, or VMP, is based on the value generated by the use of water in each district. Instream user demand for commercial agricultural water is based on the current stream flow. In low water years irrigation supplies and natural instream flows generally will both be depressed. In high water years, irrigators will have more water available to them; their supply curve would shift out and they would be willing to lease their water at a lower price. At the same time the instream demand would be low because instream flows would be fed with high natural flows. To accommodate the variability in the instream users supply of irrigation water as demonstrated in Figures 7a, 7b and 7c, supply curves for several initial water availability levels were generated in this study. Analysis of instream demand was not included in this research. Details on the supply curve generation and other specific model information are presented in the next chapter.

3. MODEL DESCRIPTIONS

This chapter contains a specific description of the models and the underlying assumptions. The farm-model characteristics are outlined including crop rotations, water lease options, a description of each alternate irrigation practice, and crop production costs and returns. The nonlinear programming models objectives and constraints are explained with a series of equations in summation notation.

3.1 Specific Farm Models

Two farm production models were designed: one to represent a farm producing in the NUID and one to represent COID commercial farms. Three variations of each district model were constructed. They are explained in section 3.4.

Crops commonly produced on NUID farms include carrot seed, garlic seed, peppermint, wheat, and bluegrass seed. The crop mix for COID commercial irrigators includes alfalfa hay, grass hay, grain hay, pasture and peppermint. Agricultural production data for these central Oregon crops were obtained from central Oregon producers, Crook and Jefferson County extension agents, agri-businesses, and the respective irrigation districts. These data were used to compile enterprise budgets for each crop. The enterprise budgets[8] summarize economic costs and returns for one

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[8]Some of the enterprise budgets have been published by the Oregon State University Extension Service with descriptive text and machinery tables. Others are forthcoming. Appendices C through G contain forthcoming budgets in draft form for grass hay, grain hay and pasture. Published budgets include Turner and Butler, 1994a, 1994b, 1994c, 1994d, 1994e, and 1994f, and Turner and Bohle, 1995a, 1995b and 1995c.

common set of production practices given a set of farm-characteristic assumptions (ie. farm size, owned or leased equipment, cost of operating capital etc). Other combinations of inputs and operations were possible but the production methods outlined in these enterprise budgets were considered typical and representative of the region. Two budgets were necessary to represent the establishment and production costs of perennial crops. An establishment budget outlined the land preparation, planting, and first-year harvest period. A production budget showed operations that were representative of a typical production year.

Crop production data were organized with the Microcomputer Budget Management System (MBMS), which is a computer budget generator (McGrann, et al. 1986). MBMS computes variable costs (inputs, labor, machinery fuel and lube), fixed costs (depreciation, interest, land, and insurance), and net returns (gross income less total cost) based on production data and cost information. Production and cost data were collected in 1994 and 1995. Crop price and yield data represented typical or average levels for the region in recent years.

MBMS calculated variable costs based on interest rates, input prices, machinery assumptions, labor assumptions, and rates (speed) of operations. Interest on operating capital was charged based on the length of time between incurring costs and receiving income from the harvested crop. Interest was charged in perennial crop budgets on establishment costs which are not recovered during the establishment year by amortizing the unrecovered portion over the crop's production years. Machinery fixed costs were calculated by MBMS[9]. Irrigation system fixed costs were calculated externally. Interest cost (IC) on irrigation systems was calculated as:

$$IC = \left[\frac{PP+SV}{2}\right] * I \tag{13}$$

where PP = Purchase Price,
SV = Salvage Value, and
I = Interest Rate.

The interest rate used for this study was a borrowing rate of 8 percent. Depreciation (Dep) on irrigation systems was calculated using straight line depreciation, or:

$$Dep = \frac{PP-SV}{UL} \tag{14}$$

where UL = Useful Life.

A summary of the production costs, returns, and irrigation systems for the baseline budgets (budgets generated for each of the above crops with common, typical production practices and irrigation technologies) are presented in Table 2 for the NUID and Table 3 for COID. In the baseline budgets, the irrigation systems utilized by NUID irrigators included sideroll sprinklers (SP) (an elevated sprinkler system) and the traditional every-furrow (EF) irrigation (a gravity fed flood system in which water is run down furrows, or trenches, dug parallel at fixed intervals) with siphon tubes (S). In the COID baseline budgets, pasture was flood (FL) irrigated, meaning that supply ditches (the on-farm ditches which run from the irrigation district canals to the irrigated fields) empty onto the pasture without building deep furrows or using S

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[9]Repair, maintenance and depreciation costs are calculated by MBMS with procedures and formulas from the 1983 ASAE Yearbook (McGrann et al., 1986).

Table 2. Summary of Baseline Enterprise Budgets for Crops Produced on the NUID in Central Oregon, 1994.

	Garlic Seed	Carrot Seed	Peppermint Estab.	Peppermint Prod.	Bluegrass Estab.	Bluegrass Prod.	Wheat
Baseline Irrig. System[a]	SP	SP/EF-S[b]	EF-S	EF-S	EF-S	EF-S	SP
Total Irrig. Sets	11	13	12	15	12	6	6
Total Irrig. Applied (inch)	25.5	35.5	39	45	53	40	18
Yield (Unit/acre)	17,000 lb	400 lb	60 lb	75 lb	800 lb seed 1 acre straw	1,000 lb seed 1 acre straw	110 bu
Price ($/Unit)	.14	6.00	16.00	16.00	1.00 seed 10.00 straw	1.00 seed 10.00 straw	3.75
Variable Cost[c] ($/acre)	1,424	964	1,014	691	625	576	296
Fixed Cost[c] ($/acre)	237	231	196	223	177	162	140
Total Cost[c] ($/acre)	1,192	1,195	1,210	914	801	738	436
Net Returns ($/acre)	1,188	1,205	-250	286	7	272	-23

[a] Although other systems may be in operation, these are commonly used and are considered the baseline systems
[b] In the baseline carrot seed budget, carrot seed is sprinkler irrigated in the fall and furrow irrigated in the spring
[c] Includes a $15 per hour charge for owner labor and $100 land charge. All baseline crop budgets except wheat include a variable water charge for irrigation system equipment. The wheat budget contains a flat water fee and irrigation system equipment is included in the land charge.

Table 3. Summary of Baseline Enterprise Budgets for Crops Produced on COID in Central Oregon, 1994.

	Alfalfa Estab.	Alfalfa Prod.	Grass Hay Estab.	Grass Hay Prod.	Winter Grain Hay	Peppermint Estab.[d]	Peppermint Prod.[d]	Pasture Estab. Yr 1	Pasture Estab. Yr 2	Pasture Prod.
Baseline Irrig. Systems[a]	SP	SP	SP	SP	SP	EF-S	EF-S	FL	FL	FL
Total Irrig. Sets	11	11	16	12	4	12	15	4	4	4
Total Irrig. Applied (Inch)	24	36	40	36	12	39	45			
Yield (Unit/Acre)	4.50 ton	5.50 ton	6.00 ton	6.00 ton	6.00 ton	60.00 lb	75.00 lb	5.00 ton	5.00 AUM 3.00 ton	8.00 AUM
Price ($/Unit)	80.00	95.00	75.00	75.00	75.00	16.00	16.00	75.00	15.00 75.00	15.00
Variable Cost[b] ($/acre)	502	440	458	383	339	1,014	691	387	185	79
Fixed Cost[c] ($/acre)	138	207	122	120	129	196	223	150	119	126
Total Cost[b,c] ($/acre)	640	647	581	501	468	1,210	914	519	302	201
Net Returns ($/acre)	-280	-124	-131	-51	-18	-250	286	-144	-2	-86

[a] Although other systems may be in operation, these are commonly used and are considered the baseline systems

[b] Includes a $15 per hour charge for owner labor. Also all budgets contains a flat water fee except mint which includes a variable fee.

[c] Includes a $90 land charge except mint which contains a $100 land charge. All COID baseline crop budgets assume irrigation system equipment costs are included in the $90 land charge except mint. In other budgets, a charge for the irrigation system is included in addition to the land charge.

[d] Peppermint establishment and production in COID requires sprinkler irrigation. The published baseline enterprise budgets are typical of the NUID and include furrow irrigation.

or gated pipe (G). SP was used to irrigate the remaining crops. The number of irrigation sets and the application levels in Tables 2 and 3 represent typical levels in recent years as reported by interviewed farmers. Some of the irrigation levels are in excess of the recent annual per acre allotments. For example, irrigators in NUID have received about two acre-feet but the typical application for peppermint production is nearly four acre-feet. The duty of the NUID Deschutes rights is over five acre-feet. Irrigators may irrigate land with a water right up to the duty of the right. Other land will probably be fallow and(or) other crops in production must be less water intensive if crops such as peppermint are produced. As long as land is irrigated once every five years, the beneficial use requirement underlying Oregon water rights is met.

To investigate the economics of water conserving irrigation systems, additional budgets were generated for each crop. They incorporate alternate irrigation practices and crop rotations. The alternate irrigation practices were chosen based on the availability of previous irrigation system efficiency research and water conservation potential. Also, only those systems that showed technological feasibility for central Oregon agriculture were included. The new budgets included all production operations and associated costs outlined in the baseline budgets except irrigation operations were modified for each alternate irrigation system and land preparation costs were modified when necessary for specific crop rotations.

In addition to EF, SP and FL systems, a total of six other primary irrigation-technology/management-strategies were considered. Variations of some of these irrigation schemes were also considered. The primary water-conserving irrigation alternatives included (1) alternate furrow (AF), (2) alternating furrow (AGF), (3) surge furrow (SF), (4) center pivot (PV), (5) laser levelling (LL), and (6) irrigation scheduling (IS). Employment of these alternatives reduces the water application required to meet crop needs by reducing deep percolation and runoff. When water is applied in excess of evapotranspiration[10] (ET), the excess leaves the field as runoff or percolation below the root zone. These strategies help close the gap between water applications and crop ET requirements. Though not widely implemented in central Oregon, they have been shown to conserve water with minimal yield impacts (Shock et al., 1994; Mitchell and Stevenson, 1994; Mitchell et al., 1993).

AF involves irrigating every other furrow throughout the season, resulting in water never flowing down half the furrows. Irrigating every other furrow widens the application spacing and causes the water to move laterally rather than down. The result is reduced deep percolation and runoff. Water-use efficiency increases as a greater percent of the water applied is used by the plant (Crabtree, et al, 1985; Stone et al., 1979; Grimes et al., 1968).

When irrigating with AGF, every other furrow is irrigated during an irrigation set and those furrows not irrigated in the current set are irrigated in the following set (Mitchell et al., 1993). AGF is similar to AF in that it also reduces deep percolation and runoff and increases water-use efficiency. By alternating the furrows that are irrigated each set, water is applied to both sides of each crop row following two irrigation sets. This can not only reduce total water application levels but also increase the lateral movement of water (Mitchell et al., 1993).

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[10]Evapotranspiration is the combination of evaporation from the soil and plant transpiration, or the amount of water the plant requires to grow.

SF involves use of an automated valve to apply water intermittently in surges (Miller et al, 1991). After a surge of water is applied to a furrow, the standing water is allowed to drain. The next surge of water does not filter into the soil as rapidly as the first causing the infiltration rate to decline at the top of the furrows. This reduces deep percolation that commonly occurs at the top of the field under furrow irrigation and increases irrigation efficiency (Mitchell and Stevenson, 1994).

PV distributes water through a linear overhead sprinkler system that rotates in a large circle (Bailey, 1990). This system tends to apply water more efficiently than furrow systems because water is distributed more evenly and the excess water application that furrow systems require to move water across the entire field length is not required. PV is common in COID for hay crops although this system did not appear in any baseline budgets. A single center pivot can irrigate about 135 acres. More than one crop may be produced under one center pivot. In this research, crop acreages are not defined by the size of the irrigation system. Actual farm crop rotations will reflect the irrigation systems as well as field sizes on the farm.

The next two basic alternatives evaluated are not irrigation technologies but a means of improving the efficiency of existing irrigation systems. These practices, combined with an irrigation technology, can reduce the amount of irrigation water required to meet crop needs. The first management technique involves levelling fields to reduce the chance of uneven water distribution and the need to over-water parts of a field to gain a minimum application over the entire field. Levelling fields allows a more uniform distribution of water on an even surface when water is applied with any irrigation technology by eliminating low and high points on a field. To improve the level of accuracy, a laser can be used to determine slope uniformity when levelling a field, hence the term laser levelling, or LL.

Gross irrigation applications can also be reduced by monitoring the soil water content and crop ET to schedule irrigation sets (IS) (Walker and Skogerboe, 1987). One means of monitoring soil water content involves placing soil probes in an irrigated field and using a meter to read the water content of the soil. This practice combined with monitoring crop ET can help irrigators optimally time irrigation sets. IS can increase irrigation efficiency by providing the irrigator with pertinent information regarding the optimal irrigation timing and application level necessary to satisfy plant water requirements.

With the exception of SF, all other furrow systems could be operated with either gated pipe or siphon tubes. SF requires gated pipe due to the intermittent application of water directed by a pre-set surge unit. Siphon tubes must be individually submerged in the supply ditch and one end placed at the top of the furrow creating a suction-effect to move water out of the ditch onto the field. SF using siphon tubes would require a tremendous amount of labor to continuously place and remove siphon tubes throughout an irrigation set. Gated pipe is a plastic pipe located on the surface of a field along the top of the furrows that disperses water into individual furrows through gates or openings in the pipe. The gates can be adjusted for a range of application rates. Using gated pipe may reduce seepage from the supply ditch because water is piped rather than allowed to flow through an unlined ditch. It was assumed that water application would not change as a result of using gated pipe versus siphon tubes with EF, AF, or AGF.

The last variation to the primary systems was the addition of a pump back system (PB) to each furrow technology. Enough water must be applied with any furrow system such that the bottom end of the furrows receive adequate water. To accomplish this, water is over-applied to facilitate the movement of water to the lower end of a field. Some water does not infiltrate the soil and leaves the field as runoff. The efficiency of a furrow system can be increased by collecting this runoff and redistributing the water. A ditch constructed along the bottom of the field collects the runoff and accumulates it in a pond. The water can be pumped from the pond and reapplied to crops. If SP and PV systems are operated properly, substantial runoff will not occur and therefore the addition of a PB system is not appropriate for these systems.

Replacing on-farm supply laterals with pipe could conserve water by reducing transportation losses, but this practice is not directly addressed in this model. The increase in efficiency resulting from piping supply ditches is partially represented by the use of gated pipe and sprinkler systems. The use of gated pipe eliminates the need for open ditches because the water is run through the gated pipe. Water must be pressurized for a sprinkler system to be used. Therefore, water is piped from the pump to the sprinkler or center pivot line. The conservation realized by piping water from a weir, the farm-delivery point on an irrigation district canal, to a pump for sprinkler irrigation or to the gated pipe for furrow irrigation is not captured in this model because of the extreme variations in cost and water conservation potential. Based on conversations with the Jefferson County Farm Service Agency, the agency responsible for cost sharing the adoption of irrigation conservation practices, the materials necessary, the acreage serviced by piping supply ditches from weirs to pumps or to gated pipe and the increased efficiency varies significantly for each farm (Brown, 1995). Therefore, estimating an average cost per acre and an average level of water conservation realized by eliminating open on-farm supply ditches and piping water through PVC pipe was not feasible.

Lining and piping irrigation district canals was addressed externally of the NLP model. Lining and piping district canals would reduce deep percolation losses between the Deschutes River and the farms diversions. The Bureau of Reclamation worked with irrigation districts in central Oregon to study various canal lining methods and associated costs. The Bureau divided each district canal systems into over 40 individual lining or piping projects. Results of the study appear in Table 4 for the North Unit and Table 5 for Central Oregon Irrigation District. The model in this research was not optimized on the cost and water savings resulting from lining district canals. The results (the price profit-maximizing irrigators could require to lease their water) are compared to the Bureau of Reclamation's cost-effectiveness estimates to line and pipe district canals. This provides a comparison of the price external users could face when leasing water from irrigators versus the price they could face if they lease water saved as a result of lining district canals.

Table 6 contains an outline of the water use assumptions, fixed costs and labor requirements for each primary irrigation system and related feasible variations. Labor requirements were based on estimates provided by agricultural producers and extension agents. Hired labor, charged at $7 per hour, was used for sprinkler irrigation. All other systems were managed by the owner/operator. Owner labor was charged at $15

Table 4. Central Oregon Irrigation District Cost Effectiveness Analysis

District	Feature	Main Canal	Annualized Construction Cost	O & M Cost	Water Saved	Cost per AF Saved
1. COID	Smith Rock grp #2 2A	CO	$ 15,880	$ 1,000	600	**$ 28**
2. COID	pipe lateral F	PB	166,101	2,818	2,700	**32**
3. COID	O'Neil Re-Reg #1	CO	284,255	71,600	11,000	**32**
4. COID	lateral E	CO	1,351	541	50	**38**
5. COID	lateral F-2	CO	16,178	6,473	550	**41**
6. COID	lateral A	CO	30,039	12,020	1,020	**41**
7. COID	lateral P	CO	25,664	10,255	870	**41**
8. COID	lateral E	PB	30,408	12,167	1,030	**41**
9. COID	lateral G	PB	16,876	8,752	570	**41**
10. COID	lateral H & H2	CO	36,461	14,590	1,230	**42**
11. COID	lateral A-1, A-2	CO	27,031	10,816	910	**42**
12. COID	lateral J-9	CO	38,373	14,554	1,220	**42**
13. COID	lateral I	CO	126,152	60,479	4,210	**42**
14. COID	lateral F	CO	11,439	4,577	380	**42**
15. COID	lateral D	PB	12,656	5,064	420	**42**
16. COID	pipe lateral H	PB	162,343	3,295	2,400	**45**
17. COID	lateral B & B2	PB	150,310	60,145	5,100	**50**
18. COID	main canal A	PB	461,516	184,672	12,710	**51**
19. COID	pipe lateral C	PB	248,072	6,000	3,810	**64**
20. COID	lateral C	CO	37,211	14,890	1,250	**54**
21. COID	lateral C	PB	108,124	43,285	3,680	**54**
22. COID	lateral D - sub 123	CO	30,039	12,020	1,020	**55**
23. COID	main canal B	PB	278,206	111,322	6,850	**57**
24. COID	pipe lateral C	CO	91,696	3,602	1,310	**61**
25. COID	Equeat. Mdws Grp #2	CO	58,757	3,700	1,000	**62**
26. COID	pipe lateral B & B2	PB	372,109	9,000	5,310	**64**
27. COID	main canal A	CO	439,195	176,740	9,500	**65**
28. COID	lateral A	PB	156,893	62,779	3,960	**65**
29. COID	lateral H	PB	68,083	27,243	2,320	**66**
30. COID	main canal B	CO	704,913	282,055	14,160	**70**

Table 4. Continued

District	Feature	Main Canal	Annualized Construction Cost	O & M Cost	Water Saved	Cost per AF Saved
31. COID	main canal C	PB	177,420	70,993	3,500	**71**
32. COID	pipe lateral D - sub 123	CO	152,718	5,988	2,030	**71**
33. COID	lateral F	PB	76,818	30,737	2,590	**73**
34. COID	pipe lateral B	CO	74,234	1,796	480	**78**
35. COID	main canal C	CO	371,803	148,094	5,790	**90**
36. COID	lateral M M3-M6	CO	27,686	11,078	430	**90**
37. COID	lateral N	CO	15,498	6,200	240	**90**
38. COID	pipe lateral A	PB	421,723	10,200	4,220	**93**
39. COID	lateral O	CO	8,109	3,245	120	**95**
40. COID	pipe lateral L	CO	111,633	2,700	710	**105**
41. COID	lateral L	CO	41,531	16,618	650	**150**
42. COID	Jonson RD #16 Re-Reg	CO	16,674	525	100	**172**
43. COID	lateral B	CO	27,617	11,051	440	**176**
44. COID	Meadow Lark #16-A	CO	2,008,843	126,500	9,000	**237**
45. COID	Meadow Lark #16-C	CO	591,637	37,250	2,000	**314**
46. COID	Meadow Lark #16-B	CO	922,639	58,100	3,000	**327**

Source: Bureau of Reclamation, 1995

Table 5. North Unit Irrigation District Cost Effectiveness Analysis

District	Feature	Annualized Construction Cost	O & M Cost	Water Saved	Cost per AF Saved
1. NUID	pipe lateral 41	$ 88,449	$ 1,795	800	**$ 20**
2. NUID	lateral 34	18,178	7,274	660	**39**
3. NUID	pipe lateral 51	103,583	2,102	1,410	**41**
4. NUID	lateral 56-A	303	121	10	**42**
5. NUID	lateral 53-B	806	242	20	**42**
6. NUID	lateral 53-A	606	242	20	**42**
7. NUID	main canal O-1371	1,214,793	486,089	30,980	**55**

Table 5. Continued

District	Feature	Annualized Construction Cost	O & M Cost	Water Saved	Cost per AF Saved
8. NUID	lateral 32	3,956	1,583	100	**55**
9. NUID	lateral 58-B	11,537	4,616	290	**56**
10. NUID	lateral 63-A	21,937	8,778	550	**56**
11. NUID	lateral 55	17,202	8,883	430	**56**
12. NUID	lateral 63	59,387	23,783	1,480	**56**
13. NUID	lateral 60	9,229	3,693	230	**56**
14. NUID	lateral 53-B	31,047	12,423	770	**56**
15. NUID	lateral 56	4,843	1,938	120	**57**
16. NUID	lateral 52	18,824	7,532	460	**57**
17. NUID	lateral 51-B	10,255	4,103	250	**57**
18. NUID	lateral 53	4,938	1,975	120	**58**
19. NUID	pipe lateral 61	103,583	2,102	990	**58**
20. NUID	lateral 31	5,686	2,275	130	**61**
21. NUID	lateral 41.1	22,013	8,809	500	**62**
22. NUID	lateral 57	73,762	29,515	1,500	**69**
23. NUID	lateral 45	30,582	12,237	820	**69**
24. NUID	mail canal 1371-2378	933,434	373,505	18,850	**69**
25. NUID	pipe lateral 37	236,461	4,800	2,630	**70**
26. NUID	lateral 50	15,484	6,198	310	**70**
27. NUID	lateral 37	100,180	40,086	2,490	**80**
28. NUID	pipe lateral 43	191,940	3,898	1,730	**80**
29. NUID	mail canal 3023-3582	253,025	101,246	4,200	**84**
30. NUID	main canal 2376-3023	518,719	207,561	8,470	**86**
31. NUID	lateral 64	32,437	12,979	510	**89**
32. NUID	lateral 64-A	5,734	2,294	90	**89**
33. NUID	lateral 48	5,325	2,131	80	**93**
34. NUID	lateral 61-A	4,710	1,885	70	**94**
35. NUID	lateral 51	65,538	28,224	1,320	**106**
36. NUID	lateral 61	37,884	15,159	940	**108**
37. NUID	lateral 58, 58A, 58C	297,342	118,979	4,280	**115**
38. NUID	pipe lateral 58, 58A,	650,287	13,200	4,670	**126**
39. NUID	lateral 43	37,668	15,073	730	**152**
40. NUID	lateral 41	37,688	15,073	730	**173**

Source: Bureau of Reclamation, 1995

Table 6. Alternate Irrigation System Assumptions

System	Estimated Efficiency (Percent of Water Applied)[a]	Deep Percolation (Percent of Water Applied)[b]	Fixed Cost[c] ($/acre)	Labor Hours Per Set Per Acre
EF-S	50 %	25 %	2.16	.25
EF-G	50 %	22.5 %	9.41	.25
EF-PB	70 %	30 %	8.17	.05
AF-S	60 %	22.5 %	1.08	.17
AF-G	60 %	22.5 %	8.33	.17
AF-PB	75 %	25 %	8.17	.05
AGF-S	60 %	22.5 %	1.08	.17
AGF-G	60 %	22.5 %	8.33	.17
AGF-PB	75 %	25 %	8.17	.10
SF	70 %	17.5 %	12.95	.02
SF-PB	80 %	20 %	20.20	.02
SP	70 %	20 %	54.00	.50
PV	80 %	10 %	35.00	.01
FL	20 %	45 %	negligible	.0875
EF-LL[d]	55 %	22.5 %	15.66	.50
SP-LL[d]	72.5%	17.5 %	25.25	.25
IS	increased by 10% for each alternative	reduced by 5% for each alternative	1.86	negligible

[a] Efficiency is defined here as the percent of water applied that is available for plant uptake. source: Martin, et al, 1991; USDA Soil Conservation Service, Montana State University Extension Service, 1989; Miller, et al., 1991; Shock, et al., 1994; Miller and Shock, 1992; Henggeler, et al.; Merriam and Keller, 1978; Mitchell, Light and Page. 1993; Mitchell, and Stevenson. 1994.

[b] Source: based on Whittlesey et al., 1986; Brown, 1995

[c] Fixed cost assumptions are delineated in Appendix B

[d] LL is only allowed in combination with EF and SP baseline systems such that for each baseline budget with EF there exists alternative EF-LL and for each baseline budget with SP there exists alternative SP-LL.

per hour in the baseline budgets. The NUID and COID models were calculated for this level as well as alternate levels. Irrigation system fixed cost assumptions are outlined in Appendix B and are based on 1994 cost data provided by central Oregon irrigation businesses.

In reality, the efficiency of a irrigation system is based on several factors including soil type, slope and uniformity of fields, degree of management for individual systems, and climatic conditions. This study used a single efficiency and deep percolation rating for each system. Irrigation efficiency and deep percolation was assumed uniform across crops.

The flood system used for pasture irrigation in COID was assumed to be the least efficient technology/management strategy considered with an efficiency rating of only 20 percent. That is, 20 percent of the water applied to the field was assumed available for plant uptake. Flood allows for high amounts of deep percolation as water pools in low sections of a field and infiltrates below the root zone. High runoff also results with this system because fields may be sloped such that water can run off before it permeates the soil and(or) no borders exist to stop the water from running off the field.

The standard practice of irrigating every furrow was assumed to have an efficiency rating of 50 percent. AF and AGF utilized slightly less water than EF with an efficiency rating of 60 percent each. SF requires the least water to meet crop needs of any of the primary systems. The addition of a pumpback system to all furrow technologies improves efficiency. Both IS and LL were assumed to result in a small water savings[11]. PV was assumed to be a fairly efficient system in which only 20 percent of the water applied was not available for plant uptake.

3.2 Water-Yield Response

Several factors influence the amount of water that irrigators will apply to crops. Although the baseline budgets state a total water application level applied annually to produce each crop, in reality this will vary from year to year based on annual irrigation district water allotments, crop rotations, and climate. In this model, water was assumed to be the only variable input and other inputs such as fertilizer and pesticides were fixed at the levels reported in the baseline budgets. Water production functions were generated to show the relationship between water and yield with a computer algorithm written in GAMS programming language (a mathematical programming software) by Jeff Connor, a PhD candidate at Oregon State University[12]. This model used irrigation system efficiency and deep percolation to influence yield as a function of water applied. Specifically, it estimated the percent of a crop's maximum potential yield in response to a set of water application levels. Maximum potential yield was crop-specific. It was the maximum yield attainable when utilizing the operations in the baseline budgets with unlimited water supplies.

The output from this model was regressed to estimate a water-yield response relationship for each irrigation alternative considered. The production function

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[11]Based on personal communication with Jim Burr, retired Oregon Extension Agent

[12]Connor's model is based on a conceptual model by Warrick and Yates (1987).

estimates (regression output) for all irrigation schemes are summarized in Appendix H. Efficiency and deep percolation were held constant across crops.

Crop ET estimates for the central Oregon region were used to represent crop water requirements necessary to achieve maximum yield. Agrimet[13] averages were used for available crops. Crop ET's not generated by Agrimet were estimated by adjusting the Agrimet estimates for similar crops with input from Extension Agents, producers and the Agrimet consultant in central Oregon. Estimated ET values used in this study are shown in Table 7. The crop water application level data in the baseline budgets is not used because of the unknown efficiencies of the systems operated by the irrigators who helped construct the baseline budgets. The specific functional form of the water production function and how it was used in the NLP model is explained below.

3.3 Specific Nonlinear Farm Production Model

COID and the NUID were modelled as two independent models. The objective functions and constraints were entered as GAMS language and the models solved with GAMS software. The NUID and COID models were identical in their basic design but crops, farm size, irrigation district water charges and irrigation technologies differed between the districts.

[13]Agrimet ET values are generated using water use functions and central Oregon climate data by Martin Zimmerman, a consultant and former Extension Agent. These values are available via telephone and daily newspaper in central Oregon.

Table 7. Average Agrimet Crop ET in Inches

Crop	Ave. ET	Crop	Ave. ET	Crop	Ave. ET
Alfalfa Est.	34.5	Winter Grain Hay	17	Mint Prod. (NUID)	24.5
Alfalfa Prod.	34.5	Mint Estab. (COID)	26	Bluegrass Estab.	15
Pasture Estab.	31.5	Mint Prod. (COID)	24.5	Bluegrass Prod.	15
Pasture Prod.	31.5	Garlic Seed	18	Wheat	21
Grass Hay Estab.	34	Carrot Seed	15		
Grass Hay Prod.	34	Mint Estab. (NUID)	26		

Source: Agrimet, 1995 and earlier years, and County Extension Agents.

Irrigation choices in each programming model was limited to simple combinations of irrigation technologies and related practices. Although growers may adopt several new practices over time, initial capital investments will tend to limit the number of changes occurring at once. In the model, the following furrow irrigation alternatives could be adopted individually with gated pipe or siphon tubes, with or without a pumpback system and(or) IS: EF, AF, and AGF. SF also fit this scenario except that it required gated pipe to disperse water into the furrows. The sprinkler and flood systems, SP, PV and FL, were utilized individually or in combination with IS. LL was only added to the baseline systems, EF and SP.

Some systems or combinations of systems were deemed inappropriate for certain crops. For example, peppermint cannot be furrow irrigated in the Powell Butte, Oregon area of COID because it stresses the plants. Peppermint near Madras, Oregon in the NUID, however, is commonly furrow-irrigated. Feasibility is based on conversations with farmers and Extension Agents.

All feasible crop\irrigation technology combinations and associated production costs are outlined in Appendix I. Additional costs of production accounted for in the model but not included in these figures were owner labor, management (decision-making) and land. Owner labor was initially charged at $15 per hour. A sensitivity analysis of alternate wage rates was conducted. The model was recalculated for each owner labor rate. To capture a cost for management, a ratio of the weighted average net returns to the weighted average gross revenue across crops in the baseline budgets for each district was calculated. This ratio multiplied by the net returns for individual crops was presumed to represent costs charged by the farmer to cover risk and management[14]. Based on the assumption that farmers expect a higher return to their management activities with higher valued crops, this calculation for management costs allows variable returns to management that are directly related to the gross income of each crop. A land charge was not included in the models because the objective used in this research was to maximize net returns to land.

The basic model maximized farm net returns with the production of a specific crop mix, irrigation technology and yield levels without including a cost for land.

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[14] Risk and management charge calculations assumed pure profit, total revenue less the sum of all costs including land, are zero.

Land price is excluded because it is almost totally determined by the irrigation water available and its value in agricultural production. Hence including a land cost would result in a lower estimated value for water than is the case. In enterprise budgets, a land charge is generally represented either by the average lease rate for land in a particular region suitable for a particular crop mix or the sum of interest and tax charges which are based on the land's market value. If land was included in this model, the result would be an additional fixed cost uniform across crops. Therefore net returns would be reduced, producing crops would appear less profitable and water would be leased at a lower price. Maximizing returns to land assumes land costs are not covered and the net returns are available to cover costs associated with owning or leasing land. Land in the study region is used to produce both high and lower valued crops. If land were owned and a high valued crop was planted, a large return to the land would be expected. The opposite would hold for a lower valued crop. With a lease agreement, lease rates do not change as crop rotations change from low to high valued crops.

In summation notation, the profit maximizing objective function can be written:

$$
\begin{aligned}
\text{Max } \Pi_j = \\
&\sum_{c=1}^{n}\sum_{i=1}^{m}\sum_{a=1}^{14} [Q_{ciaj} * ((YIELD_{ciaj} * REV_{cj}) - Z_{ciaj} - MANG_{ciaj} - (L * LABOR_{ci}))] \\
&- [XW * R] + [LSW_j * LSPR] + \sum_{i=1}^{m}\sum_{a=1}^{p} [Q_{diaj} * GP * BU * 85\%] \qquad \textbf{(15)} \\
&+ \sum_{e=1}^{s}\sum_{i=1}^{m}\sum_{a=1}^{14} [Q_{eiaj} * DP * BU] \qquad \forall j
\end{aligned}
$$

where Π_j = annual net returns,
j = irrigation district where $j = 1,2$,

c = crop choices represented by a current crop and a previous crop where c = 1,...,n,
i = irrigation alternatives where i = 1,...,m,
a = defined percent of maximum yield where a = .35,.40,...,1,
e = subset of c, wheat production acres associated with wheat program, e = 1,...,s,
Q_{ciaj} = crop acres,
Y_{ciaj} = crop yield,
REV_{cj} = revenue per crop unit,
Z_{ciaj} = crop establishment/production cost per acre,
$MANG_{ciaj}$ = management and risk-bearing costs,
L = returns per hour to owner labor,
$LABOR_{ci}$ = total owner labor hours required per crop per crop year,
LSW_j = leased water in acre-feet per year,
LSPR = lease price per acre-foot,
DP = deficiency payment per bushel of wheat in wheat program,
BU = bushel of wheat,
GP = guaranteed payment per bushel of wheat in 0-85 wheat program,
XW = extra water available for purchase from irrigation district, and
R = price of water purchased over allotment.

Revenue was generated by producing crop c with irrigation technology i and yield a on Q acres and(or) leasing water. Crop establishment operations and related costs were dependent on the previous crop produced on a particular field. Crop choice c was therefore defined as a crop following a specific crop in rotation. Fallow acreage was treated as a crop that required no farming operations or inputs but a district water charge was assigned to fallow as well as producing acreage. Costs associated with crop production on previously fallowed ground were included in crop establishment operations.

The income generated per unit of crop produced (REV_{cj}) is outlined in Tables 2 and 3. Yield is defined as a function of water applied. Taking irrigation efficiency into account, a maximum yield can be produced by applying $\frac{1}{EFF_i} * ET$. Deficit irrigation causes a decline in yield to some level less than 100 percent when water is applied below crop requirements. A water yield response function was generated independently of the farm models using Connor's water production function algorithm. It was generated to accommodate deficit irrigation by calculating the percent of maximum yield associated with varying water application levels. The results were entered into the NLP models using a quadratic function:

$$PMY_{ia} = \beta 0_i + \beta 1_i W_{ia} + \beta 2_i W_{ia}^2 \tag{16}$$

where PMY_{ia} = percent of maximum potential yield,
W_{ia} = multiple of crop evapotransporation applied to crop,
$\beta 0_i$ = regression intercept,
$\beta 1_i$ = change in PY given W_{cia} , and
$\beta 2_i$ = change in PY given W_{cia}^2.

The quadratic functional form is common in water production functions and was used here because it explained the relationship between the independent variable W_{ci} and the dependent variable PMY_{cia} well. W_{ia} was defined as

$$W_{ia} = \frac{1}{EFF_i} \tag{17}$$

where W_{ia} = multiple of ET required to produce a percentage of maximum yield, *a*, and irrigation technology, *i*.

Water use for each activity was therefore defined as

$$WTRAPP_{cia} = W_{ia} * ET_c \tag{18}$$

where $WTRAPP_{cia}$ = water applied to crop *c* with irrigation technology *i* and percent maximum yield *a*.

The initial model formulation proved difficult to solve because of the nonlinear constraints used to address deficit irrigation. To deal with the solution problems, the nonlinear water-yield production function (16) was linearized by limiting the percent of maximum yield to 14 precise levels ranging from 35 percent to 100 percent with 5 percent intervals. This linearization did not substantially change the results because all nonlinear functions were monotonically-increasing functions of water use throughout their entire range. Linearizing these functions permitted the models to be solved using linear programming. Five percent yield intervals appeared to provide an adequate representation of the nonlinear water-yield relationship based on trials conducted by solving the model with 2.5 percent intervals and comparing the results to 5 percent yield intervals. The larger range did not reduce the accuracy of the results as the crop rotations were nearly unchanged and the yields varied only slightly. The lowest percent of maximum yield allowed was 35 percent. Lower yield levels could be ignored because farmers would lose less money by fallowing the land rather than reducing yields. Also the water-yield production relationship calculated with Connor's algorithm was considered less accurate at lower yield levels.

YIELD was calculated by multiplying PMY_{ia} by the maximum crop yield. The maximum yield was based on the crop yields in the baseline budgets which are summarized in Tables 2 and 3. $YIELD_{ciaj}$ * REV_{cj} resulted in the total revenue generated from crop sales.

Harvest and post-harvest costs such as seed cleaning and association fees can vary with yield. All harvest and yield-related post-harvest costs which appeared in the enterprise budgets as per-unit costs were adjusted with yield. It was not possible to accurately modify those not given on per-unit basis.

Addition revenues included income from leased water and income generated through the government farm programs. The NUID model was formulated assuming the farm had a 100 acre wheat base and no base for feed grains. Because wheat and barley are not commonly produced in COID, COID model was assumed to have a zero acre base for wheat and feed grains. Participating farmers receive payments based on the farm "base" operated by a particular farmer and their individual program yield[15]. Proven yield for wheat was set at 90 bushels per acre[16]. The amount of wheat produced on a farm participating in the wheat program is limited to the level of base acreage. If 85 to 100 percent of the farm base is planted to wheat, the grower receives a deficiency payment on 85 percent of the base acreage. The deficiency payment (DP) is set annually based on the difference between the national target price and the national average wheat price. In 1994, the deficiency payment was $0.61 per program bushel.

If less than 85 percent of the base acreage is planted, the farmer may participate in the 0/85 program. This program requires that at least 15 percent of the base acreage be fallow. A guaranteed payment (GP) is made on 85 percent of the fallow base acreage at a payment level which is determined at the beginning of the year regardless of the national average wheat price. The 1994 0/85 payment was $0.83 per program bushel. The 0/85 program is particularly attractive for this study because it allows farmers to fallow land and still receive a return on that land, while also freeing up water that can be used elsewhere on the farm or sold for instream use.

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[15]Program yield is determined for each participant by the Farm Service Agency, the agency that administers the United States Department of Agriculture wheat program.

[16]Based on information from the Farm Service Agency.

The wheat program acreage for the NUID farm was limited by (19) and the total acreage on the *j*th farm was limited to that of a representative farm operating in each district (20).

$$\sum_{d=1}^{t}\sum_{e=1}^{s} Q_{deij} \leq 85 \qquad \forall\ i, j \tag{19}$$

where d = subset of c, fallowed acreage associated with the wheat program.

$$\sum_{c=1}^{n}\sum_{i=1}^{m} Q_{cij} = A_j \qquad \forall\ j \tag{20}$$

where A = farm size in acres.

In the NUID, A = 500 and in COID, A = 300. To account for roads, ditches, and fences, one percent of the total acreage was assumed in continuous fallow (21).

$$\sum_{f=1}^{n}\sum_{i=1}^{m}\sum_{a=1}^{p} Q_{fiaj} \geq A_j * .99 \qquad \forall\ j \tag{21}$$

where Q_{fiaj} = fallow acreage.

Water rights holders in each district receive an annual water allotment. The total water applied to crops plus the total amount of water leased must be less than or equal to the annual allotment (22).

$$ALLOT_j * A_j \geq \sum_{c=1}^{n}\sum_{i=1}^{m}\sum_{a=1}^{p} WTRAPP_{ciaj} * Q_{ciaj} + LSW_j \tag{22}$$

where $ALLOT_j$ = per acre annual water allotment in acre-feet,
$WTRAPP_{ciaj}$ = irrigation water applied in acre-feet, and
LSW_j = water leased from farm in acre-feet.

An initial value for WAL of one acre-foot was used for the NUID, then WAL was increased at one half foot intervals up to three acre-feet. For COID, WAL ranged from two acre-feet to four acre-feet. These ranges encompass actual historical allotments for both districts.

The price received from leased water, $LSPR_j$, represents the monetary compensation that irrigators could be offered to lease their water. Initially, $LSPR_j$ was set equal to 0 and the model solved to determine the crop rotation and irrigation managements that would maximize profits without a water market. This value was increased at $5 per acre-foot increments to determine how operations would change given various lease rates in a water market.

A charge for the purchase of excess water was also included to cover costs associated with purchasing water over the two acre-foot allotment in NUID. When up to two acre-feet are available in NUID, a flat district water charge must be paid. This is a cost of production inherent in Z. If over two acre-feet are available, the flat fee must be paid for the first two acre-feet and additional water may be purchased if available. COID irrigators do not have to pay for water over a set level but they are required to pay a annual fee of $150 per water right. These costs were included as appropriate.

A series of constraints not outlined here were included in the NUID and COID models to assure specific rotational constraints were met. Garlic and carrot seed acreage was limited by contracts. No more than 40 acres of garlic and 20 acres of carrot seed were allowed in the NUID model. Fifteen percent of COID land was assumed to be lower quality land and reserved for pasture or idle acreage.

3.4 Options Analyzed

All of the above constraints apply to each of the three scenarios studied; 1) AllTech: all irrigation alternatives available for adoption, 2) Base: only baseline systems allowed, and 3) Conserve: involvement in the conservation program.

The AllTech option allows farmers to adopt any of the feasible irrigation technology/crop rotation combinations described and lease water to maximize profit. It assumes that irrigators have knowledge of every system described. Leasing water required that the land with the appurtenant water right be nonirrigated. In this option, fallow land was not irrigated permitting the water allotment associated with the fallow land to be leased. Land may also be fallow without leasing water, however. Irrigators may use their total annual allotment on any portion of their acreage with the water right as long as they do not exceed the limits of their rights. Therefore they can fallow acreage and use the water associated with that acreage on other land. The inequality constraint presented in equation (23) reflects this option:

$$\sum_{a=1}^{p}\sum_{i=1}^{m}\sum_{f=1}^{r} Q_{fiaj} * ALLOT_j \geq LSW_j \qquad \forall j \tag{23}$$

where f = all fallowed land as a subset of crops c.

The Base option represented farm production with the baseline irrigation systems. The only difference between Alltech and Base was that the irrigation technologies were limited to the baseline systems, every furrow, sprinklers, and flood. This was accomplished by replacing irrigation technologies *i* with a subset *g* that included only the technologies in the baseline budgets.

Finally, irrigators could choose to participate in Oregon's allocation of conserved water program, which involves adopting a water conserving irrigation system that is recognized by OWRD's conservation program as a qualifying conservation practice. All systems except the baseline systems were considered qualifying practices. This option, represented as Conserve, eliminated the requirement of leasing water associated with non-irrigated land. The objective function remained unchanged. The only constraint affected was the water leasing constraint, equation (23). The ACWP does not require land to be fallowed in order to lease water. Land with a water right can remain in production while a portion of the water is leased and the land irrigated. Following the guidelines of the ACWP, the irrigator is required to prove the conservation potential of the new system to the OWRD and the state retains a portion of the conserved water for instream use. The irrigator may use the remaining conserved water in any manner. The exact portion of conserved water allocated to the state is determined on an individual basis under the law but the minimum is currently set at 25 percent. In the model, it was assumed that 75 percent of any water saved with the water conserving technologies (those not in the baseline budgets) could be leased in addition to the water associated with fallowed acreage. Equation (23) becomes

$$\left\{ \sum_{f=1}^{v} \sum_{i=1}^{m} \sum_{a=1}^{p} Q_{fia} * ALLOT_j \right\} + \left\{ \left[\sum_{c=1}^{m} \sum_{i=1}^{n} \sum_{a=1}^{p} BSWTRUSE_c \right] - WTRAPP_{cia} \right\} \geq LSW_j \qquad \textbf{(24)}$$

where LSW_j = quantity of water leased in acre-feet

and

$$BSWTRUSE_c = \left\{ \sum_{a=1}^{p} \left\{ \sum_{g=1}^{m} Q_{cga} \right\} * WTRAPP_{cga} * E_{ic} \right\} \quad \forall\ c \qquad (25)$$

where E_{ic} = a matrix of 0's and 1's and 1 identifies baseline system,
g = a subset of *i* containing only baseline systems, and
$BSWTRUSE_c$ = water applied to crops if baseline systems were utilized.

Up to 75 percent of the total water applied to all crops less the water applied to all crops using only irrigation systems found in the baseline budgets could be leased. In addition, the water associated with all fallowed land could be leased.

Each option provides an alternate means of freeing water to lease for instream flows. Varying the lease rate offered irrigators and recording the NLP results illustrated the difference between how irrigators might react, or how they could change their crop rotations and irrigation management in response to each option. Results are presented in the next chapter.

4. EMPIRICAL RESULTS

In this chapter, the empirical results for the NUID and COID models are presented and compared. First, the mathematical programming results are summarized. Results are analyzed for each irrigation district in terms of the quantity of water leased, crop rotations, irrigation technologies and deficit irrigation resulting from various water lease prices and allotment levels. Also included is an explanation of the changes that occurred when returns to owner labor were reduced from $15 to $10 and $7 per hour. Finally, all results are brought together with the cost data on lining and piping irrigation district canals to suggest an overall strategy to use in obtaining water for instream uses.

Individual supply curves for three leasing and irrigation technology combinations are presented as options AllTech, Base, and Conserve. The Base option represents the activities currently dominating commercial crop production in COID and NUID with the general lease rule that land must not be irrigated. AllTech and Conserve represent the possible adoptions of feasible water conserving activities. In AllTech, land again must not be irrigated if an appurtenant right is leased. The conservation program is currently available but a lack of involvement has been noted. Conserve illustrates the changes in water supplied to a water market if irrigators participate in Oregon's water conservation program assuming the reasons for the present non-involvement are not limiting.

Figures 8 through 17 graphically illustrate the water lease results in the form of water supply curves. Each figure represents model results for a unique annual allotment and a $15 per hour owner labor charge. They illustrate the minimum lease price irrigators were willing to accept to lease their water. Each point on the supply curve is the profit maximizing quantity of water leased at each price level given the crops, irrigation technologies, lease options, and annual allotment level assumptions.

The models were solved for a $0 lease price (assuming no water market) then re-solved with the water lease price increasing at $5 increments until either the price reached $225 per acre-foot or a total of 100,000 acre-feet was supplied to the market. The supply curves were estimated by connecting the individual price/lease quantity solutions found at the $5 price intervals. A maximum lease price of $225 was used because it is highly unlikely that a price in excess of $225 per acre-foot would be paid for a one year water lease based on previous market activity in central Oregon. The minimum recommended streamflow for the middle Deschutes River is 250 cfs. The flow during the irrigation season can be as low as 30 cfs. The 220 cfs needed to raise the flow to 250 cfs is equal to about 440 acre-feet per day. The normal irrigation season for NUID is April 15 to October 15 (180 days). The COID irrigation season runs through a seven month period, from the beginning of April to the end of October. If water is leased from commercial irrigators over the 180 day irrigation season, a total supply of 79,200 acre-feet would be needed to meet the minimum flow level. Supply estimates were generated for up to 100,000 acre-feet to indicate the supply response if this or slightly greater minimum streamflow was desired.

The lease results for each irrigation district should not be compared directly across allotment levels because in any given year it is highly unlikely that both districts will have the same per acre allotment. For instance, in what could be considered a low water year, the NUID may have close to one acre-feet per acre whereas COID may deliver two acre-feet per acre of land with water rights. This is because COID has a different set of water rights that supply more water per acre than the NUID rights. Also, the models assumed that no water was traded between irrigators. Each allotment level represents the amount of water distributed by the irrigation district and this was the only source of water available to irrigators.

The Bureau of Reclamation estimated the cost per acre-foot saved to line and pipe the NUID canals. The results are presented in Tables 4 and 5. The construction cost to line or pipe each canal segment was annualized over 20 years at 7.75 percent interest. The costs per acre-foot saved (CAF) were calculated as

$$\frac{ACC + OM - PCS}{WS} = CAF \qquad \textbf{(26)}$$

where ACC = annualized construction cost,
OM = annual operations and maintenance costs, and
PCS = power cost savings.

Power cost savings are realized with lining or piping some canal sections. The canal lining water supply curve outlined in Figures 8 through 12 shows the quantity of water supplied at various canal lining or piping costs as the sum of the NUID and COID canal water supply curves. The Bureau's study of canal lining costs assumed a constant water savings regardless of water availability. Therefore a single canal supply curve exists which is not dependent on the water year. Some canal sections could potentially be lined or piped. When both options existed for a particular canal section, the most cost effective option was used. This curve can be considered the cost to instream water users for water leased as a result of lining district canals if the water saved was not distributed among the irrigators but leased by instream users at the cost to line the canals.

4.1 North Unit Irrigation District Results

The NUID models were constructed based on the activities of a single hypothetical farm operating in the NUID. Because the activities were considered representative of the district, it follows that these results based on data generated at the farm level can be considered representative of the whole district. Therefore, farm level leasing results calculated based on a 500 farm are presented in terms of the 50,000 acres in the NUID for which Deschutes water rights are held for Deschutes River water.

4.1.1 Average Allocation

The NUID has received about two acre-feet per acre of water right in recent years. The water supply curves estimated for this allotment level are presented in Figure 8. When water price is equal to zero, the results of Base show all crops entering the profit maximizing crop rotation except peppermint. With a two acre-foot allotment, peppermint never entered the rotation. This is not surprising because, while annual allotments have been approximately two acre-feet in recent years, mint acreage is declining in the region. Bluegrass and garlic were deficit irrigated to produce 85 percent of their maximum yields and wheat was produced at 75 percent of its maximum yield. With the exception of carrot seed, every-furrow irrigation was the

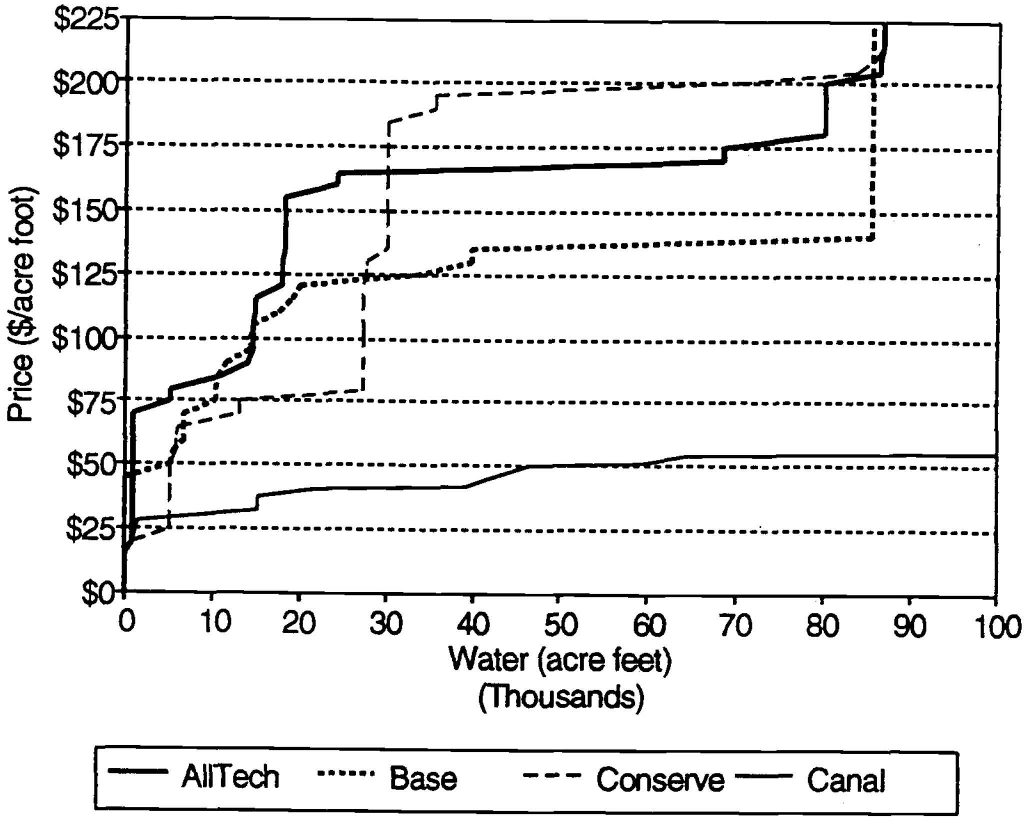

Figure 8. NUID Estimated Supply Curves for a Two Acre-foot Allotment

only irrigation technology utilized. Carrot seed was produced with a mixture of sprinklers and every-furrow irrigation, the practices outlined in the baseline carrot seed enterprise budget. Carrot and garlic seed were produced at their maximum seed-contract acreages. Bluegrass dominated crop production with about half the crop acreage dedicated toward its production. Both the wheat production and set-aside government wheat programs entered the profit maximizing crop rotations with the set-aside or 0-85 program on most of the base program acreage. With a water market price of zero, the 0-85 program was utilized not to free water for leasing but to provide additional water for other land. Idling the land without involvement in the program would not have generated any revenue whereas the 0-85 program offers a guaranteed wheat payment on the program yield for the idled acreage. Almost 20 percent of the total acreage was idled with most of it in the 0-85 program.

At lease prices below $55, land was fallowed solely to provide some crop acreage with more than two acre-feet of water. At $55 and $60 per acre-foot, a negligible water quantity captured by further deficit irrigating wheat and bluegrass, respectively, was leased. As the price was increased at $5 increments, increased deficit irrigation of wheat and bluegrass continued to reduce water applications to and reduce yields. Only one irrigation system was used in conjunction with deficit irrigation in Base. Every furrow, the most inefficient system in this research, was used to deficit irrigate. At $95 per acre-foot, sprinkler irrigation, a much more efficient but also more capital intensive system, was used to produce garlic.

Above $115 per acre-foot, the supply curve for Base became very elastic and the water leased at $135 per acre-foot was twice that leased at $115. Wheat dropped out of the rotation and the maximum government base acreage was utilized for the 0-85 program. Bluegrass acreage was cut in half and sprinklers were used for carrot seed production. Bluegrass production ceased and only garlic and carrot seed were grown at 100 percent yields with sprinkler irrigation at $140 per acre-foot. Discontinuing bluegrass production at $140 per acre-foot supplied enough water to the lease market to meet the minimum recommended streamflow in the Deschutes River. Figure 8 illustrates that lease prices of over $100 per acre-foot would be required to lease any significant quantity of water if irrigators use the systems that currently dominate on the NUID. With only the inefficient furrow irrigation and the capital intensive sprinklers to work with, irrigators eliminated the most marginal crops first, peppermint, wheat, then bluegrass, and switched from furrow irrigation to sprinklers as the lease price offered irrigators increased.

The AllTech supply curve was similarly shaped to that of Base (Figure 8). Over time it was presumed that irrigators would become familiar with and consider adopting a number of water conserving technologies. By expanding the range of irrigation technologies available, the opportunity existed to use a given water quantity to irrigate more acres thus increasing crop production and reducing the number of idle acres. Only the mandatory one percent (for roads, service areas) of the farm was fallowed when no water market existed.

Without a water market, the 0-85 program was not utilized. Surge furrow irrigation with irrigation scheduling was employed for all crops and deficit irrigation was not practiced. Using the water conserving technologies allowed all crops including peppermint to be produced. In Base, peppermint, a very water intensive crop never entered the rotation. With AllTech, by utilizing the more efficient irrigation systems, peppermint was a more profitable crop than wheat. Wheat does not require nearly the water input and therefore applying a water conserving technology would not save much water. The water saving per dollar of net return earned with wheat was apparently lower for wheat in AllTech than peppermint, causing peppermint to remain in production at higher lease rates.

Employing the more water conserving technologies caused the initial lease price to drop from $50 to $20 per acre-foot and peppermint to remain in production until the lease price exceeded $165. Water was freed to lease by eliminating wheat production at $95, then peppermint at $165 and bluegrass at $205. Above $205, only the speciality seed crops were produced.

The supply curve for the Base option crosses the AllTech supply curve between $120 and $125. Over the range of lease prices that the Base supply curve lies above the supply curve for AllTech, crop production with the inefficient systems allows a smaller quantity of water to be leased under the profit maximization objective. As lease price increased, the value in production of bluegrass became less than the value in the lease market and the water used to produce bluegrass was leased. With the more efficient systems water is more valuable in crop production and the lease value does not exceed the value in bluegrass production until over $150 per acre-foot. Now the Base option supply curve lies under AllTech because water is more valuable to the irrigator for crop production when more water conserving systems are used.

Both options AllTech and Base required land to be fallowed to lease water. This requirement is eliminated in the Conserve option. Up to $20 per acre-foot, the conservation program was not used and the model results were identical to AllTech. But when lease prices exceeded $20 per acre-foot, the crop acreages were reduced allowing water to be freed for leasing. Only a few acres of mint are produced when the lease price equals $25 to $60. The value of water in other uses exceeded the value in peppermint production at $65 per acre-foot. At $80 per acre-foot the 0-85 program is initiated. A highly inelastic range of the Conserve supply curve occurs from $80 up to $195. Whereas price changes by over $100 per acre-foot, only a few thousand additional acre-feet are supplied to the lease market.

Driving the water supply curves for Conserve are the lease rules of the conservation program. Up to 75 percent of "conserved water" can be leased in addition to water tied to fallowed land. Conserved water is defined as the quantity of water used to produce crops with the baseline systems less the water used when using a non-baseline system (any technology other than that in the baseline enterprise budgets). The amount of water that can be leased was limited in AllTech by the amount of fallow land. At some lease price levels, the profit maximizing crop irrigation levels are less than the per acre allotment and since only water tied to fallow land can be leased, some portion of the allotment is not used. The conservation program allows the lease of all the water not used to produce crops up to the total allotment less the states' portion. The states' portion is automatically left instream, thus reducing the quantity of water needing to be purchased for instream use. An irrigator using Oregon's conservation program can potentially lease more water than someone not involved in that program and this would generate greater returns to land. When lease prices exceeded $165 for the Conserve option in Figure 8, returns to land were maximized by using water conserving technologies that required less water than the baseline systems and leasing up to 75 percent of the conserved water. This is compared to AllTech where the conserved water option does not exist and land must be fallowed before leasing can occur.

The marginal crops in the NUID models were wheat and peppermint. Peppermint never entered the optimal rotation for any lease price and wage rate combination in Base and did not enter the rotation in Alltech and Conserve. Bluegrass was the "key" crop for supplying water. The elasticity of the supply curves was extremely dependent on the elimination of bluegrass from the profit maximizing crop rotation. As lease prices increased high enough that leasing water to produce bluegrass was more profitable than using it in crop production, a very elastic portion of the supply curves was generated for all options. Carrot seed and garlic seed, the two highest valued crops on the hypothetical NUID farm, were produced at all water allotment levels and lease prices considered. Wheat production and the wheat program were common to all profit maximizing rotations. Both the basic wheat program and the 0-85 wheat program entered the rotations in all models.

From the irrigators' perspective, a water market led to increased profits. Programming solutions for the Base option were the least profitable for a given lease price followed by AllTech and Conserve. The most profitable irrigation technology was surge furrow with irrigation scheduling. Combining this technology with the conservation program resulted in the greatest profits but a higher reservation price for water quantities of over 40,000 acre-feet. Therefore irrigators benefitted from the conservation program when surge furrow was used. Instream users wishing to lease upwards of 40,000 acre-feet would prefer that irrigators not be involved in the program because it increases the value of water in agricultural production.

In an average water year (as illustrated by the results in Figure 8), the cost per acre-foot to lease water from commercial irrigators exceeded the cost per acre-foot of water saved by lining canals (Canal in Figure 8). The exception was the conservation program option with up to about 5,000 acre-feet, associated with surge furrow irrigation. Leasing water at the canal lining cost would be less expensive than leasing directly from irrigators. If water availability allowed for average farm deliveries in the long run, canal lining appears to be the most cost effective to free water for instream use regardless of whether the opitons AllTech, Base or Conserve exists. When comparing these supply curves to canal lining costs it must be noted that if canals are lined, payment for construction costs must be made regardless of the water availability whereas leasing water can be performed on a year to year basis.

4.1.2 Below-Average Allocation

Figure 8 and the above discussion illustrate the leasing results obtained from the NUID model for an average year. To estimate the supply response in below-average water years, supply curves were generated for one acre-foot and 1.5 acre-feet.

Leasing results for a one acre-foot allotment are presented in Figure 9. The supply curves are very simplified compared to those in Figure 8. With the Base option, sprinkler irrigation is the only technology employed. The supply curve has

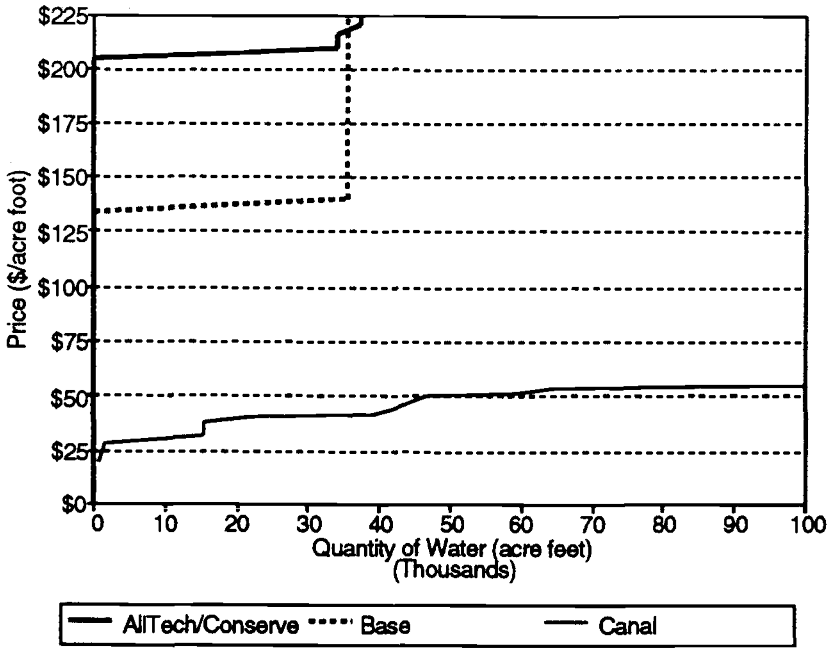

Figure 9. NUID Estimated Supply Curves for a One Acre-foot Allotment

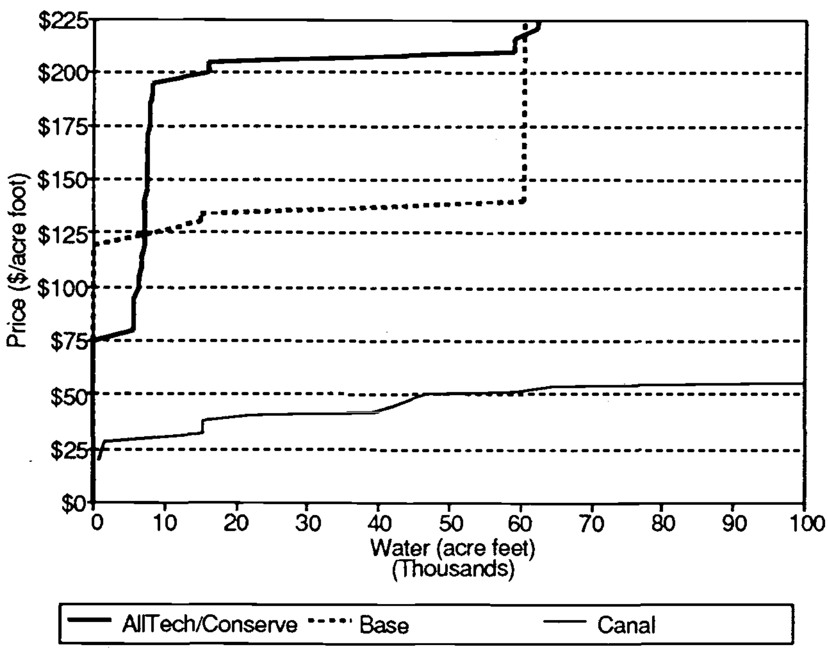

Figure 10. NUID Estimated Supply Curves for a 1.5 Acre-foot Allotment

two distinct regions, $0 to $125 and $130 to $225. Over the first range the specialty seed crops and bluegrass were produced. At $130, bluegrass was eliminated from the rotation. Nearly half of the acreage was fallow with lease prices between $0 and $125. The maximum 0-85 acreage allowed was entered into the government program at all points on the supply curve. Deficit irrigation did not occur. The supply curves for AllTech and Conserve were identical because there was no involvement in the conservation program. Peppermint did not enter the rotation and bluegrass was reduced at $210 per acre-foot and eliminated at $220 per acre-foot. The highly inelastic portions of the supply curves occur near 40,000 acre-feet. At this point, water is leased from most but not all of the fallowed acres. Some water from idled acres was used in crop production so that the average irrigation application was greater than one acre-foot.

Investment necessary for canal lining projects may not be merited when Deschutes River flows are adequate to meet environmental needs. In short water years, however, lining canals represents the least expensive option for instream users provided they can lease the water saved at a rate equal to the annualized project cost.

Figure 10 illustrates the leasing results for a 1.5 acre-foot allotment. The initial lease with the Base option was greater than that for a two acre-feet allotment but less than for the one acre-foot allotment. Bluegrass began to drop out of the rotation at $115 per acre-foot. The lease price required to lease the first unit of water under Alltech and Conserve was greater than that for the two acre-foot allotment. The shift in the supply curve at $80 was caused by a decrease in wheat production acreage and an increased involvement in the 0-85 program.

As was expected, water was more valuable to the irrigator in crop production when water was scarce. Much higher lease prices were required before irrigators supplied water to the lease market. The on-farm changes that occurred when water was leased included the elimination of bluegrass production, involvement in the 0-85 program and deficit irrigation of wheat in Alltech and Conserve and bluegrass in Base.

4.1.3 Above-Average Allocation

The impact on the irrigators' supply curves in years when water supply to the NUID is greater than average is illustrated in Figures 11 and 12. All supply curves shifted down to the right to some degree indicating that increased water supplies made farmers more willing to lease water at lower lease prices.

Given a 2.5 acre-foot allotment with the Base option, deficit irrigation of wheat, bluegrass and garlic was reduced slightly (yields increased) and crop acreage shifted but the general rotations remained the same as that with a two acre-foot allotment (Figure 11). Also involvement in the 0-85 program did not begin until lease price reached $50 per acre-foot. Results for AllTech and Conserve were nearly identical to those for a two acre-foot allotment. Peppermint was phased out of production and the 0-85 program was adopted at a lower lease price. Most of the additional half of an acre-foot was leased. With no water market, profit was maximized by applying just over two acre-feet per acre. The full allotment was not needed for crop production as it was with Base because more efficient systems were used. Assuming irrigators take advantage of the conservation program, instream users

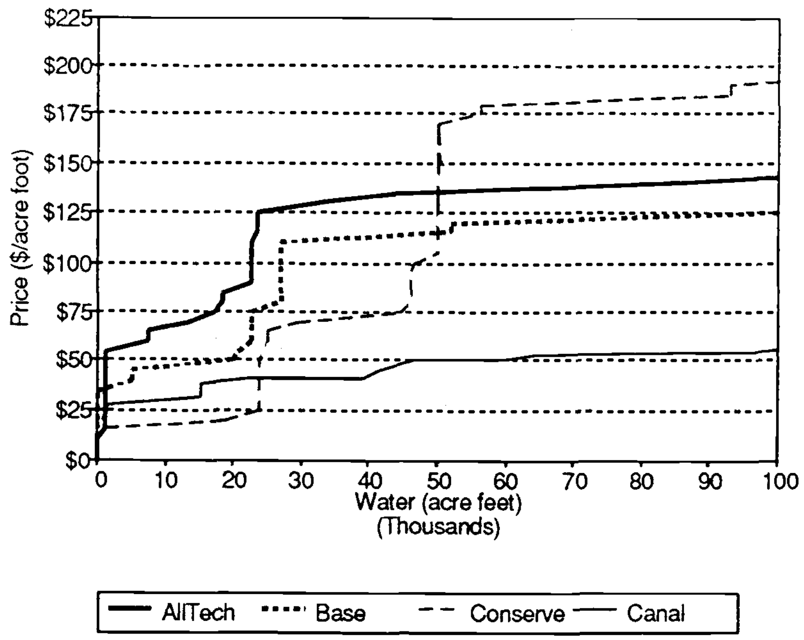

Figure 11. NUID Estimated Supply Curves for a 2.5 Acre-foot Allotment

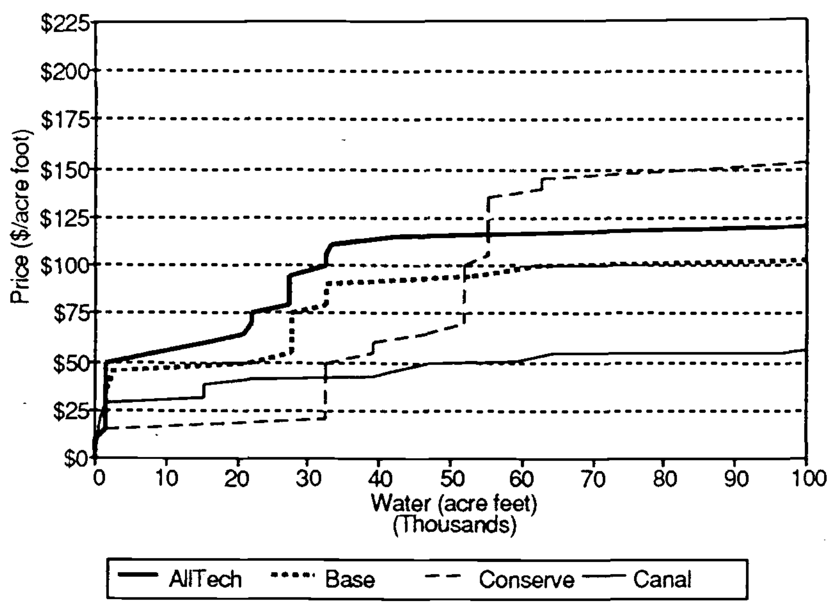

Figure 12. NUID Estimated Supply Curves for a Three Acre-foot Allotment

would be able to lease nearly 25,000 acre-feet under the Conserve option for up to $25 per acre-foot making this the least expensive scenario. Canal lining to save this amount of water would cost nearly $45 per acre-foot. In surplus water years, water above the actual flow level may not be needed in the river and, because lease agreements can be made on an annual basis, it may not be necessary to have any expenditures on water to enhance flows. If a canal lining project has been completed, the construction cost must be paid regardless of the water year. In low water years, it would pay to line canals but if in the long run water availability is high, the commitment to canal payments would not be justified.

The model results for a three acre-foot allotment continued the same pattern as the 2.5 acre-foot allotment results. Supply curves were shifted down to the right, the same crop rotations and irrigation technologies were used, and more water was available for lease. With a greater allotment, irrigators would again use the conservation program to meet their profit maximizing objective and over 30,000 acre-feet could be leased for less than $25 per acre-foot. Beyond this quantity, canal lining remained the least cost scenario to conserve water.

4.1.4 Changes in Labor Costs

Varying the rate of returns to owner labor had no effect on the irrigation systems used. As the wage rate was reduced from $15 to $10, the lease price increased by about $10 per acre-foot. Reducing it further to $7, the wage rate used for most baseline enterprise budgets, reduced the cost of production enough that lease rates increased about another $5 per acre-foot. As the cost of production went down, irrigators could maximize profits by using water in crop production and not entering the market until lease prices increased slightly.

4.2 Central Oregon Irrigation District Results

The COID models were designed with the same underlying assumptions as the NUID but specific COID crop, irrigation system, and water allotment modifications were included. Farm-level leasing results were calculated based on a 300 acre hay producing farm in the COID. Like the NUID, the COID production activities were considered representative of commercial agriculture in the district. Therefore, the results based on data generated for COID at the farm level can be considered representative of the approximately 10,000 acres of full time commercial farms located the district.

Figures 13 through 17 illustrate the COID water lease results in the form of water supply curves. Each figure represents results for a unique annual allotment ranging from two to four acre-feet and a $15 per hour owner labor charge. The sum of the individual district canal lining supply curves is illustrated in each figure.

4.2.1 Average Allocation

Three acre-feet per acre represents an average allotment in recent years for COID irrigators. Assuming irrigators are maximizing profits and utilizing the baseline systems (Base option), instream users could lease most of the COID commercial

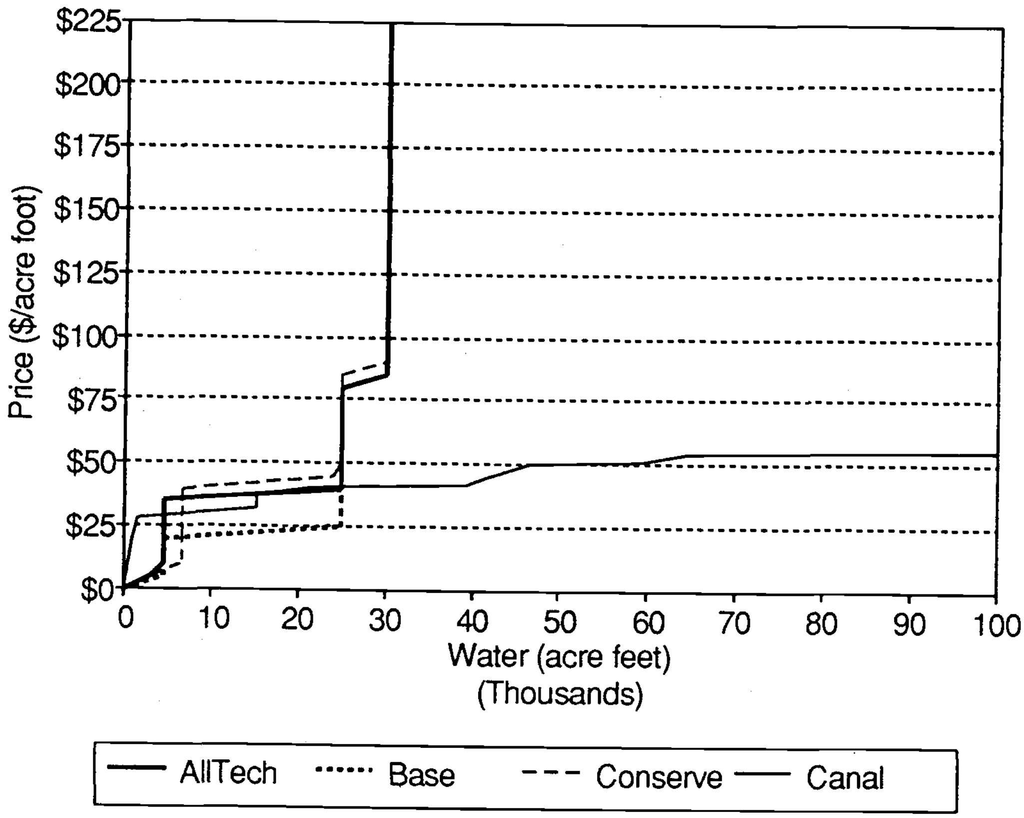

Figure 13. COID Estimated Supply Curves for a Three Acre-foot Allotment

irrigators water at $25 per acre-foot. Crops produced under the Base option included about 13 percent of the crop acreage in mint (one quarter of which was in mint establishment), and 72 percent in grain hay. The maximum cropped acreage allowed was utilized leaving the remaining 15 percent available for pasture or fallow as idle land. Pasture, grass hay and alfalfa did not enter the rotations. Both crops produced were irrigated to reach maximum potential yield. Because only baseline practices were allowed in Base and because the baseline irrigation systems for the crops produced used sprinklers, sprinkler irrigation was the only technology used. At $25 per acre-foot, grain hay acreage dropped from over half the farm acreage to about six percent. Finally, if irrigators using only the baseline systems were compensated with $85 per acre-foot, all land would be idled and all water rights leased.

When center pivots and irrigation scheduling were included in the irrigators technology choice set (Alltech), the crop rotations included peppermint on the maximum acreage. About eight percent of the total acreage was in grain hay, 22 percent was in alfalfa (20 percent of which was in alfalfa establishment) and the remaining land was in grass hay. Irrigation scheduling was not used but center pivots were used to produce grass hay, alfalfa, and grain hay. Grass hay production was replaced with alfalfa production and water was leased at $5 per acre-foot. At $40, over 20,000 acre-feet were supplied to the water market, alfalfa production ceased, and grain hay acreage declined.

The conservation program was utilized with a three acre-foot allotment. At this level, enough water was available that losing 25 percent of the conserved water to the state in order to lease the remaining conserved water was practical to maximize profits. From $10 to $85, more water was leased than would be allowed without involvement in the program. The quantity leased with the conservation program is not noticeable in Figure 13 from $45 to $85 because it is so small. Grass hay and alfalfa were produced until lease prices reached $50. Above $85, the results paralleled the Base option.

Supply curves for all three options, Alltech, Base and Conserve are perfectly inelastic at about $90 and up as the lease price was enough to bid all water out of crop production. This lease quantity is sustainable in the long run so long as a transfer agreement has been made. Transfer to an instream flow is considered a beneficial use and therefore water does not have to be applied to the land once every five years.

In comparing the canal lining supply curve to the irrigation option supply curves in Figure 13, irrigators were willing to lease most of their allotment for less than it would cost to save the same quantity by lining the most cost effective COID and NUID canal portions. Instream water users could lease about 25,000 acre-feet over an irrigation season from COID irrigators at $25 per acre-foot.

4.2.2 Below-Average Allocation

Figures 14 and 15 illustrate the leasing results if water availability to the COID was only two acre-feet and 2.5 acre-feet per acre, respectively. When the water allotment was reduced, only minor differences occurred. Given a two acre-foot allotment, grass hay was not produced with the AllTech option. The dominant crop was grain hay with over half the acreage in grain hay production until the lease price

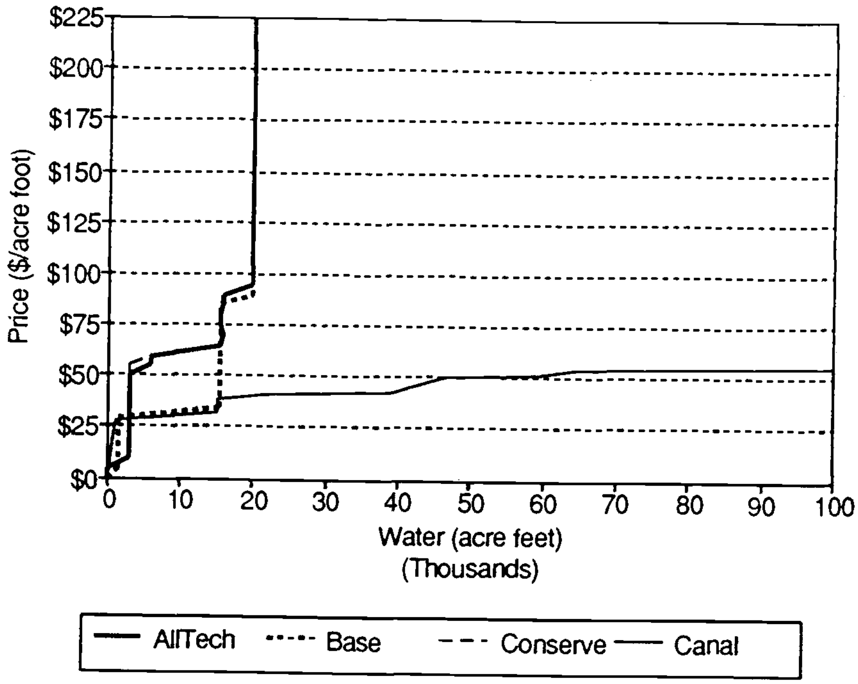

Figure 14. COID Estimated Supply Curves for a Two Acre-foot Allotment

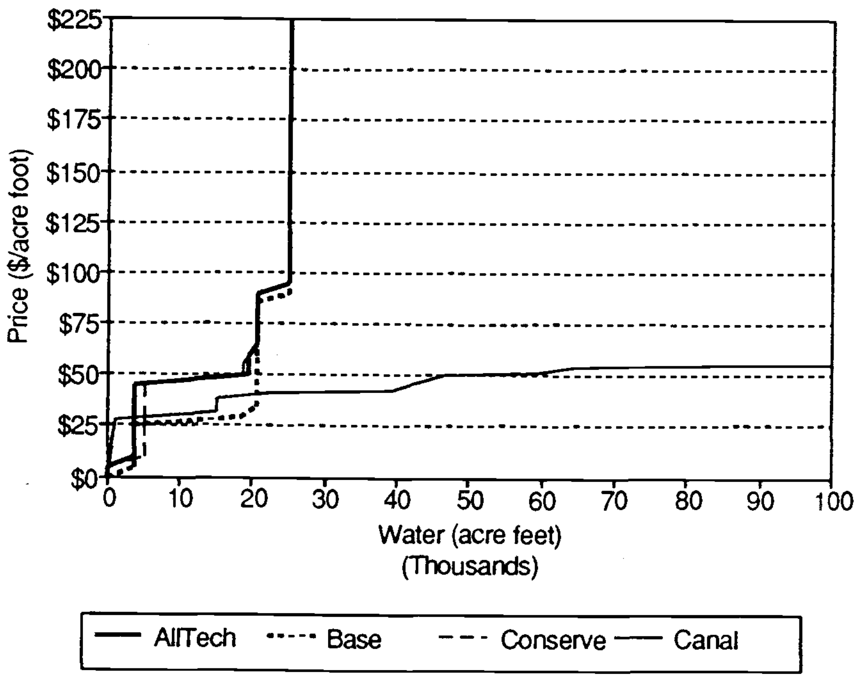

Figure 15. COID Estimated Supply Curves for a 2.5 Acre-foot Allotment

reached $65 per acre-foot. At this point, grain hay acreage was reduced and the crop was deficit irrigated such that 75 percent of its maximum yield was produced. Alfalfa was produced but it dropped out of the profit maximizing rotation when the lease price reached $55 per acre-foot. Also at $55 per acre-foot, grain hay acreage declined and 15,000 acre-feet were supplied to the market. All acreage was fallowed at $90 per acre-foot. In the Base option, deficit irrigation of grain hay began at $70 per acre-foot. Initially water was applied to grain hay to produce 95 percent of maximum yield. This was reduced to 90 percent at $85 per acre-foot. The Conserve option results revealed that grass hay production was not merited with only two acre-feet of water available. At $10 per acre-foot, alfalfa production ceased and a minimal amount of water was involved in the conservation program up to $55 per acre-foot.

Alfalfa acreage increased over the two acre-foot level with a 2.5 acre-foot allotment in AllTech. At $90, all acreage was fallowed. The reduced water supply to irrigators caused the supply curves to shift up and to the left from the three acre-foot allotment meaning that irrigators were less willing to give up their water. There was minimal involvement in the conservation program between $10 and $55 per acre-foot.

4.2.3 Above-Average Allocation

The water market supply changes resulting from an above-average allotment are depicted in Figures 16 and 17. Grass hay and alfalfa were produced until lease prices reached $35 per acre-foot with the AllTech option. The lease price at which crop production ceased was lowered to $75 with 3.5 acre-feet and $65 with a four acre-foot allotment. Programming results for Base remained unchanged from a three

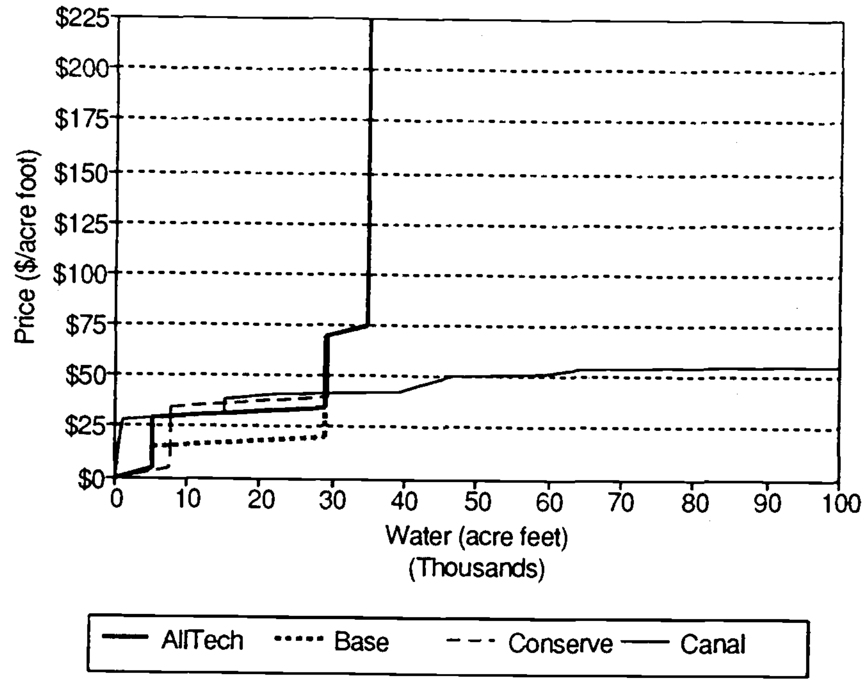

Figure 16. COID Estimated Supply Curves for a 3.5 Acre-foot Allotment

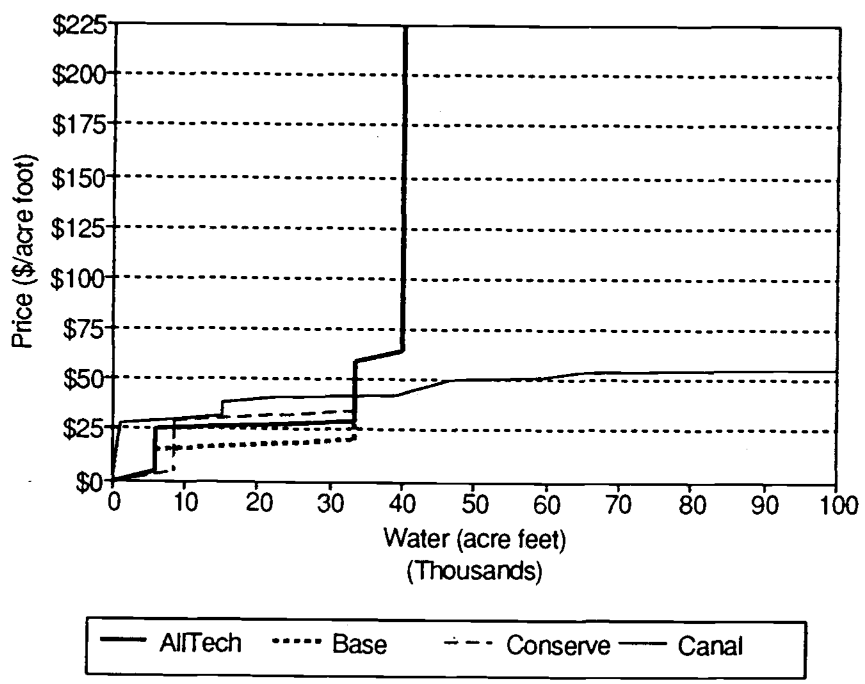

Figure 17. COID Estimated Supply Curves for a Four Acre-foot Allotment

acre-foot allotment except for the price at which all land was fallowed and all water leased. Each additional one half acre-foot of water reduced the lease price required for irrigators to supply all of their water by $5. In Conserve, a 3.5 acre-foot allotment allowed alfalfa to be produced on about one third of the total farm acreage until it was eliminated at $40 per acre-foot. With four acre-feet, both alfalfa and grass hay remained in production until lease price exceeded $30 per acre-foot. Enrollment in the conservation program maximized profits at all lease prices until all acreage was fallowed. The maximum price at which all water was leased in each options was lowered to $70 for the 3.5 acre-feet and $65 for the four acre-feet allotment. The Base option remained the least expensive means for instream water users to acquire water but the irrigation options AllTech and Conserve became very competitive with the cost to line canals.

As a result of the greater water allotment and lower valued crops in COID, the COID models generally estimated lower lease prices than the NUID. The maximum supply from COID is much less than the NUID, however, because only an estimated 10,000 acres of commercial, full time farms are in COID.

4.2.4 Changes in Labor Costs

Varying the rate of returns to owner labor again had no effect on the irrigation systems used. As the wage rate was reduced from $15 to $7, the lease rates increased about $5 per acre-foot. There was minimal impact on the supply curves when the owner labor wage was reduced.

4.3 Total Commercial Agricultural Water Supply

The total supply of water from commercial agriculture in the NUID and COID is equal to the sum of the individual district supplies. This is the estimated supply function that instream users would face for commercial agriculture with rights impacting the flow of the Deschutes River. The total supply curves are presented for what is considered a low, average and above-average flow level for each district.

The supply curves for a low flow year are illustrated in Figure 18. The representative allotment for a low water year is one acre-foot for NUID and two acre-feet for COID. Clearly the least expensive source of water to instream water users would be savings from canal lining. A quantity of about 15,000 acre-feet (100 percent from COID) could be leased from irrigators operating with the baseline systems at a price slightly higher than the cost to line canals. Quantities greater than 15,000 acre-feet are obtained much less expensively through canal lining.

The sum of the district supply curves for an average year is shown in Figure 19. Assuming that instream users will negotiate lease agreements with individual growers (thus practicing perfect price discrimination) the first 25,000 acre-feet could be leased at or below $25 per acre-foot. At very low lease quantities, leasing directly from irrigators competes with the cost to line canals but as larger quantities were supplied, lining canals was the least cost scenario. In high water years, all irrigation options compete with canal lining. If farmers were involved with the conservation program, they would be willing to supply enough water to meet the minimum recommended streamflow in the Deschutes River for up to $50 per acre-foot. Historically, high water years are uncommon which suggest that canal lining should be strongly considered as the most cost effective way to increase water supplies available for instream flows.

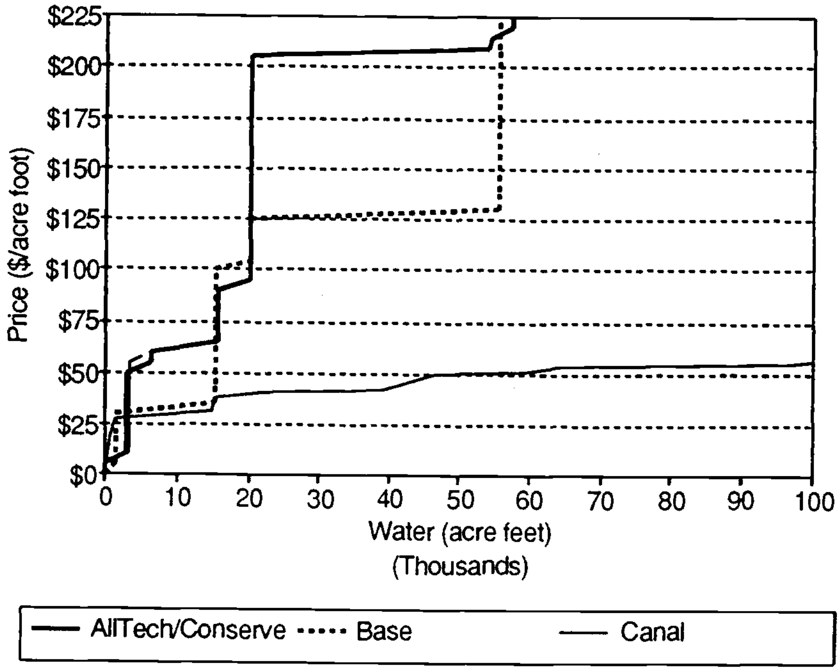

Figure 18. Total Commercial Agriculture Estimated Supply Curves for a Low Water Year

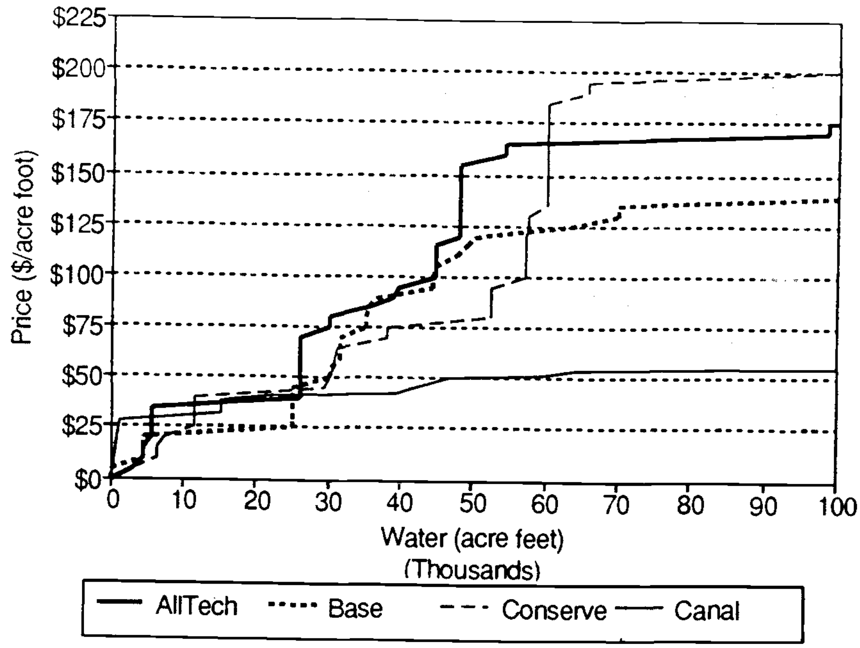

Figure 19. Total Commercial Agriculture Estimated Supply Curves for an Average Water Year

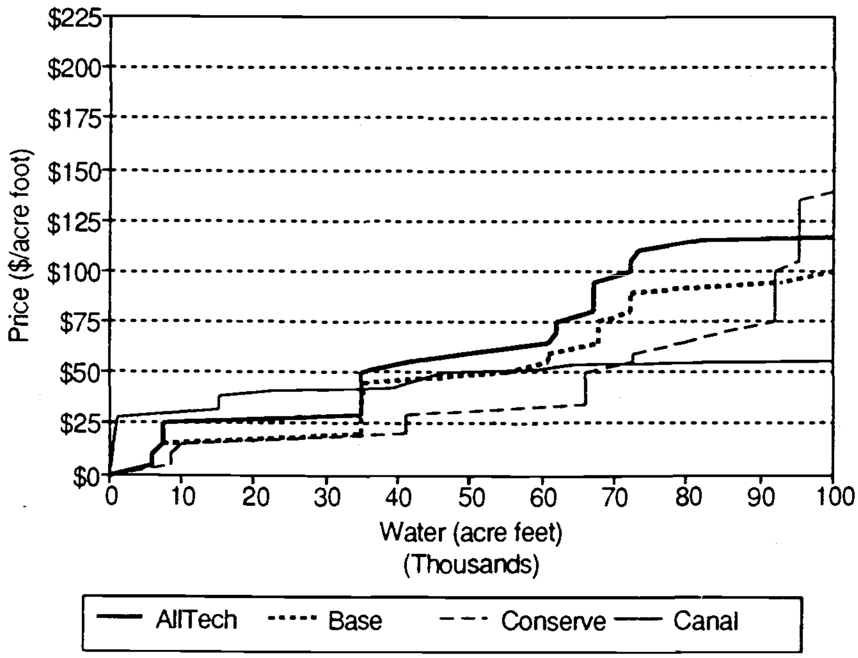

Figure 20. Total Commercial Agriculture Estimated Supply Curves for a High Water Year

5. SUMMARY AND CONCLUSIONS

Low flows partially caused by irrigation diversions in the Deschutes River of central Oregon impact water quality particularly between Bend, Oregon and Lake Billy Chinook. In low flow areas, water temperature and other factors are not at the preferred level for fish habitats thus reducing the water quality. The irrigation districts hold legal water rights to divert quantities greater than the current flow but have agreed to leave about 30 cfs in the river during the irrigation season. The recommended minimum Diack flow level, the water level as needed for state scenic waterways to support recreation, fish, and wildlife, is 250 cfs during the irrigation season for the Deschutes River.

The development of a water market to reallocate water among irrigators and instream uses is one alternative to help alleviate the water quality problems. In the water market, water would be supplied by irrigators for instream use at a minimum price not less than the value of their water when used for irrigation. This thesis focussed on water markets for water used on commercial farm operations, recognizing that hobby farmers are often more interested in lifestyle than profit maximization.

The North Unit Irrigation District and Central Oregon Irrigation District hold rights to Deschutes River water as well as water stored upstream in two reservoirs near the head of the Deschutes River. Natural flow rights and storage rights could potentially provide water for instream uses in the critically low portions of the river. While the general irrigation purpose on all commercial farms in NUID and COID is to irrigate agricultural land, soil productivity, elevation and other factors influence the crops produced and irrigation systems used in each district.

Two farm production models, one for each irrigation district, were developed to identify practices that irrigators could use to free water for instream uses, and to estimate the value of water to commercial agriculture, or the minimum compensation required by irrigators to lease their water assuming the water will move to a higher valued use. The basic model was adapted to individual district characteristics. Three scenarios were assumed when estimating the irrigator's water supply functions: AllTech: irrigators could adopt water conserving practices, Base: the irrigation practices currently used would remain in operation, and Conserve: irrigators could become involved in Oregon's conservation program. Finally, the results were compared to the cost to line irrigation districts canals as an alternative supply of water for instream use. If canals are lined, the water saved would belong to the irrigators. With increasing public pressure to reallocate water to support the environment, water saved from lining canals could be sold to meet instream needs.

Profit maximizing irrigators wanting to lease water for instream flows have several choices including fallowing land, deficit irrigation, changing crop rotations, adopting water conserving practices, and(or) using Oregon's conservation program. All these alternatives were used to some extent in the models. Water allotment levels and the crop mix on each district impacted the results.

5.1 North Unit Irrigation District Irrigators

Assuming NUID irrigators are operating with the assumptions outlined in the Base option, they could free water for a water market by not producing mint, participating in the 0/85 program and reducing and eventually eliminating bluegrass. Deficit irrigation of wheat, bluegrass and garlic also could provide small quantities of water to the water market. In an average or below average water year, utilizing the government wheat program as a means of fallowing land benefited irrigators who received a government wheat payment while either leasing the water or using it on other crops. This would also hold true for above average water years and high water lease prices.

The adoption of more water conserving irrigation technologies made water more valuable in crop production and caused irrigators to be less willing to lease their water. Surge furrow irrigation with irrigation scheduling was a particularly desirable technology to conserve water. The same general crop rotation conclusions for Base applied to the AllTech option where changing crop rotations freed water as lease prices rose. If irrigators adopt water conserving practices, mint production would be merited in average and above average water years.

Like many of the water conserving practices in this study, the conservation program is not currently being utilized in Oregon. This research shows that if a water market were available, the conservation program would be worthwhile to irrigators in average and above-average water years by increasing profits as well as increasing water supplied for instream flows. Given a below-average allotment, participation in the conservation program is not merited because the water available for crop production is already low and the conservation program would further reduce the irrigators' allotments by transferring part of it to the state. Involvement in the conservation program increased the willingness to lease at two acre-feet and above. The conservation option supply curves have the same basic shape as those generated from AllTech because the basic shifts in practices and related changes in quantity leased occurred as lease prices increased. The conservation program should be considered if in the long run water availability is predicted to be average or above average. The loss of a portion of the conserved water to the state is not preferred in below average water years.

5.2 Central Oregon Irrigation District Irrigators

In COID, programming results for Base revealed that pasture, grass hay and alfalfa were not part of a profit maximizing crop at any allotment level. Where peppermint was the most marginal crop in the NUID, in COID it was always one of the last crops to be eliminated. Peppermint was more water intensive and less profitable compared to other NUID crops. But in COID, it is one of the less water intensive crops and a higher valued crop than hay. In addition to crops produced, the only other practices that occurred in Base to lease water was to deficit irrigate grain hay and to fallow land. The lease price at which land was fallowed ranged from $90 to $65 per AF at two and four acre-feet, respectively.

The cropping patterns shifted slightly in AllTech in comparison to Base as alternatives to sprinkler and flood irrigation were introduced. Center pivots were utilized on all hay crops and sprinklers on peppermint. Irrigators could maximize profit and lease water by eliminating grass hay, alfalfa, grain hay and finally peppermint from the rotation. Deficit irrigation and irrigation scheduling of grain hay at higher lease prices allowed water to be freed for lease. Laser leveling was never an optimal activity in COID.

The conservation program had a very small but positive impact on the level of water leased. Irrigators could lease by using center pivots to irrigate hay crops and eliminating the most marginal crops first.

5.3 Total Water Supply

Instream users seeking the least-cost source of water should first consider buying from commercial irrigators in COID before the NUID. If instream users lease water from irrigators under the current conditions (represented by option Base), in an average water year about 25,000 acre-feet could be purchased for less than $25 per acre-foot. All of this water would come from COID. Even in a high water year however, leasing all the COID commercial agricultural water would not bring the flow to the recommended level. Total irrigator supply in both districts was enough to meet the recommended minimum flow for less than $125 per acre-foot in all irrigator options, AllTech, Base and Conserve, in a high water year. Based on historical data, to sustain a high irrigation allotment over several years is doubtful. It is important to study the full range of water availabilities, however, to determine the general trend in on-farm practices and the source of water supplies to instream uses as water allotments vary.

In a low water year, irrigator lease prices remained below $50 per acre-foot for small lease quantities but soared above $125 per acre-foot for over 15,000 acre-feet where all the COID water was assumed to be leased. This result underscores the argument made in Chapter 2, that in years when the irrigation district allotments are low, irrigators will be less willing to give up their water.

Before water is bid away from peppermint and grain hay in COID, instream users should purchase water supplies from NUID as they eliminate their lowest valued crops, peppermint and wheat. Once the COID supply is exhausted, instream users will have to refer back to the NUID for additional water.

In the long run, irrigators will likely adopt the water conserving technologies and may choose to use the conservation program if water continues to be scarce in the region and(or) a water market develops. In this case, instream users should expect to pay higher prices for NUID and COID irrigation water. Irrigators would be less willing to lease their water because on a per acre basis, the conserving practices allow water to be used on more crop acreage or for more water intensive crops such that it is worth more in crop production than in the lease market.

Based on the assumptions used in this research, lining canals would clearly be the major least cost avenue to obtaining the 79,200 acre-feet needed to meet the minimum flow recommendation during the irrigation season. For large quantities of water it appeared to be the best alternative regardless of irrigator activities.

5.4 Research Limitations

Linear programming provides the tools to solve farm production models such as those developed in this research but it also has some limitations. The models developed in this thesis were based on a single set of crop production activities, which contained simplifying assumptions. Prices, yields, soil productivity and production operations were assumed to represent the region in a static manner. In reality, many factors can impact production activities on a particular farm from year to year including disease, field characteristics and climatic conditions are among others. Off-farm conditions may also vary as input and output markets fluctuate over time. Obviously, crop production is an ever-changing venture. These factors were not captured in this model.

The NUID and COID representative farms do not depict any particular farm situation. Therefore the supply curves, the water lease rates and corresponding quantities leased do not completely reflect the actual irrigators' water supply functions to instream uses. What this research does provide is insight into the choices that irrigators could make to supply water to a lease market, given various water and leasing assumptions. Individual irrigators would not necessarily decide to lease water at a particular lease price but are more likely to adopt a practice on their farm and determine how much water they could lease as a result given their unique production setting. This research provides irrigators with information on a set of practices that are optimal for their consideration.

All water-conserving systems in this research are currently available to irrigators. In some instances, the systems have not been proven in commercial production to the point where widespread adoption is occurring. In addition, irrigators may not have complete information about different technologies. The models assumed that irrigators made profit maximizing decisions based on perfect knowledge of irrigation system cost and efficiency levels.

The limitations farmers face when desiring to plant the same crop on an entire field, for example, is difficult to handle in linear programming because all activities must be continuous. Also, the crop rotational results show the average acreage in a particular crop throughout the rotation. Some crops may not be produced every year so the results do not necessarily reflect annual crop acreage.

5.5 Recommendation for Further Research

This research was an attempt to investigate the economics of commercial agricultural water supply to instream uses in the Deschutes River based on representative farms in NUID and COID. Further research is needed to investigate the role of factors which impact production activities and water supply to instream uses.

Evaluating soil and field characteristics including slope and productivity in these districts would indicate how different land attributes impact crop production activities, yields, and how water is used. In addition to land, evaluating variations in annual climatic conditions, the length of the growing season and annual precipitation, would provide greater insight as to how irrigators make their production and irrigation decisions. The analysis could be extended to include an evaluation of crop water requirements on a weekly or monthly basis. This would lead to an examination of mid-season water transfers.

Surge furrow irrigation appeared to be the most cost effective irrigation technology in the NUID models. Additional research is needed for a thorough evaluation of this technology and its impact of crop production activities.

Finally, an evaluation of the investment in water conserving irrigation technologies and canal lining under uncertainty is needed. These options, especially canal lining, appear profitable in low water years. Such capital investments must be profitable, on average, across high and low flow years to justify their costs.

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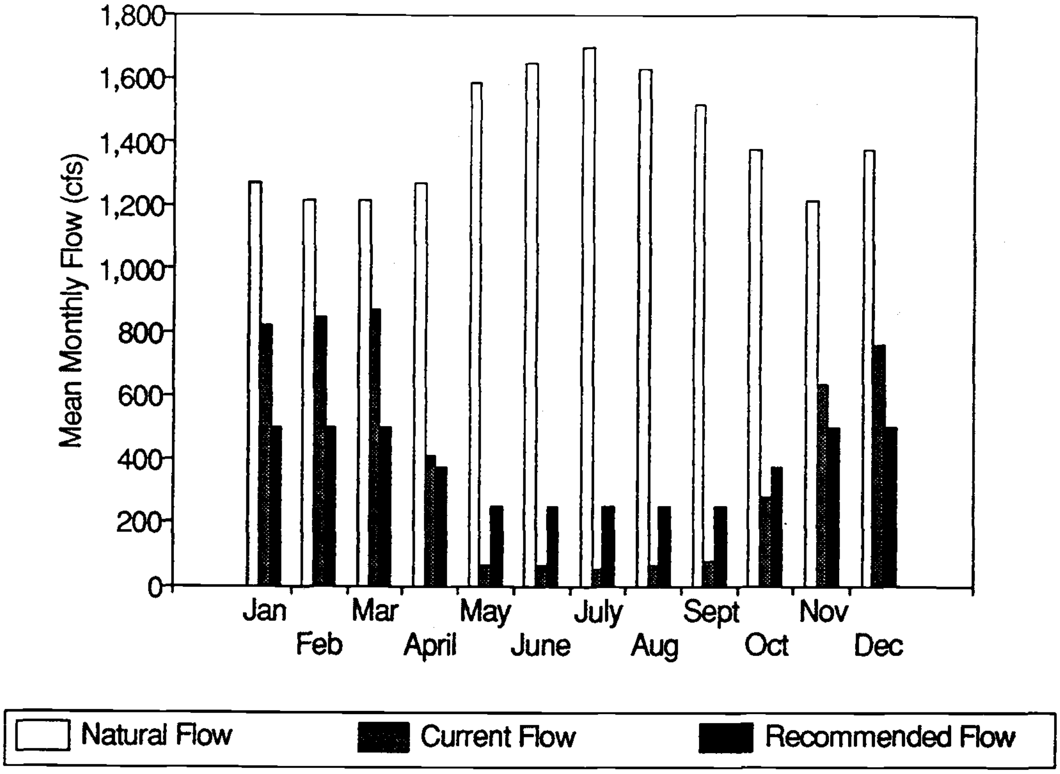
APPENDICES

Appendix A. Natural, Current and Recommended Mean Monthly Flow for Scenic Waterways in the Deschutes River from Bend to Lake Billy Chinook



Source: Director OWRD, 1991