# AN ABSTRACT OF THE THESIS OF

Barbara J. Wyse for the degree of Master of Science in Agricultural and Resource Economics presented on August 19, 2004.

Title: Farm and Community-Level Impacts of Irrigation Water Supply Reductions: A Case Study of Malheur County, Oregon

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Agricultural water supplies are becoming increasingly uncertain in the western United States due to rising demand from competing water users, environmental restrictions on surface water withdrawals due to water quality and endangered species concerns, and, potentially, climate-induced hydrological changes. Since many rural areas in the West depend economically upon irrigated agriculture, increased water supply variability may not only affect the agricultural sector, but may also have significant regional economic impacts.

This study investigates the distribution and magnitude of farm and community-level economic impacts of water supply fluctuations through a case study of an irrigation district located in an agriculturally-dependent county in southeastern Oregon. In addition to estimating the value of irrigation water, this study examines the effectiveness of three strategies to mitigate the economic consequences of fluctuating water supplies: 1. increased accuracy of water supply forecasts, 2. additional irrigation technology adoption, and 3. implementation of a water market or water bank.

Two models were utilized to estimate the economic impacts. First, a linear programming model written in the General Algebraic Modeling System (GAMS) was used to estimate the profit and revenue effects of four water supply scenarios on six representative farm types. Second, results from the linear program were used to conduct a regional impact analysis in an input-output model to ascertain how the farm revenue effects impact community-level employment and income.

Results indicate that expected annual revenue losses due to water shortages under current conditions range from 4 to 14%, while the expected annual profit losses range from 9 to 12%. Expected annual farm profit losses on the large ranches, feedlot operations, and row crop farms comprise 75% of total expected farm profit losses. County-level employment and income losses due to water supply variations in this irrigation district (comprising 16% of irrigated land in the county) were limited to less than 1%, even in the most severe water shortage scenario. Results also suggest that of the three mitigating strategies, additional irrigation technology adoption best reduces farm and community-level economic losses. A doubling of the current levels of sprinkler and drip irrigation technology resulted in a 5% increase in expected farm profits and a 0.1% increase in expected county income. Although water trading and improved accuracy of water forecasts similarly reduced farm profit losses due to water shortages, both resulted in greater expected farm revenue losses and hence greater community-level economic losses.

# Farm and Community-Level Impacts of Irrigation Water Supply Reductions:

## A Case Study of Malheur County, Oregon

by

Barbara J. Wyse

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## Chapter 1: Introduction

Historically, economic development in the seventeen western states has depended most heavily upon development of one natural resource: water. Given the arid nature of this region, many areas would not have an adequate supply of water without man-made reservoirs to retain river water and canals to transport it. Consequently, the western United States is home to some of mankind's most impressive water projects: Hoover Dam in Nevada, which stores the equivalent of two years of Colorado River flow; Grand Coulee Dam in Washington, which is the largest concrete structure in the United States; and the Central Valley Project in California, which encompasses 18 dams and over 600 miles of canals. Throughout the West, over a million man-made reservoirs, lakes, and ponds store up to 294 million acre-feet of water (Wilkinson, 1992).

As long as more water resources could be developed through construction of additional dams and aqueducts, demand was met. However, the big dam building era drew to a close in the mid-to-late twentieth century as the environmental costs of new projects began to outweigh the benefits. While most of the developable water supply has now been tapped, demand continues to grow. Increases in the consumptive use of water by a rapidly growing urban population, coupled with mounting environmental and recreational pressures to maintain in-stream flows, have created a scenario in which adequate water supplies have become a major concern in many areas of the western United States.

Not only is demand for water increasing in the West, there is also potential for increasing variability and uncertainty in water supplies. Variation in climate, legislation to protect endangered species, and water quality concerns may all influence water supplies. The major sources of water in most of the West are rivers fed by the spring melt of mountain snow packs. Snowmelt-fed flows in April, May, and early June comprise over 40% of the annual flow in western rivers (Wilkinson, 1992). The amount of water carried from the mountains by rivers depends not just on the quantity of precipitation, but also on the form and timing of the precipitation, as well as the pattern of winter and spring temperatures. Together, these factors determine how much water will flow during the spring into storage reservoirs. Given the dependence of water supplies on this multitude of climatic factors, variability of water supplies may increase with any impending change in global weather patterns (Moss, 1991).

In addition to climatic variables, there is uncertainty about water supplies due to legal requirements to protect endangered species habitat and water quality. Since water rights have been historically allocated only for consumptive and not in-stream uses, summer water levels have dropped in many western rivers and lakes, threatening numerous species and degrading water quality. For example, of the ninety-three species of fish listed as threatened or endangered in the United States, sixty-seven are found only in western rivers (Moore et al. 1993). Enforcement of the Endangered Species Act (ESA) of 1973 results in the necessity to maintain federally-mandated water levels in several western lakes and streams, such as Upper Klamath Lake in southern Oregon. Many western reservoirs are owned and operated by the United States Bureau of Reclamation (USBR), which, as a federal agency, must comply with section 7 of the ESA. This section compels all federal agencies to work toward the conservation of listed species and prohibits any federal action that jeopardizes listed species or their habitat. Thus, the many areas dependent upon federally-managed water supplies may be particularly vulnerable to decreased water availability for traditional out-of-stream uses.

Of all economic sectors in the West, the most water-dependent is arguably agriculture. Agriculture accounts for 80 to 90% of all water consumed in the seventeen western states. Almost 43 million acres are irrigated in the western states, while only 1.4 million are irrigated in other states. Irrigated lands also disproportionately contribute to total western agricultural value; although irrigated lands comprise only 27% of agriculture acreage in the West, they account for 72% of all crop sales (Gollehon and Quinby, 2000). The dependence of western agriculture on irrigation, and the proportion of the West's water that it consumes, signifies the extent to which agriculture is inextricably tied to and impacted by western water concerns.

With demand for water from other sectors increasing while available supplies are potentially decreasing, western agriculture's access to stable water supplies is becoming less certain. In the past, western agricultural producers have had to adjust to natural variations in water supplies, but in the future they will likely have to increasingly cope with both natural and legally-imposed water shortages. Since many rural areas in the western United States are dependent upon irrigated agriculture, water supply variation may have significant local economic impacts.

## 1.1 Problem Statement

One rural area heavily dependent upon irrigated agriculture is Malheur County, Oregon. Almost 20% of all county employment is agriculturally related. Malheur agriculture, however, has recently been greatly affected by natural water supply variations. In addition to these natural variations, in the future certain areas of the county may potentially be affected by societal-imposed restrictions on water usage.

One irrigation district in the county, the Vale Oregon Irrigation District (VOID), is particularly vulnerable to both natural and human-induced water supply variations. The VOID has faced very short water supplies (less than 2.5 acre-feet per acre) in six of the last fifteen years. The VOID is very susceptible to natural fluctuations in its water supply for four main reasons. First, it has a proportionately low level of reservoir storage for the number of acres it irrigates; when the VOID reservoirs are completely full, only 1.5 years' worth of water is stored. This means that the district is not able to store much water from an excellent water year into following years. Second, the Malheur basin, from which the district draws its water, is proportionately small. This results in more water supply uncertainty because there are fewer acres from which to collect runoff. Also, there is a higher probability that the basin, since it covers less area, will be bypassed by major storms and will not receive adequate snowfall. Third, many of the soils in the VOID are shallow and do not retain water well, which implies that crops are less able to utilize applied water. Finally, the VOID has very long canals, most of which are open, earthen ditches. These ditches result in a relatively high evaporation and seepage rate. Although some of this water 'lost' in seepage may become available for crop usage elsewhere in the Vale hydrological system, it is likely that some seepage will be lost to deep percolation or will drain into areas outside the VOID.

The Malheur basin, in addition to supplying VOID with irrigation water, is home to a member of the salmon family, the bull trout (*Salvelinus confluentus*), that is currently listed as threatened under the ESA. Throughout its range, it is believed that bull trout populations have declined partly because of diminished water levels due to irrigation (Oregon Fish and Wildlife, 2002). In its listing criteria, the United States Fish and Wildlife Service stated that "irrigation withdrawals including diversions can dewater spawning and rearing streams, impede fish passage and migration, and cause entrainment" (Federal Register, 1999).

Since the VOID is a USBR irrigation district, it is particularly vulnerable to ESA restrictions on its water withdrawals. As mentioned earlier, since it is a federal agency, the Bureau is legally bound to act to conserve endangered species and is prohibited from taking action that would jeopardize an endangered species. As was illustrated in 2001 with the USBR irrigation project in the Klamath Basin of Oregon and California, if water withdrawals potentially threaten an endangered species, the USBR can be required to reduce irrigation water availability. If actions of the USBR in its operation of the reservoirs that supply the VOID were determined to adversely affect the bull trout, the Vale Project may likewise be subjected to "federally-imposed drought".

Water quality is another concern in the VOID. One of the waterways in the VOID, Willow Creek, has been found to contain high *E. coli* levels. Willow Creek is actually part of the VOID distribution system; it functions as an irrigation conveyance canal for both withdrawals and return flows. Return flows refer to water that has been applied on one agricultural field, runs off, and then drains back into the irrigation ditches and other water courses to be used again in another field. The VOID distribution system currently relies heavily on these return flows in order to deliver water to all irrigators. The return flows, however, have caused a water quality problem in Willow Creek because the runoff contains fertilizer, pesticide, and, potentially, animal waste residues.

It is expected that in the next twelve years, return flows will be prohibited due to water quality concerns (Phillips, personal communication). If return flows are prohibited in the VOID, the district must either establish alternative return flow ditches or implement more efficient irrigation technologies, such as sprinkler and drip, in order to avoid potentially severe water shortages.

The Vale Oregon Irrigation District has faced water shortages repeatedly in the past decade. It may be that these natural water supply fluctuations will be exacerbated in the future by either climate change or environmental concerns to protect endangered species and safeguard water quality. Before such changes occur, it is important to gain an understanding of the importance of water to agricultural producers and ways in which producers adjust to, or mitigate for, changes in water supplies. Also, more generally, the dependence of the Malheur economy on irrigated agriculture combined with its diversity of agricultural production make it an excellent case study of the effects of drought on different types of producers and the greater regional economy.

## 1.2 Objectives

The overall objective of this study is to assess the economic importance of stable water supplies in an irrigation-dependent agricultural region such as Malheur County. The economic impacts of water variability to be analyzed include both direct impacts on agricultural producers and indirect impacts on other economic sectors. Specific objectives include: 1. Assess the potential for irrigators and the irrigation district to adjust to and mitigate the effects of water shortages, 2. Ascertain the potential for water transfers, either through water markets or water banks, to mitigate economic impacts,

3. Determine the economic value to producers and the irrigation district manager of improved weather forecasting, and 4. Calculate the economic consequences of these changes on the performance of the Malheur County economy.

### 1.3 Description of Study Area

The study area is located in Malheur County, which borders Idaho and Nevada in the southeastern corner of Oregon. According to the 2000 Census the county has 31,615 inhabitants. The largest town is Ontario, with a population of 10,985, while the county seat is located in Vale, population 1,976. Boise, Idaho, which is about 57 miles east of the county border, is the closest metropolitan area.

Land usage in the county is dominated by rangeland managed by the Bureau of Land Management (BLM), but intensively irrigated agriculture in the northeastern section of the county contributes heavily to the county economy. Malheur County has an arid climate; most lowland areas receive less than 10 inches of precipitation a year. Since the little precipitation that does fall arrives primarily in the winter months, irrigation is necessary for most agricultural production.

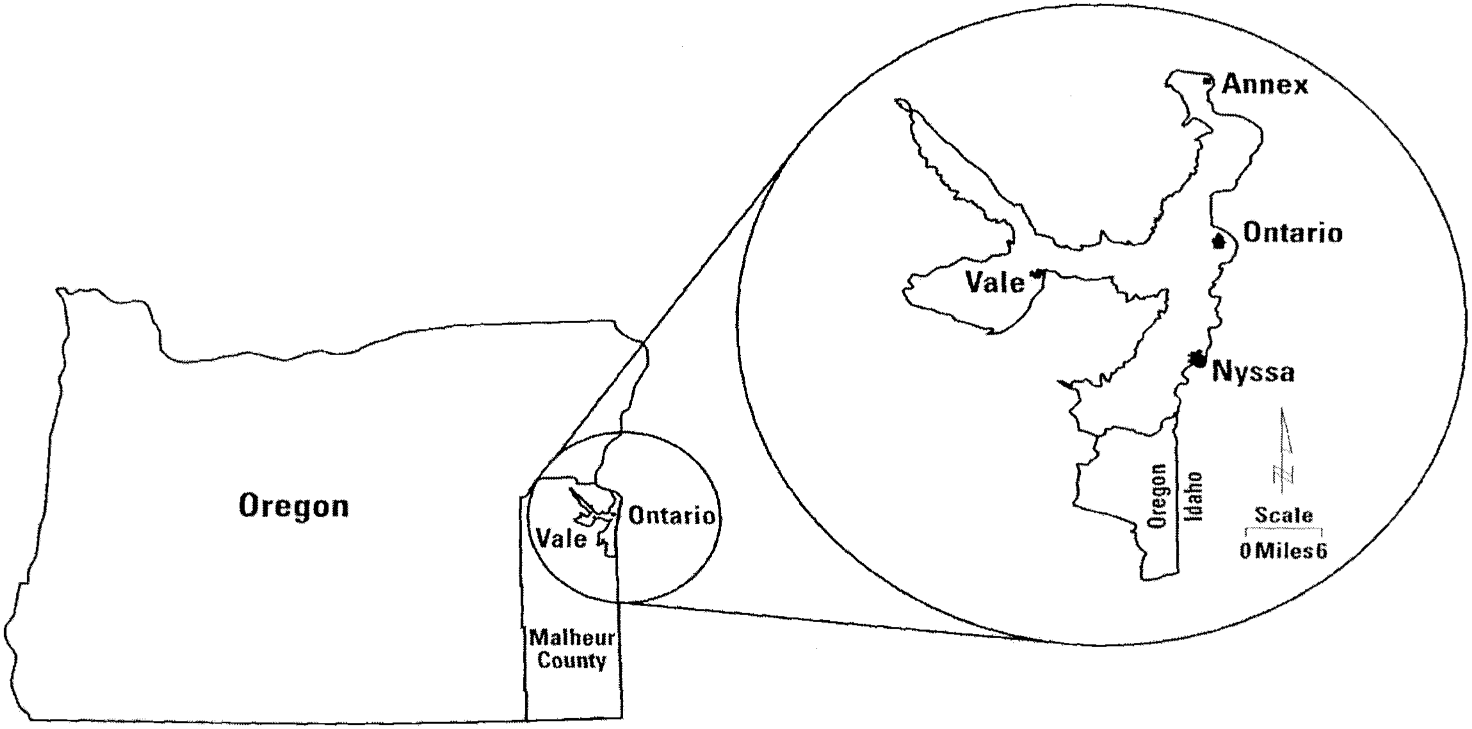
Of the three main irrigation districts in the county, the Owyhee, Warm Springs, and Vale districts, this project will focus specifically on the importance of water for irrigators in the Vale District and the subsequent economic ripple effects from the VOID to the other economic sectors in the county. The VOID, like the other irrigation districts, obtains its water supply from reservoirs that store spring snowmelt and runoff from higher elevations. The district depends upon three reservoirs, Warm Springs, Beulah, and Bully Creek that are located, respectively, on the Middle Fork of the Malheur River, the

North Fork of the Malheur River, and Bully Creek. Combined, these reservoirs provide the VOID with storage of 185,000 acre-feet of water.

The district's extensive canal system conveys water to 34,993 acres on 410 farms. Principal crops grown in the district include alfalfa hay, wheat, corn, sugar beets, onions, pasture, and potatoes. There are numerous cattle ranches in the district, as well as several large cattle feedlots and a few dairy operations. In 2002 the annual gross crop value in the VOID was $10, 945,422.

## Map 1: Location of Malheur County Agricultural Areas

(VOID comprises most agriculture west of Vale in the inset)



Source: Malheur Experiment Station, http://www.cropinfo.net/OtherReports/CooperativeStewardship.html

## 1.4 Thesis Organization

This thesis is organized into five remaining chapters. Chapter 2 contains a literature review of past studies of the importance of water for agricultural producers and their local economies. Chapter 3 provides a theoretical background for the mathematical programming and input-output models constructed for this analysis. It then describes the methodology and specific empirical models utilized in obtaining the necessary farm and county-level data. Chapter 4 presents an overview of the Malheur County economy. Chapter 5 presents and analyzes the model results for both the farm-level analysis and the county impact analysis under each water supply scenario. Finally, Chapter 6 summarizes the project findings and discusses implications and potential areas of further research.

# Chapter 2: Literature Review

## Overview

There is a vast body of literature examining the economic value of water in various uses. This literature review focuses on three areas of this work. First, it will discuss research on the value of water to farm-level production. Second, since the value of water to irrigators depends upon their ability to adjust to changes in water supply, this section will review studies of farmer responses to water shortages. The final area of research relevant to this project, the value of water supplies to agriculturally-dependent regional economies, will then be reviewed.

## 2.1 Value of Water to Farm-Level Production

The increased demand for water from non-agricultural sectors has motivated many studies of the value of agricultural water. Since water has historically been allocated by legal or institutional means rather than by markets, until recently there has been a lack of market price information from which to ascertain the agricultural (or other use) value of water. Due to this absence of market information, resource economists developed techniques to infer water values. These inferred values generated by economic assessments can be affected by a variety of factors: the measurement techniques employed, the nature of the data, and the types of assumptions made by the analyst (Adams, personal communication). Additionally, values for irrigation water depend upon the type of agricultural production, the production technology, and prices for agricultural inputs and products. While estimates of the economic value of agricultural water do vary, patterns emerge that provide a good understanding of the determinants of agricultural water values.

In economic terms, water use may be classified by its use as an intermediate good or an end good (Gibbons, 1986). Water that is used in production of another good or service, as in the case of irrigated crop production, is an intermediate good. Water used directly by the consumer in recreational activities or in the household is classified as an end good. The economic value of water in these two categories differs; the value of water as an end good is a function of the utility directly derived from its consumption, while the value of water as an intermediate good is derived from the value of the resultant product or service (Gibbons, 1986).

Since water is an intermediate product in agriculture, its value depends on the value of the crop that is being produced. Thus, a farmer's demand for irrigation water is a derived demand that depends on the demand for the product that the farmer is selling. As one would expect from demand theory, numerous studies have shown that the marginal value of water is higher for high-value crops than for low-value crops. For example, in a survey of valuation studies, Gibbons (1986) reports the marginal value of water (value of the last unit applied) can range from just a few dollars per acre-foot for a low-valued crop (grain sorghum) to $450 per acre-foot for a high-valued crop (fresh tomatoes). (Unless otherwise specified all water values are in 2002 dollars as adjusted by the agricultural prices received index.)

While many studies provide crop-specific marginal values of water, other studies estimate marginal and average water values based upon the current proportion of acreage dedicated to each crop type at a given location. The majority of these studies utilize mathematical programming models to estimate the value of water for the crops grown on farms representative of a region. For example, in a Colorado study of the foregone benefits of irrigation water transferred for urban use, the average value of water used to irrigate a crop mixture of alfalfa, corn, and sorghum on a representative farm was found to be $34 per acre-foot (Taylor and Young 1995). Another study of irrigation water transfers to hydroelectric generation found foregone benefits to representative farms in the Columbia River basin to range from $25 to $33 per acre-foot (Hamilton et al. 1989). Additionally, Adams and Cho (1998) report values for four regions of the Klamath Irrigation Project in southern Oregon and Northern California. In a region of the project dominated by low-valued crops, the marginal value of water across the crops in the region was $39 per acre-foot; in another region dominated by high-valued crops, the marginal value of water across the set of high-valued crops was $74 per acre-foot.

The marginal value of water depends not only on the value of the crop to which it is applied, but also on the quantity of water used by the crop. As water-use efficiency (defined as the proportion of applied water that is actually utilized by crops) increases, one expects that the marginal value of the water (or marginal willingness to pay for water) will also increase. Empirical evidence of this effect is found in a study by Bernardo et al. (1987), who inferred marginal values at $113/acre-foot when water was severely restricted and at only a few dollars per acre-foot when water supply was not restricted.

Another factor influencing the value of agricultural water is the productivity of the soil. As soil productivity increases, one expects that the value of irrigation water would also increase. This result has been verified by several hedonic price studies in

Oregon. Hedonic price analysis uses econometric methods to estimate the price of a property amenity (in this case, water rights appurtenant to the land), by comparing the price of properties with the amenity to the price of properties without the amenity. In an analysis of the value of water in the Klamath Basin, the estimated average value of irrigation water varied from $226 for very productive soils to $45 for less productive soils (Heffner, 1999). In a similar study of water values in Malheur County, the average value of one acre-foot of water was estimated at $35 per acre-foot for productive soils and $7 per acre-foot for the least productive soils (Faux 1996).

Finally, although water has traditionally not been allocated through markets, an increasing number of water transfers have occurred over the last decade from which we can directly obtain water prices. An example of a recent water transfer agreement is the Quantification Settlement Agreement (QSA) between two southern California irrigation districts, the Imperial Irrigation District of California (IID) and the Coachella Irrigation District (CID), and two urban water authorities, the San Diego County Water Authority (SDCWA) and the Metropolitan Water District of Southern California (MWD). Under a 40-year agreement finalized in October 2003, the IID and CID will reduce their water usage through conservation and fallowing and sell the water to the urban water authorities at the initial price of $223 per acre-foot (SDCWA, 2003).

## 2.2 Farmer Responses to Water Supply Fluctuations

The value of a stable water supply to irrigators depends upon factors affecting their ability to adjust to water shortages. Farm operators producing irrigated crops must decide which crops to produce, how many acres of each crop to plant, and what production technology to utilize on each crop. Their ability to adjust in making these decisions depends upon several factors, including their adaptation possibilities, unavoidable costs, and flexibility in input decisions (Iglesias et al. 2003).

For farms with high adaptability, significant water usage reductions can be achieved with relatively little impact on farm profits. One simulation of farming in the Columbia Basin found that economic returns to land, management, and fixed costs of irrigation declined less than 8% when water supply was reduced more than 36% and consumptive use was reduced by 29% (Bernardo et al. 1987). Other studies have revealed high costs to agricultural producers of unexpected, and hence unmitigated, reductions in water supply (Moore and Negri 1992, Keplinger et al. 1998).

When faced with limited irrigation water, one option available to irrigators is to deficit irrigate, which is to reduce water application to crops below optimal yield-maximizing levels. Bernardo et al. (1987) in their model of Columbia River Basin farms found that reducing water supply to alfalfa was the first adjustment that profit-maximizing irrigators would make in response to water supply reductions. In a separate simulation of Columbia Basin irrigators, Houston and Whittlesey (1986) found that modest changes in crop water consumption could be achieved with little reduction in crop value.

Irrigators can also reduce water usage by increasing water-use efficiency through better management and more labor-intensive techniques of surface irrigation. More frequent, smaller volume applications can increase water efficiency by reducing deep percolation, runoff, and residual water in the soil profile at the conclusion of the irrigation season. A study of representative Columbia River Basin farms showed that as water supply was reduced, it became profitable for irrigators to increase application efficiency utilizing labor-intensive management techniques (Bernardo et al. 1987). In other words, as water supply was reduced, its value rose relative to the cost of labor so irrigators substituted labor for the increasingly valuable water.

Another response possibility for irrigators facing short water supplies is substituting crops in production. Moore, Gollehon, and Carey (1994) found that as water price increases, irrigators are increasingly likely to reallocate acreage across crops. (Although this and many other studies focus on farmer response to water price, similar effects can be expected for farmer response to water shortage since as water becomes more scarce, its value tends to increase.) In an econometric analysis of western USBR irrigation districts, Moore and Negri (1992) found that water allocation levels are a strong determinant of crop acreage decisions. It appears that irrigators tend to allocate more land to low water-usage crops, such as barley, and less land to higher water-usage crops such as alfalfa, or to crops with higher value per unit of applied water (Bernardo et al. 1987, Houston and Whittlesey 1986, Moore and Negri 1992).

In addition to crop substitutions in response to water supply changes, irrigators can vary their total level of production by fallowing acreage. This alternative is typically utilized only when water supplies are drastically reduced. A study of seven representative farms in the Snake-Columbia River Basin revealed that profit-maximizing irrigators would begin idling land only when water supplies were reduced to 63% of normal (Hamilton et al. 1989). A similar pattern was found in a different study of Columbia Basin irrigators by Houston and Whittlesey (1986).

Other studies have focused on the effect that water supply availability or price have on irrigators' irrigation technology decisions. Traditional irrigation technology uses surface irrigation methods in which water is delivered across a gently sloped field by means of gravity. More modern irrigation technologies, such as sprinkler and drip systems, enable conservation of water since they result in higher rates of water use efficiency. The literature indicates that many factors, including soil quality, terrain, availability of groundwater, and factor input costs, influence the adoption of irrigation technology.

As economic theory would predict, empirical studies have revealed that irrigators tend to adopt more water-conserving technologies when it becomes economically advantageous (Negri and Brooks 1990, Lichtenberg 1989, Caswell and Zilberman 1985). Caswell and Zilberman (1985), in an econometric analysis of irrigation choices in the Central Valley of California, found that water price increases resulted in adoption of water-saving technologies such as sprinkler and drip. They also found that users of groundwater were more likely to adopt these more modern technologies because it was less costly for them to switch to the pressurized sprinkler and drip systems than it was for surface water users who used a system that was designed for gravity-fed surface irrigation. Although these studies indicate that irrigators behave in a profit-maximizing manner, it is important to note that several studies have found that the investment benefits of the modern irrigation technology may need to exceed the costs by a significant margin before irrigators will adopt the technology (Carey and Zilberman 2002, Khanna et al. 2000). This may be due to uncertainty about future water availability and prices, irreversibility of the technology switch, and the option to wait and invest at a later date.

Studies have shown that water-saving irrigation technologies are more economically advantageous on farms with lower quality soils that do not retain water well or are more steeply sloped (Caswell and Zilberman 1986, Negri and Brooks 1990, Dinar and Yaron 1990). In addition to conserving water, drip and sprinkler irrigation types increase yield because they enable more uniform water application on a farm field. Under surface irrigation, crop yields on lower quality soils suffer more from lack of uniform water application than crops on higher quality soils. Thus, more modern irrigation technologies can be "land quality augmenting" and cause a greater yield increase on poorer quality land.

Finally, the adoption of any of the aforementioned strategies will depend on the type of farm and the level of information and experience of the individual farm operator. Negri and Brooks (1990), in their econometric analysis of irrigation technology choice found that both regional location and farm size impacted irrigators' irrigation decisions. To explain the regional variation, the authors hypothesized that technological information is shared more in some regions than others, while farm size influenced the suitability of fields to pressurized irrigation. Additionally, Dinar and Yaron (1990) found that more experienced farmers and older farmer were less likely to adopt more modern irrigation technology.

## 2.3 Value of Water to Agriculturally-Dependent Regional Economies

The value of irrigation water in an economy extends beyond its direct value to agricultural production. When agricultural production varies due to water supply fluctuations, economic impacts will spread from agriculture through the local economy to other sectors. The extent to which other sectors will be impacted depends largely upon the structure of the local economy. In particular, the importance of the agricultural sector and the extent of economic links between the agricultural sector and other sectors will determine the magnitude of the total economic effects of water supply changes.

Economic responses to policy or resource changes can be classified into three effects: direct, indirect, and induced (as discussed in Charney and Woodard, 1990). Direct effects refer to impacts on employment and income that are immediately and explicitly related to the exogenous policy or resource change. In this case, the exogenous change is the reduction in farm revenue caused by water supply shortages. The direct effects are the initial impacts of the water supply shortages on businesses such as dairies, row-crop farms, and feedlots that produce agricultural commodities. (Direct effects as defined here are similar to the 'initial impacts' referred to by Miller and Blair, 1995.) Indirect effects are the effects caused by changes in inter-industry purchases due to the exogenous change. For example, the exogenous water supply change will affect demand from the agricultural sector for inputs from other sectors (such as fertilizer and farm machinery) and will thus affect the output of these sectors. Finally, there are induced impacts, which include any changes in spending from households as income increases or decreases due to changes in production in the directly and indirectly impacted sectors.

Although there are numerous studies on the direct value of water to agricultural producers, relatively few studies have focused on the indirect and induced impacts of agricultural water supplies on local economies. The overall importance of agriculture to economies has been extensively studied, however. For example, several studies have focused on the overall contribution of agriculture to a state's economy. A study of agriculture in Oregon found that all agricultural and food-processing sectors together contributed more than 143,000 jobs, or 8.4% of total Oregon employment (Cornelius et al. 2000). Leones et al. (1994) found in an input-output analysis of the California state economy that eliminating agricultural production would result in 8.8% and 9.9% declines in, respectively, total state income and employment.

The regional economic impacts of various agricultural programs have also been studied. One program in particular, the Conservation Reserve Program (CRP, a federal program that pays irrigators to take highly erosive farmland out of production), can result in indirect economic effects analogous to the effects imposed by water shortages. Since the CRP is a voluntary program in which irrigators receive a payment for reducing production, personal farm income may rise, while total community income may fall due to indirect, negative impacts on agriculturally-related industries. Since irrigators receive payments to offset reduced production, it is expected that the indirect and induced economic impacts of the CRP would be lower than for uncompensated production losses caused by water shortages. These studies, however, provide insight into the type and magnitude of effects caused by lower agricultural production.

Several CRP studies have illustrated that the net effects of reduced agricultural production depend upon the nature of local agricultural production and economic structure. A study of CRP effects in three, agriculturally-dependent Oregon counties revealed that effects on counties could range from a gain in local personal income of $22.65 per acre to losses of $79.62 per acre, depending upon the quality of land retired and the extent of local agriculturally-related industries; the higher the quality of land and the more developed the agriculturally-related industries, the greater the negative impact of reduced agricultural production (Martin et al. 1988). The study also indicated the sensitivity of assumptions about the effects of economic change on migration; with an additional assumption that 20% of population would migrate out of the county, personal income estimates ranged from a loss of $1.53 per acre to a loss of $101.55 per acre. The potential magnitude of CRP effects is also illustrated in a study on the state of North Dakota. Findings indicated that $54 million in reduced agricultural expenditures (farm purchases of supplies, insurance, and reduced farm labor income expenditures) resulted in indirect and induced effects totaling $140 million (Leistritz, et al. 1993).

Several of the studies investigating the regional economic effects of a reduction in groundwater availability have examined the impacts of water transfers that shift water from rural, agricultural use to urban areas. Although water transfers can create economic opportunities, they also often create economic hardship in the original usage area (Gollehon, 1999). One water transfer study analyzed impacts of agricultural to urban transfers in the Arkansas Valley of Colorado. This area is heavily dependent upon agriculture and has a large food-processing industry. Findings indicate that water transfers comprising 14% of original water consumption resulted in a loss of 157 local jobs and net income loss of $52 per acre-foot of water (Howe et al. 1990).

Another water transfer study examined the effects of "water farming" in Arizona. Due to the scarcity of water, many speculators in Arizona are purchasing farmland not for the land, but for the water rights appurtenant to the land. This study estimated the impacts on one county of retiring 1,000 acres of agricultural land with a crop mix consisting of equal parts high-valued and low-valued crops. Findings indicated that reduced production in the county would result in 17 lost jobs and reduced total personal income of $356,000 (Charney and Woodard, 1990).

A comprehensive study of the regional effects of the transfers of water from agriculture to the environment that occurred in the Klamath Basin in 2001 presents both estimated and actual economic impacts of agricultural water shortages (Jaeger, 2001). The regional impacts were based on an estimated 86% reduction in irrigated acres causing a direct loss of 50% of agricultural output ($85 million). The subsequent indirect regional losses in output were estimated by the regional model to be $19 million, and the induced output impacts were assessed at $17 million. Combined, these output reductions were estimated to result in a $82 million loss of personal income (3.4%) and a loss in regional employment of 1,956 jobs or 3.3%.

The actual reported outcomes in the Klamath Basin study were less severe, primarily due to an unexpected number of newly drilled wells providing irrigation water to crops, emergency government payments, and above average crop prices in 2001. The reported acreage declined only 53% (compared to the estimated 86% reduction) contributing to a loss of agricultural output of 25.6%. The actual regional employment impact was reported to be a loss of 2.3% (compared to the estimated 3.3% reduction). The disparity between the estimated and actual value of agricultural production acreage resulted in higher estimated regional economic losses and employment impacts than were actually experienced in the Klamath.

Although outside the scope of this study, it should be noted that in addition to the economic value of water to irrigators and their communities, there is a cultural value of water supplies for rural, agrarian economies. In their study of water in the Southwest, Ingram and Brown (1987) found that water is closely tied to community perceptions of security, opportunity, participation, and well-being. For rural communities with a tradition of irrigation-based agriculture, a stable water supply can be of considerable value in enabling continuation of a way of life (Ingram and Oggins, 1992).

## Chapter 3: Analytical Procedures

This study utilizes two types of models: a mathematical programming model to simulate farm-level responses and associated changes in income due to water supply fluctuations, and an input-output model to estimate county-level economic effects of the changes in farm income. Specifically, a linear mathematical programming model is constructed to analyze the economics of agricultural production under varying water supplies in Malheur County. Responses of irrigators to water changes given current irrigation technologies are modeled, as well as more long-term production responses when irrigation technology is allowed to vary. Additionally, the model is solved under varying assumptions about the accuracy of water supply forecasts and resultant allocations of water to irrigators to estimate the value of more accurate forecasts. The use of a water market or a water bank to improve allocation efficiency is also investigated with the farm-level model. Under each water allocation scenario, changes in farmer income, as well as changes in total agricultural production value, are estimated.

Results from the linear programming model are then used in the second model, an input-output model of the Malheur County economy. The input-output model enables analysis of how the change in agricultural production value due to the water resource changes will affect other economic sectors in the county. Using this model, estimates of the regional economic income and employment will be obtained for each water allocation scenario. Additionally, the regional income and employment effects of adopting additional irrigation technology and/or a water market or a water bank are investigated.

## 3.1 Models of Firm (Farm) Behavior

Economics is usually defined as the study of the allocation of scarce resources between competing ends for the maximization of those ends over a specific period of time (Casavant et al. 1999). For example, with respect to problems of the firm, a substantial amount of economic study is directed at how firms maximize profit subject to resource constraints such as land and labor. Since linear programming models are quantitative tools utilized to solve optimization problems, linear programming (LP) is a very useful tool in studying problems of firm output or production. Agricultural production is particularly well-suited to linear programming analysis since there are clearly defined resource constraints and production costs, and these are often well approximated by linear functions (Hazell and Norton, 1986).

In constructing the linear programming model used to simulate agricultural production in the VOID, certain important aspects of economic theory were utilized. Specifically, the farm in this model is analogous to the concept of a multi-output firm in microeconomic theory, so the theory of the firm and its production decisions is particularly relevant. This section will briefly review the foundations of production theory and how it is applied in the model.

To facilitate analysis of the economic behavior of firms, one typically begins with an assumption of the firm's underlying objective. This study is based on the assumption of most production economics: firms, or in this case, farms, seek to maximize profit. Profit can be expressed as total revenue minus costs, or mathematically:

$$\Pi = \sum_{i=1}^{n} p_i\, y_i - \sum_{j=1}^{m} c_j\, x_j$$

where $\Pi$ = profit,
$p_i$ is a vector of output prices,
$y_i$ is a vector of outputs,
$c_j$ is a vector input costs,
and $x_j$ is a vector of inputs.

In seeking to maximize profit, irrigators must make decisions about which crops or livestock to produce, how much of each of these commodities to produce, and what technology to utilize in their production. Central to the study of how firms make these decisions is the concept of the production function, which describes the relationship between inputs to the production process and the resulting outputs. Using the vectors defined above, a generic multi-output production function can be specified as:

$$Y_1, Y_2, \ldots\ldots Y_n = f(X_1, X_2 \ldots\ldots X_m)$$

In this expression, the vector of Y outputs are a function of the quantities of the vector of X inputs using a production technology represented by the function *f*. More concretely, we can define a production function for a specific crop output:

$$\text{Wheat (ton/acre)} = f(\text{Water, Labor, Fertilizer, Soil Quality})$$

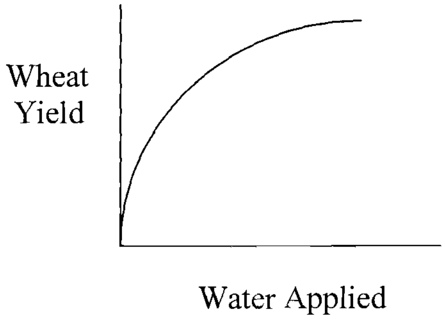
In this expression, the output of wheat is an unspecified function of the quantity of inputs of labor, water, fertilizer, and quality of soil, given a level of technology.

As is the case in this study of varying water supplies, economists are often interested in how output will change when only one of the inputs varies and the other inputs are held fixed. An example would be an expression of wheat as a function of water applied when labor, fertilizer, and soil quality are constant. Mathematically, this can be expressed as:

$$\text{Wheat (ton/acre)} = f(\text{Water} \mid \text{Labor, Fertilizer, Soil Quality}).$$

When production functions are expressed in this manner, the analyst can gain a better understanding of the response of the output (i.e. wheat) when one input (i.e. water) varies. Limiting the analysis to one variable also facilitates graphical representation, such as the stylized wheat response function depicted in Figure 1.

**Figure 1: Hypothetical Response of Wheat Yield Output to Water Input**



The area under the curve in Figure 1 represents the technologically feasible production area, while the line represents the maximum possible wheat production for any given level of water input.

This type of graphical analysis is also helpful in understanding the value of the water applied. In Figure 1, wheat yield does not increase at a constant rate as more water is applied. The marginal product of water (the additional unit increase in wheat due to an additional unit of water) varies for different levels of water applied. Mathematically, the marginal product of an input is the partial differential of the production function with respect to the input:

$$\frac{\partial f(\text{Water, Labor, Fertilizer, Soil Quality})}{\partial \text{ Water}}$$

In Figure 1, when water application is low, increasing the water applied results in a sharp increase in the wheat yield, or a high marginal product. However, as more water is applied, there is less of a response in the wheat yield (lower marginal product), since the slope of the function decreases as more water is applied. Production functions are often this shape due to the common phenomenon of diminishing marginal rates of return: when other inputs are held fixed, as more units of one input are added to the production process, each additional unit of input results in fewer additional units of produced output.

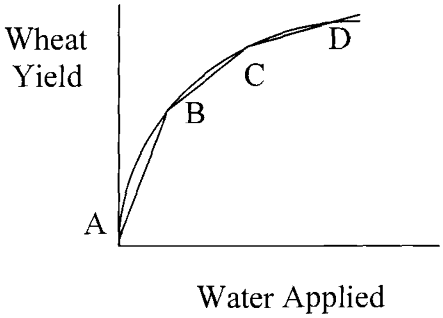
In the production process, the value of an input such as water is measured solely by its contribution to increasing physical output, such as an additional bushel of wheat. The value of that increase in physical units can be obtained by multiplying the increased output by the price of the output. For this example, the marginal value of one additional unit of water (also known as the marginal value product, MVP, of water) can be calculated as the marginal product of water multiplied by the price of wheat. When the production function exhibits diminishing returns then, the marginal value product of an input (the value of the last input unit added) will decline as the input level rises. Mathematically, the marginal value product can be expressed as:

$$\frac{\partial f(\text{Water, Labor, Fertilizer, Soil Quality})}{\partial \text{ Water}} * \text{Price}_{\text{wheat}}$$

Thus, the MVP of an input depends not only on how much of the input is being utilized, but also on the value of the output.

In the case of linear programming, where all functions are linear, a curved production function such as that represented in Figure 1 has to be approximated. This is possible by defining multiple, linear response relationships between the input and the output for different levels of the input. Using the above example of wheat output and water input, we could define three linear relationships between wheat and water. This is graphically represented as:

**Figure 2: Linear Approximation of Nonlinear Production Function**



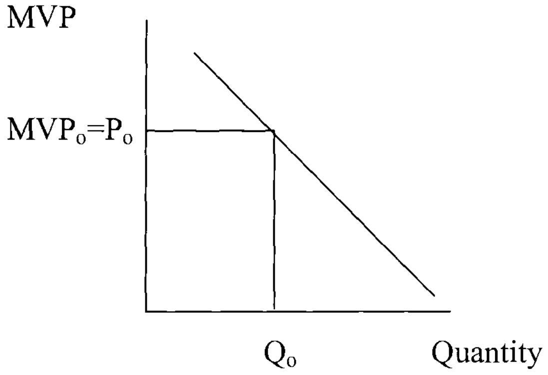
For water application rates between points A and B, one linear equation would apply, while between points B and C, a different linear equation is appropriate, and between points C and D, yet another linear equation would apply. Utilizing multiple, or segmented, response functions thus enables linear programming to approximate non-linear production relationships.

In order to maximize profits, firms should utilize an input up to the point where the marginal cost of the input (the input or factor cost) is equal to the marginal value product of the input. For example, if the marginal cost of water were $4 per acre-foot, water should be utilized until the MVP of water applied is equal to $4 per acre-foot. This is probably best understood when one considers the case when MVP, or marginal revenue, is different from the marginal cost: if the revenue from using a unit of water is greater than the price of water ($4 per acre-foot), then the producer could make more profit by applying more water. Likewise, if the revenue from that next unit of water is less than $4 per acre-foot, then the producer is reducing total profit by utilizing the last unit of water. Only when the revenue of an additional input equals the cost of the input can the producer maximize profit.

In the case of a restricted water supply, in which the farmer cannot simply buy more water on a market to achieve the equilibrium between revenues and input costs, water cost is often best reflected in its opportunity cost. Opportunity cost reflects the value of a resource based on the highest value of the resource in an alternate use. For example, consider a farm on which water may be used to produce a range of crops. If a unit of water is utilized in producing wheat, the farmer is foregoing the use of the water in producing another crop, so the opportunity cost of water in wheat production is the marginal value product of the water in the next highest-valued crop. When the MVP of an input is equalized across all crops, the farmer can maximize profits under restricted water supplies.

The MVP is an important economic concept because it underlies the demand, or willingness to pay, curve for an input. Since MVP represents the additional value to the producer of utilizing an input or resource, it is the maximum amount the producer would be willing to pay for the next unit of the resource. The construction of a demand curve therefore entails finding the MVP of an input for different input levels. If the production function exhibits diminishing rates of return, and thus decreasing MVP, then the demand function will be downward sloped:

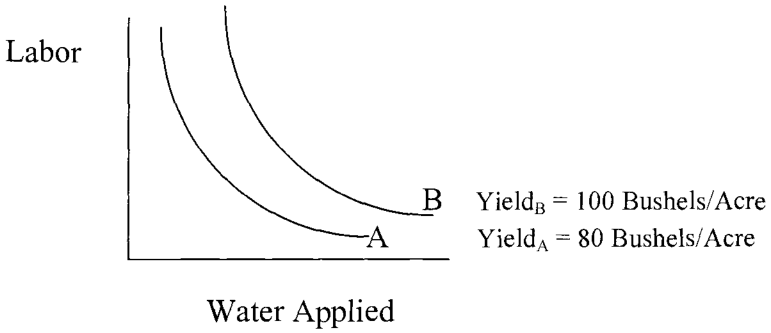
**Figure 3: Input Demand Curve Constructed from MVP**



In the above diagram, at the quantity $Q_0$, the MVP is equal to $MVP_0$, so this is the maximum the producer would be willing to pay for one more unit of Q. If the producer faces a market factor price of $P_0$, then he or she would demand quantity $Q_0$ of the input.

Inputs, or factors of production, can be substituted in most production processes. For example, to obtain the same yield, more intensive labor practices could be substituted for water. This can be represented graphically as:

**Figure 4: Factor Substitution Isoquants for Wheat Yield**



The curves in Figure 4 are isoquants; along each individual curve, the output is the same, but the combination of inputs varies. For example, combinations of inputs along isoquant B enables production of 100 bushels of wheat per acre, while every combination of inputs along isoquant A enables production of 80 bushels of wheat per acre. The fact that isoquant B represents more total output reflects the higher amounts of each input in the combinations represented by the isoquant. As we move along isoquant A to the right, we are substituting water for labor, while holding output constant. The rate at which one input can substitute for another input along an isoquant is called the marginal rate of technical substitution (RTS.) Mathematically this is the slope of the isoquant, which in this example is:

$$\text{RTS} = -\frac{\text{d labor}}{\text{d water}}$$

By computing the total differential along an isoquant, we can also determine that the RTS is equal to the ratio of the marginal products of the two inputs for every point on the isoquant:

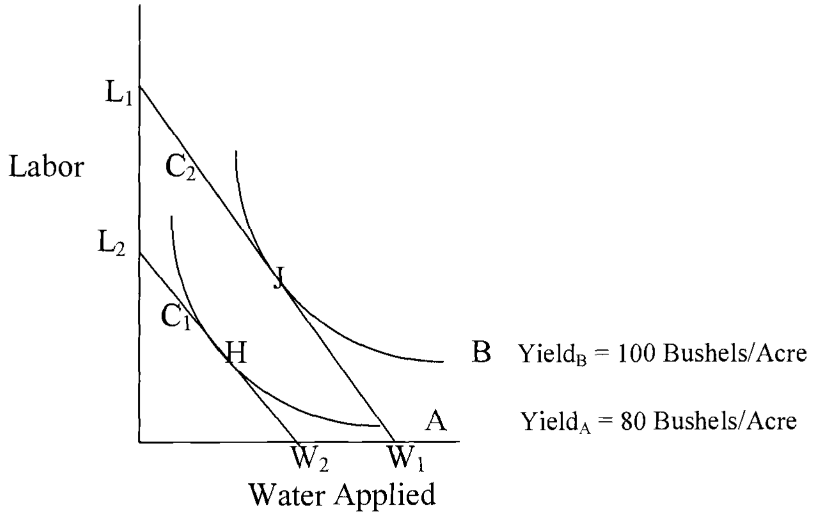
$$\text{RTS} = \frac{\partial f(\text{water, fertilizer, soil quality})/\,\partial\ \text{labor}}{\partial f(\text{water, fertilizer, soil quality})/\,\partial\ \text{water applied}}$$

In order to maximize returns to the farm's resources, irrigators need to cost minimize; that is, they need to produce their outputs using the least expensive combination of inputs. Irrigators can do this by substituting inputs such that the RTS of two inputs is equal to the ratio of input prices. In our example, this would be:

$$\frac{-\partial f(\text{water, fertilizer, soil quality})/\,\partial\ \text{labor}}{\partial f(\text{water, fertilizer, soil quality})/\,\partial\ \text{water}} = \frac{\text{Price}_{\text{labor}}}{\text{Price}_{\text{water}}}$$

Graphically this is represented as:

**Figure 5: Cost Minimization Subject to a Given Level of Output**



Lines $C_1$ and $C_2$ in Figure 5 are isocost lines; total costs are the same for all combinations of labor and water along each isocost line. The slope of the isocost line is equal to the price ratio of water/labor.[1] Since costs are increasing as we move away from the origin (because we are utilizing more inputs), to minimize the costs of producing a given level of production, the firm should produce on the isoquant at the closest feasible point to the origin. This point is where the isocost line is tangent to the isoquant representing the desired level of production. As we can see from the graph, to minimize the costs of producing 80 bushels of wheat per acre, we would want to use the combination of labor and water at point H, while to minimize costs of producing 100 bushels of wheat per acre, we would want to produce at point J.

To increase production from 80 to 100 bushels per acre, we would move from point H to point J. We could add to the graph an infinite number of isocost curves and

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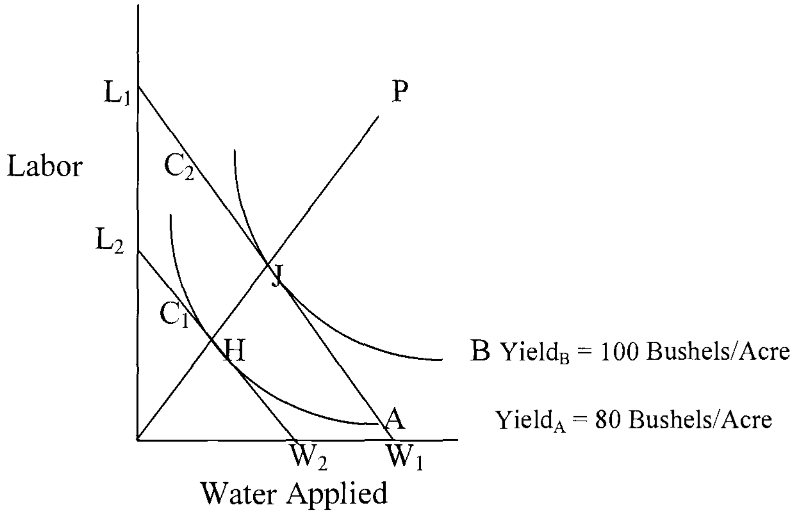
[1] To calculate the slope of the isocost line: The x-intercept is equal to Total Cost/Price of Water, while the y-intercept is equal to the Total Cost/Price of Labor. The slope is the ratio of the y-intercept/x-intercept, and we thus get slope=Price of Water/Price of Labor.

isoquants to obtain a firm's expansion path, or locus of cost-minimizing strategies (Nicholson, 2002). Graphically, the expansion path is depicted as:

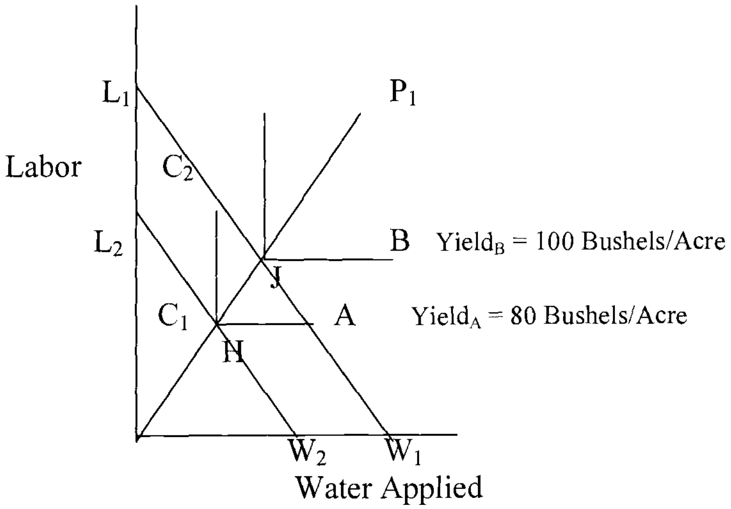
**Figure 6: Expansion Path P of a Wheat Producing Farmer**



The line from the origin to P is the expansion path and describes how this farmer can minimize inputs in order to produce any level of wheat. Although the expansion path in Figure 6 is linear, this is not always the case.

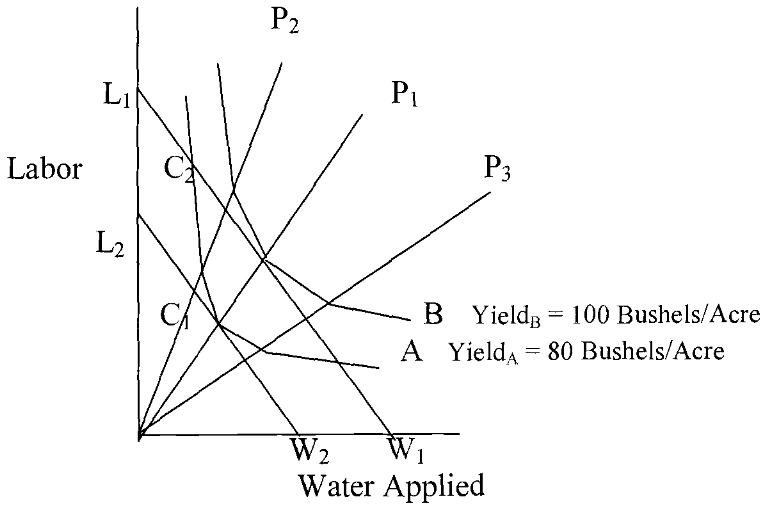
As depicted in Figure 6, isoquants are typically curved to illustrate that inputs are continuously substitutable. In linear programming, however, inputs are not continuously substitutable. Rather, input resources are specified in fixed ratios as depicted in Figure 7. Along, for example, isoquant A, the inputs of water and labor are fixed at point H in order to produce 80 bushels of wheat per acre. In order to increase production to 100 bushels of wheat per acre, the farmer would have to produce at point J. This is the only means for the model to achieve greater production, but it may not represent the least cost method of production since it does not allow full factor substitution.

**Figure 7: Expansion Path $P_1$ of a Wheat-Producing Farmer**



Since inputs are often substitutable, it is important for a model of farm production to reflect input flexibility in order to better simulate reality. To allow the programming model to select other, potentially less costly, expansion paths, multiple isoquants are constructed that represent additional production processes. This then results in an approximation of the curved isoquant and enables the model to choose between multiple production possibilities.

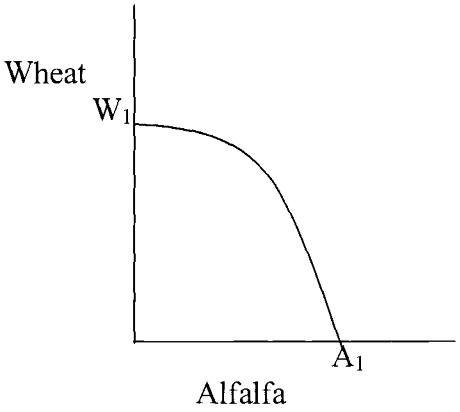
**Figure 8: Expansion Path $P_2$ of a Wheat-Producing Farmer**



In Figure 8, the expansion path $P_3$ could represent the least costly means of producing wheat under one type of intensive irrigation technology, such as furrow irrigation, while expansion paths $P_2$ and $P_3$ could represent least cost production using less water intensive irrigation technologies, such as sprinkler and drip irrigation. Constructing multiple isoquants with different production technologies in a linear programming model thus enables factor substitution by approximation of non-linear isoquants.

The expansion path describes the method by which profit-maximizing producers can choose *how* to produce their products: they substitute inputs until the ratio of the marginal value products is equal to the input prices. In addition to factor substitution, irrigators can substitute outputs, such as alfalfa for wheat, in an effort to increase profits. The optimal mixture of outputs, or what and how much the farmer produces, is determined in a similar manner. The choice between outputs for a fixed level of inputs is represented by the production possibilities frontier (PPF).

**Figure 9: Production Possibilities Frontier for an Acre of Land**

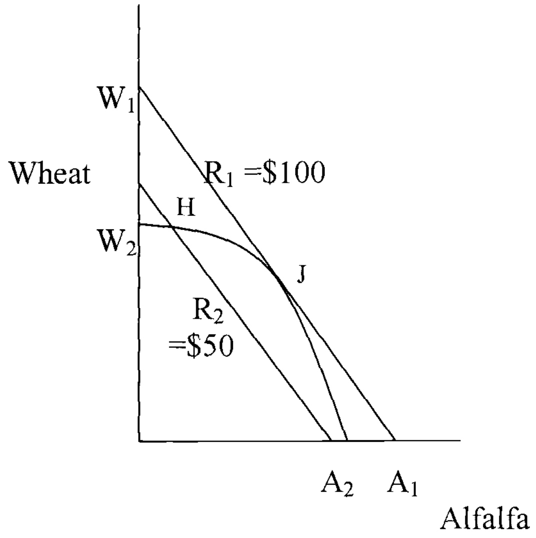


For a given level of inputs, say two acre-feet of water per acre, it is feasible to produce any combination of alfalfa and wheat outputs in the area under the PPF. The PPF itself represents the maximum possible production of outputs for the given inputs or resource endowment. As is evident from Figure 9, there are trade-offs for the farmer between producing wheat and producing alfalfa. The slope of the PPF gives the rate at which one output can be substituted for another given the resource endowment, and is called the rate of product transformation (RPT). For the above example, the RPT can be mathematically expressed as the change in wheat divided by the change in alfalfa:

$$-\ \frac{d\ \text{Wheat}}{d\ \text{Alfalfa}} = \text{Slope of PPF}$$

This production trade-off between physical outputs can be related to the profit maximizing level of outputs by connecting the change in output shares with the change in profit. Figure 10 diagrammatically illustrates these tradeoffs.

**Figure 10: Profit Maximization Subject to a Given Level of Output**



The lines $R_1$ and $R_2$ in Figure 10 are isorevenue lines; all combinations of outputs along each isorevenue line $R_1$ result in net revenue of \$50 per acre, while all combinations of outputs along $R_2$ result in net revenue of \$100 per acre. All isorevenue lines for two outputs have the same slope: the ratio of the output prices, or in this example,

$\text{Price}_{\text{alfalfa}} / \text{Price}_{\text{wheat}}$.[2]

Since revenue is increasing as we move away from the origin (because we are producing more outputs, and prices are assumed to remain constant), to maximize profit for a given level of resource endowment, the firm should produce on the isorevenue line at the farthest feasible point from the origin. This point is where the isorevenue line is tangent to the PPF. As we can see from Figure 10, to maximize profit given the levels of inputs represented in the PPF, we produce the combination of wheat and alfalfa represented by point J. Mathematically, we express this optimal share of production between outputs as the point where:

$$\text{RPT (slope of PPF)} = -\frac{d\ \text{Wheat}}{d\ \text{Alfalfa}} = \frac{\text{Price}_{\text{alfalfa}}}{\text{Price}_{\text{wheat}}}$$

Thus, the farmer produces a level of each commodity such that the ratio of prices is equal to the ratio of the marginal opportunity costs of producing the commodities.

Finally, economic analysis of firm behavior also depends upon the type of market in which the firm is believed to be operating: monopolistic, imperfectly competitive, or competitive. As in most models of agricultural production of annual crops, we assume the classic case of a perfectly competitive market. Important characteristics of a perfectly competitive market include:

1. Large numbers of buyers and sellers, such that no firm's production affects price of inputs or outputs,
2. Free entry and exit of firms into the market,

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[2] The slope of the isorevenue line can be calculated as follows: The Y-intercept equals Revenue/$\text{Price}_{\text{wheat}}$ while the X-intercept equals Revenue / $\text{Price}_{\text{alfalfa}}$. The slope then is $\text{Price}_{\text{alfalfa}}/\text{Price}_{\text{wheat}}$.

3. Perfect knowledge and information among producers about technologies, market prices and costs,
4. Homogeneous products, such that consumers cannot differentiate output from different producers.

Although agriculture may not be a perfectly competitive industry, it is generally regarded as well approximated by the perfectly competitive model (Casavant et al. 1999).

### 3.2 Applicability of Linear Programming

Linear programming is a mathematical optimization technique; its purpose is to find the maximization (minimization) solution to a linear function subject to a set of constraints. This linear function to be maximized (minimized) is referred to as the objective function and is expressed in terms of decision variables. In this application, the decision variables include the mix of crops produced and the production technology utilized. The values of the decision variables must be feasible, where feasibility is defined by a linear set of resource constraints, such as limits on available land and water. Implicit in linear programming models are several assumptions about the production process, the resources utilized, and the decision variables. As outlined in Hazell and Norton, important assumptions implicit in all linear programming models include:

1. *Optimization*: There is an objective function to be optimized. For example, in this study, economic returns are maximized for the crop decision variables. This assumption is reasonable for the VOID model since it is generally assumed that farmers' behavior is consistent with maximization of profit.

2. *Finiteness*. There are a finite number of possible decision variables and constraints. Since the decision variables for VOID irrigators are well approximated by a limited set of crop and production choices, and the constraints are limited to well-defined production requirements, this assumption is not unduly restrictive for the VOID model.
3. *Fixedness*: At least one constraint has a non-zero limit. This applies in the case of the VOID since both water and land resources are finite and limited.
4. *Determinism*: All coefficients in the model are assumed to be known and constant. For example, the parameters in the production process do not vary between irrigators and are known to the analyst. In the VOID, the variation across the production parameters of individual irrigations is largely accounted for by utilizing six representative farms to represent the diversity of production alternatives. Additionally, the use of location-specific enterprise budgets and interviews with VOID farmers assures a level of accuracy in the parameters utilized in the model.
5. *Continuity*: The resources and decision variables can be utilized and produced in fractional quantities. In the VOID LP Model, there are no resources or decision variables that are definable only in integer quantities so this assumption is also reasonable. For example, fractional quantities of acres of wheat could be produced, and on any farm, fractional quantities of fertilizer or hours of labor could be utilized on every acre.
6. *Additivity*: The contributions of each decision variable to the objective function are additive such that there are no interaction effects between

decision variables. For example, the value of wheat production does not vary depending on the value of other decision variables, such as corn or alfalfa production; the total product value for the farm is the sum of the individual crop production values. Although there are interaction effects between crops produced due to differences in soil nutrient use by different crops, they are well controlled in the model by applying crop rotation constraints.

7. *Proportionality*: The price and resource requirements of each unit of a decision variable should be constant such that the total contribution of each decision variable to the objective function is proportionate to the level of production. The constant price implies a competitive market in which the firm is a price taker, and the fixed resource requirements assume constant returns to scale and a linear expansion path from the origin. Constant prices for all levels of production of decision variables are reasonable since agricultural products in the VOID are sold on competitive markets and the production of any commodity in the VOID is not large enough to affect the price for that commodity. Production requirements in the VOID are not necessarily proportionate, but by incorporating representative farms of different acreage sizes and allowing various technologies to be utilized, the model approximates curved isoquants and non-linear expansion paths. Consequently, the model does not strictly require proportionality in resource requirements and enables this assumption to be relaxed.

It thus appears that the general conditions for linear programming to be a valid modeling framework are sufficiently met to justify the use of linear programming to model agricultural production value in the Vale Oregon Irrigation District.

### 3.3 Description of the Linear Programming Model

A linear programming model incorporating six representative farms was constructed to simulate the response of VOID irrigators to various water supplies and the resulting effects on farm revenue and returns. The model was written in the General Algebraic Modeling System (GAMS), which is a modeling system for mathematical programming problems. Initially, a baseline model was created in which irrigation and production technologies were set at estimated 2004 levels.

It was assumed in this baseline model that irrigators had no information about the water allotment when deciding their crop mix other than knowledge of the historical probabilities of different allotments. Therefore, this model predicted a set crop mix (to be planted every year) that maximized expected farm returns based on the historical probabilities of four annual water allocations: 3.5, 3, 2.5, and 1.67 acre-feet per acre[3]. With only historical information on water supplies, planting the same crop mix every year is a profit-maximizing behavior since every year the farmer has the same water supply information. Since the water supply information is constant, the crop mix that will maximize profit one year will be the same as the crop mix that will maximize profit every other year (assuming all else is constant).

In addition to predicting the profit-maximizing crop mix to be grown ever year, the model selected the management intensity and water level applied to each crop acre that maximized returns for each VOID water allotment level. The impact of water availability was determined by the difference in both net farm returns and total agricultural production value between a full water allotment (3.5 acre-feet) and the three water shortage scenarios. In these short-run water deficit scenarios, it is assumed that unexpected water supply changes do not affect irrigation system choice or fixed production costs.

The two decision variables for each representative farm in this model are the water application level and the quantity of acreage to plant of the major crops grown in the VOID: alfalfa hay, corn, native hay, onions, pasture, potatoes, sugar beets, and wheat. In water short years, irrigators also often plant barley. Combined, these nine crops have accounted for over 90% of the crop acreage in the VOID each of the last eleven years (see Table 1) so they represent well the available crop decision variables for VOID irrigators.

Crop production costs were obtained from local crop enterprise budgets prepared by the Oregon State University Extension Service, with additional information provided by VOID producers. Enterprise budgets summarize common production costs and returns for a crop or agricultural enterprise given certain assumptions about local production practices and farm characteristics. Several Malheur County enterprise budgets provided

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[3] Historical probabilities were calculated based on data from 1981-2003 (data from prior years was unavailable). Probabilities for each water allotment are: .3043 for 3.5 acre-feet, .2609 for 3 acre-feet, .1305 for 2.5 acre-feet, and .3043 for 1.67 acre-feet.

aggregated fixed and variable costs of production activities. Since the LP models in this study only incorporated variable costs of crop production (with the exception of fixed irrigation capital costs), it was necessary to separate the fixed and variable costs in these enterprise budgets. This was accomplished by utilizing crop enterprise budgets from other southeastern Oregon counties that provided separate variable and fixed costs for each production activity.

Proportions of variable to total costs were calculated for each production activity in these southeastern Oregon crop budgets and then the proportions were applied to the total costs in the Malheur County budgets to obtain estimates of Malheur County variable production costs. All crop production costs depicted in Table 2 were indexed to 2002 dollars and were adjusted using the National Agricultural Statistics Service index for prices paid by agricultural producers.

The numerous irrigation technologies utilized in the VOID are also incorporated in the model. Currently, VOID irrigators predominantly use surface irrigation methods (Ron Jacobs, Lynn Jensen, Lance Phillips, Scott Ward, personal communication). Surface methods include flood irrigation (FL), in which a crop (primarily pasture) is flooded periodically throughout the growing season, and furrow irrigation, in which furrows for water application have been made between the rows of planted crop. Furrow irrigation can be accomplished through the usage of siphons tubes or gated pipes, both of which apply water at the top of a slightly inclined field. Once the water is applied at the top of the field, it is then pulled by gravity down the furrows in the field. The irrigation canals from which siphons draw water can be concrete or earthen; concrete are more capital intensive but achieve a higher water use efficiency due to less seepage. Additionally, furrow systems can be coupled with tailwater reuse systems, which collect runoff water in ponds to be reused again on other crops on the farm. In the model, these various combinations of furrow irrigation types are grouped into three categories based on capital costs, labor costs, and water use efficiency: furrow, modern furrow, and modern furrow with tailwater. Furrow irrigation (F) refers to siphon irrigation with earthen ditches. Modern furrow (MF) includes both siphon irrigation with concrete ditches and gated pipe systems since the costs and water use efficiency of these two types are generally equivalent. Finally, modern irrigation types (siphon with concrete ditches or gated pipe systems) coupled with tailwater reuse systems constitute another category, modern furrow with tailwater (MFT).

Sprinkler usage has become more prevalent in the VOID in recent years, with solid set sprinklers (SS), center pivots (CP), and wheel lines (WL) as the primary sprinkler types (Lynn Jensen, Lance Phillips, personal communication). Additionally, several VOID irrigators are now utilizing drip irrigation systems (D) on onion fields. Irrigation system choice affects many aspects of crop production, including capital costs, labor costs, and water use efficiency (percent of water applied that is actually utilized by the crop). Furthermore, drip irrigation has been found to increase onion yields due to its superior uniformity in water application. This benefit to drip irrigation has been incorporated into the model by creating two onion crops with different yields: onions irrigated by drip systems, and onions irrigated by all other irrigation systems. The eight irrigation systems (FL, F, MF, MFT, SS, CP, WL, D) and their associated costs and benefits (see Table 3) are incorporated in the model as available technology options.

## Table 1: Modeled Crops as a Percentage of All VOID Irrigated Crops

| | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Alfalfa Hay | 7871 | 8579 | 9925 | 10039 | 8953 | 9356 | 11305 | 11159 | 11441 | 13285 | 14413 |
| Barley | 2890 | 1590 | 1765 | 1409 | 942 | 940 | 760 | 790 | 1994 | 516 | 379 |
| Corn | 3608 | 5787 | 4695 | 5274 | 5704 | 5732 | 5110 | 5375 | 4775 | 4004 | 4150 |
| Native Hay | 1286 | 2989 | 1536 | 1547 | 1000 | 910 | 1352 | 1258 | 2047 | 2568 | 2099 |
| Onions | 278 | 412 | 449 | 377 | 353 | 348 | 234 | 436 | 394 | 462 | 351 |
| Pasture | 6448 | 7825 | 8603 | 8623 | 9237 | 9059 | 9263 | 9634 | 9931 | 10070 | 9202 |
| Potatoes | 433 | 755 | 960 | 883 | 1151 | 1078 | 1002 | 988 | 720 | 644 | 643 |
| Sugar Beets | 827 | 681 | 772 | 871 | 658 | 495 | 821 | 678 | 874 | 879 | 702 |
| Wheat | 3706 | 3234 | 3266 | 3306 | 5303 | 5406 | 3437 | 2052 | 2045 | 1676 | 1513 |
| % District Acreage | 97% | 94% | 92% | 96% | 97% | 97% | 95% | 93% | 98% | 99% | 99% |

Source: Vale Irrigation District

## Table 2: Estimated Variable Production Costs (Maximum Yield) by Crop in the VOID*

| | Alfalfa** | Barley | G Corn | S Corn | Hay | Onions | Pasture | Russet Potatoes | Shepody Potatoes | Sugarbeets | Wheat |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fertilizer/Weed/Pest Control | 32.75 | 46.01 | 150.00 | 150.00 | 22.76 | 1048.65 | 24.95 | 447.77 | 439.44 | 408.00 | 106.50 |
| Bed Preparation & Planting | 15.11 | 43.79 | 80.03 | 80.03 | 5.11 | 313.98 | 0.00 | 419.32 | 618.88 | 138.72 | 54.13 |
| Harvesting and Hauling | 174.42 | 65.89 | 45.00 | 148.50 | 37.96 | 962.65 | 0.00 | 297.60 | 307.27 | 210.00 | 58.00 |
| Total | 228.75 | 172.53 | 283.03 | 386.53 | 68.94 | 2381.49 | 24.95 | 1210.50 | 1411.40 | 779.72 | 224.63 |

*Alfalfa costs were calculated based on the assumption of a 5-year alfalfa stand, with costs equaling a weighted average of one year of establishment costs and 4 years of production costs.

**All variable costs excluding irrigation costs

Sources: Oregon State University Extension Service, VOID producers

**Table 3: Estimated Irrigation Costs in VOID by Irrigation Type**

| | CP | D | FL | F | MF | MFT | SS | WL |
|---|---|---|---|---|---|---|---|---|
| Pre/Post Season Labor (hrs) | 0 | 2 | 0 | 0 | 0 | 0 | 1.07 | 0 |
| Labor Per Set (hrs) | 0.03 | 0.02 | 0.15 | 0.64 | 0.32 | 0.32 | 0.05 | 0.25 |
| Annualized Capital Costs ($)* | 58 | 158 | 5 | 7.5 | 18 | 50 | 131 | 46 |
| Irrigation Efficiency** | 0.8 | 0.925 | 0.375 | 0.5 | 0.6 | 0.7 | 0.75 | 0.75 |

*Annualized capital costs are equivalent to annual equipment depreciation costs.

**Irrigation efficiency is assumed to be constant for all crops.

Sources: Smathers et al. (1995), Patterson, et al. (1996a), Patterson et al. (1996b), Hoffman and Willett (1998), Wichelns et al. (1996), Letey et al. (1990), Bryant et al. (2001)

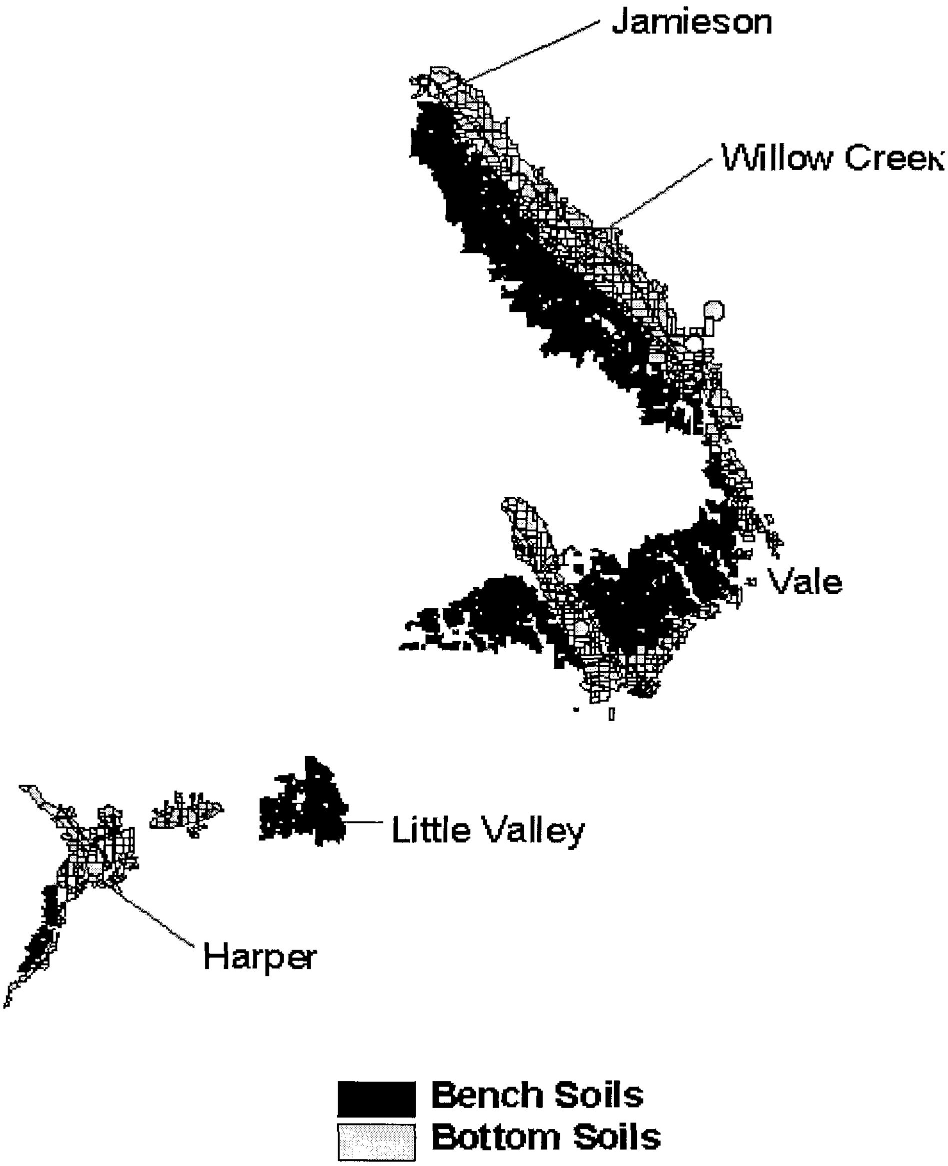
The soil types in the VOID are well described by two general soil classes: valley, or bottom lands, and lower quality, higher elevation bench lands (Lance Phillips, personal communication.) According to local officials, the bench lands are primarily cow/calf ranch operations, small mixed crop farms, and dairies, while the bottom lands are typically row crop farms, row crop/cattle feedlot combination farms, and larger ranch farms (Scott Ward, Ron Jacobs, Lance Phillips, personal communication). The Natural Resources Conservation Service (NRCS) soil survey indicates that most bench soils are only suitable for producing grains, hay, and pasture and are not well suited to row crops such as potatoes, onions, and sugarbeets. Although some of these row crops are grown on bench lands, the acreage is limited so these crops are only modeled for the bottom row crop and row crop/feedlot farms.

There are two types of cow/calf ranch operations in the district. The larger ranches tend to have cattle-grazing permits from the Bureau of Land Management (BLM) and are primarily located on more productive land (Ron Jacobs, personal communication). These large ranches graze their cows on BLM land during July and August, and then graze the animals the rest of the summer months on private irrigated pasture acreage. During the winter months these animals are fed hay. Smaller ranches usually do not utilize BLM land, but rather graze cattle on private, irrigated pasture all summer and then also feed the cattle hay in the winter.

To allow for variation in production parameters, VOID farm and ranch operations were grouped into six representative types based on soil quality, crops grown, number and type of animals raised, and farm acreage: 1. Dairies, 2. Small cow/calf ranches, 3. Large cow/calf ranches, 4. Small mixed crop farms, 5. Row crop farms, and

6. Feedlot/row crop combined operations. As noted above, farm/ranch types 1, 2, and 4 are located primarily on the poorer soils of the bench lands, while types 3, 5, and 6 are primarily located on the bottom lands.

**Map 2: VOID Soils**



Data necessary to divide district VOID acreage (34,993 acres) into representative farm types was provided by local agencies. Geographic information system (GIS) data provided by the Soil and Water Conservation District and the Farm Service Agency enabled quantification of the farmland into bottom and bench lands, while the Vale Irrigation District Office provided data on farm size. Based on these data, the approximately 35,000 acres in the VOID were divided into the six representative farm types as illustrated in Table 4.

**Table 4: Representative Farm Characteristics**

| | Dairy | Large Ranch | Ranch | Small Mixed | Row Crop | Feedlot | Totals |
|---|---|---|---|---|---|---|---|
| Acreage | | | | | | | |
| Bench | 200 | 200 | 200 | 30 | 0 | 0 | 19300 |
| Bottom | 0 | 300 | 0 | 0 | 700 | 700 | 15700 |
| Total Acreage | 2400 | 4000 | 10200 | 5100 | 4900 | 8400 | 35000 |
| Animals | | | | | | | |
| # Dairy Cows | 150 | 0 | 0 | 0 | 0 | 0 | 1800 |
| #Cows/Calves | 0 | 300 | 50 | 5 | 0 | 0 | 5800 |
| # Feedlot Head | 0 | 0 | 0 | 0 | 0 | 3200 | 38400 |
| # Farms | 12 | 8 | 51 | 170 | 7 | 12 | 260 |
| Max Crop Yields | | | | | | | |
| Alfalfa (Ton) | 4.8 | 5.25 | 4.8 | 4.8 | 5.4 | 5.4 | |
| Grain Corn (Bushel) | 80 | 110 | 80 | 80 | 120 | 120 | |
| Silage Corn (Ton) | 27 | 29 | 27 | 27 | 30 | 30 | |
| Native Hay (Ton) | N/A | 3.1 | 2.8 | 2.8 | 3.3 | 3.3 | |
| Pasture (AUM) | 4.85 | 6 | 4.85 | 4.85 | 6 | 6 | |
| Onions (cwt) | N/A | N/A | N/A | N/A | 505 | 505 | |
| Onions Drip (cwt) | N/A | N/A | N/A | N/A | 625 | 625 | |
| Russet Potatoes (cwt) | N/A | N/A | N/A | N/A | 604 | 604 | |
| Shepody Potatoes (cwt) | N/A | N/A | N/A | N/A | 529 | 529 | |
| Sugarbeets (Ton) | N/A | N/A | N/A | N/A | 31 | 31 | |
| Wheat (Bushel) | 90 | 112 | 90 | 90 | 119 | 119 | |

Based on Vale Project data, the 3,200 feedlot animals in the model are assumed to be on the feedlots for a 4-month rotation. It is also assumed that the number of farm animals in the VOID is constant; in other words, VOID operators do not sell farm animals in years when the water allocation is too low to grow enough feed to support the animals. In the model, feed for animals can be obtained either through crop production or purchase of feed. In years of water shortage, when irrigators are unable to produce sufficient feed for livestock, the model requires the irrigators to meet animal feed requirements through the purchase of feed. The assumption that the number of farm animals is constant may lead to an overestimation of economic impacts since both ranch and large ranch operators may sell livestock during low water years in order to avoid high feed costs.

County prices for feed crops such as silage, grain corn, and hay are assumed to be unaffected by VOID water supplies; usually the entire regional area must be affected by drought for feed prices to rise (Lynn Jensen, personal communication). Additionally, many feedlot owners utilize the futures market for grain to address risk in grain prices (Lynn Jensen, personal communication). Therefore, it is assumed that if feed is not produced on the farm, the farmer must only pay a 15% premium to cover shipping costs. It should be noted that the only revenue in the model is from crops; returns to animals were not included since animal returns are only indirectly affected by water shortages through the impact on crop productivity. Although omitting returns to animals does not change the impact of water on total farm profit and returns, it does result in negative profits for operations with livestock since they feed most of their crops to livestock and also purchase feed in the model.

In addition to adjusting crop acreage and irrigation technology, another option available to irrigators facing reduced water supplies is deficit irrigation, or irrigation at levels below crop requirements. Deficits in water supply to crops will reduce crop yields.

The magnitude of the impact of water deficit on crop yield varies with the crop and also depends on the growth period in which the crop is subjected to water stress. To allow for conservation of water through deficit irrigation, it is necessary to establish a relationship between crop yield and water availability in the soil. This study assumes that crop yield is a linear function of total effective water applied (water available to the crop). This is consistent with other models used in the literature (Caswell and Zilberman 1986, Dinar and Zilberman, 1991, Ulibarri et al. 1998). Specifically, the model utilizes a water response yield function in which crop yield is a function of maximum yield achievable under unlimited water supplies, effective water applied, and a crop-specific coefficient. Mathematically, this is represented as

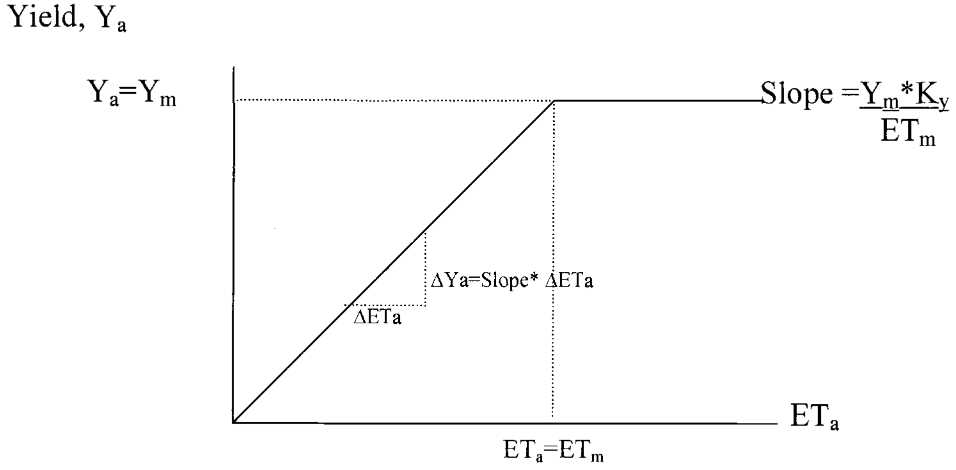
$Y_a = Y_m*(1-K_y*(1-ET_a/ET_m))$, where

| | |
|---|---|
| $Y_a$ | is the actual yield |
| $Y_m$ | is the maximum attainable yield under unlimited water supplies |
| $K_y$ | is a crop specific coefficient of the effect of deficit irrigation on yield |
| $ET_a$ | is the actual water available for evapotranspiration (evapotranspiration is the amount of water used by the soil-plant system) |
| $ET_m$ | is the maximum evapotranspiration requirement. |

This study utilizes a seasonal crop response coefficient $K_y$ (instead of multiple growth period coefficients) and assumes that if water supplies are limited, producers maximize returns by applying water in the periods when the crop yield is most sensitive to water stress.

Since $ET_m$ and $K_y$ are assumed to be constant, and $Y_m$ is constant for any given production technology for a particular crop, the only independent variable is $ET_a$. This results in the linear relationship illustrated in Figure 11.

**Figure 11: Linear Yield Response to Water**



The model incorporates seventeen water application levels, starting at 20% of maximum water requirement and rising in 5% increments to 100% of water requirement. Twenty percent was chosen as the minimum irrigation level since this was deemed to be sufficient water to keep alive the perennial crops of hay, alfalfa, and pasture that are most often deficit irrigated (Marni Porath, personal communication). It is assumed that there is no yield increase for water applied past maximum evapotranspiration. Since there are some saline soils in the Vale district, some excess water may leach salts to lower soils depths, thereby increasing yields in some years. Interviews with irrigators and water officials in the area indicated, however, that irrigation in excess of maximum evapotranspiration would not significantly affect yields. Therefore, the assumption that yield is maximized when maximum ET is reached should accurately reflect irrigator behavior.

Data for maximum crop yields ($Y_m$) in this study were obtained from the Soil and Water Conservation Service, the Malheur County Experiment Station, the Malheur County Extension Service, the VOID, and local producers. Crop evapotranspiration requirements ($ET_m$) were obtained from values recorded at the Malheur County Experiment Station, while crop response coefficients (Ky) were obtained from the United Nations Food and Agricultural Organization Irrigation and Drainage report (Doorenbos and Kassenbaum, 1979). For potatoes, yield response functions have been experimentally determined for Malheur County production (Shock et al. 2003). Since these site-specific functions are assumed to be superior to the generalized model, they are utilized for the two types of potatoes (Shepody and Russet) included in the model. Data utilized for the crop yield response to water functions for all other crops are presented in Table 5.

**Table 5: Parameters for Crop Yield Response to Water Function**

| | Maximum Evapotranspiration ($Et_m$)* | Crop Reponse Factor ($K_y$) |
|---|---|---|
| Alfalfa | 25 | 0.9 |
| Barley | 18 | 0.8 |
| Grain Corn | 25 | 1.25 |
| Silage Corn | 22 | 1.25 |
| Hay | 20 | 0.9 |
| Onions | 28.7 | 1.1 |
| OnionsDrip | 28.7 | 1.1 |
| Pasture | 20 | 0.9 |
| Sugarbeets | 33.6 | 0.39 |
| Wheat | 18 | 1.0 |

*These are an average from 1992-2002 of $Et_m$ taken at the Malheur Experiment Station. $Et_m$ figures for hay, pasture, and grain crops were reduced to 75% of maximum because it is estimated that typical yields in the district correspond to this level of irrigation.

Actual evapotranspiration ($ET_a$) of a crop depends on effective rainfall, and on both the quantity of irrigation water applied and the efficiency of the specific irrigation system (IEF). Water from rainfall is limited; as measured by the Malheur Experiment Station gauge in Vale, Vale receives an average of 3.18 inches in the growing season and 5.48 inches during the preceding six months. This summer and winter rainfall is conservatively estimated in the model to annually yield the equivalent of 4 inches of effective rainfall (ER) in soil moisture available to plants. The quantity of irrigation water applied that is actually available to the plant is determined by the IEF: the proportion of water applied by the field irrigation system that is actually evapotranspirated by the crop (Whitmore, 2000). For example, an IEF of .75 indicates that 75% of water applied is evapotranspirated by the crop and not lost through deep percolation or runoff. Thus, to enable the crop to reach the maximum ET, the water application requirement (WatReq) is the maximum evapotranspiration levels, minus effective rainfall (4 inches in this model) divided by the irrigation efficiency:

$$\text{WatReq} = (ET_m - 4) / \text{IEF}$$

The $ET_a$ then is the WatReq, multiplied by the percent of the water requirement that the producer chooses to apply, multiplied by the IEF, or amount of water applied that is available to the plant:

$$ET_a = \text{IEF} * \text{PercentW} * \text{WatReq} = \text{PercentW} * (ET_m - 4)$$

where PercentW is the percent of maximum required water ($ET_m$/IEF) that is applied.

## Objective Function

The objective in this model was to maximize net returns to land, management, and fixed capital costs (such as agricultural machinery and buildings.) Net returns are calculated as total crop revenue minus production (variable) costs. Irrigation labor costs are assumed to vary proportionately with irrigation water applied (PercentW), while harvesting labor costs are assumed to vary proportionately with yield. In the baseline model, the net returns are maximized based on the historical probabilities of the four different water allocations. The objective function is defined using the following sets:

c = set of 11 crops,
f = set of 6 farm types,
i = set of 8 irrigation technologies,
w = set of 17 water application levels
d = set of 4 water allotment years
a = set of 3 animal types

In summation notation, the objective function takes the following form:

$$\sum_{d=1}^{4} \text{Probwat}_d * \{\sum_{f=1}^{6}\sum_{c=1}^{11} \text{Price}_c * \text{SellCrop}_{c,f,d} - \sum_{f=1}^{6}\sum_{c=1}^{11}\sum_{i=1}^{8}\sum_{w=1}^{17} \text{Acres}_{c,f,w,i,d} *$$

$$[\text{VcostsO}_c + \text{Wage} * \text{LabSetUp}_i + \text{Irrcost}_i + (\text{Wage} * \text{LabSet}_i * \text{NumSet}_{c,i}) * \text{PercentW}_w +$$

$$\text{HarvLab}_c * (\text{Yield}_{c,f,w}/\text{MaxYield}_{c,f}) + \text{OpCosts}_i * (\text{WatReq}_{c,I} * \text{PercentW}_w)] -$$

$$\sum_{f=1}^{6}\sum_{c=1}^{11}\ \sum_{a=1}^{3}\sum_{d=1}^{4} \text{BuyCrop}_{c,f,a} * 1.15 * \text{Price}_c\}$$

where $\text{Probwat}_d$ = probabilities for each water allotment year d,
$\text{Price}_c$ = price per unit for each crop c,
$\text{Acres}_{c,f,w,i,d}$ = acres of crop c planted on farm f under irrigation system i with water amount w in water year d
$\text{SellCrop}_{c,f}$ = decision variables of units of crop c sold from farm f in year d
$\text{VCostsO}_c$ = all other variable costs (excluding irrigation and harvesting labor costs) for crop c
$\text{LabSetUp}_i$ = all pre-season and post-season setup costs of irrigation system i
$\text{Irrcost}_i$ = annual capital costs of irrigation system i
Wage = hourly wage rate
$\text{LabSet}_i$ = per acre labor time (in hours) for an irrigation set using irrigation system i
$\text{NumSet}_{i,c}$ = number of irrigation sets to fully irrigate crop c with irrigation type i
$\text{PercentW}_w$ = percentages of maximum water requirements applied to the crop
$\text{Harvlab}_c$ = harvesting labor costs for crop c

$\text{Yield}_{c,f,w}$ = per acre yield of crop c grown on farm type f with water amount w

$\text{MaxYield}_{c,f}$ = maximum yield of crop c on farm f

$\text{OpCosts}_i$ = all operational costs, including repairs and electricity, for every acre inch of water applied with irrigation system i

$\text{BuyCrop}_{c,f,d,a}$ = decision variables of feed crop c to be purchased on farm f

<u>Constraints</u>

The objective function is maximized subject to annual water availability, a land resource limit, a crop supply and demand constraint, certain agronomic constraints, and the necessity to provide feed for farm animals. Water for crops is assumed to be limited to irrigation water other than the aforementioned estimated 4 inches of effective rainfall. Furthermore, it is assumed that irrigation water is supplied only through surface water provided by the VOID and is not supplemented with groundwater wells. It is estimated that there are currently only enough wells in the VOID to irrigate perhaps 1-2% of the acreage, and there is little potential for greater well development due to lack of good groundwater supplies (Ron Jacobs, personal communication). It is also assumed that water is undifferentiated throughout the district such that the quality of the water for agricultural purposes is constant. Water applied to crops on each farm is thus limited to the district per acre water allotment multiplied by the VOID acreage on the farm. This constraint can be expressed in summation notation as:

$$\sum_{c=1}^{11} \sum_{i=1}^{8} \sum_{w=1}^{17} \text{Acres}_{c,f,w,i,d} * \text{PercentW}_w * \text{WatReq}_{c,i} \leq \text{FarmAcres}_f * \text{WatAlloc}_d$$

where $\text{FarmAcres}_f$ = number of acres on farm f

$\text{WatAlloc}_d$ = per acre water allotment in water year d

$\text{Acres}_{c,f,w,i}$ = acres of crop c grown on farm f under irrigation system i with water percentage w

Although the model constrains the total quantity of water available on any one farm, operators in the model can optimally allocate available water among crops to maximize returns.

VOID irrigators are also limited to existing production acres since it is not feasible to develop more farmland in the VOID. Irrigators may not utilize VOID irrigation water on land that does not have appurtenant VOID water rights, and, as noted earlier, there is little potential for irrigation of additional land with groundwater supplies. The land constraint thus limits the acres of production on each farm in each water year d to the total acres in each farm with VOID water rights:

$$\sum_{c=1}^{11} \sum_{i=1}^{8} \sum_{w=1}^{17} \mathrm{Acres}_{c,f,w,i,d} \leq \mathrm{FarmAcres}_f$$

Crops produced in the VOID can be either sold or fed to animals on the farm. There is thus a constraint that the sum of crops sold and crops fed to animals may not exceed the total production of any crop c on farm f in water year d. Crop yield for each crop on farm f applying the percentage of the water requirement w is calculated utilizing the crop water response function: $\mathrm{Yield}_{c,f,w} = \mathrm{MaxYield}_{c,f} * 1\text{-}\mathrm{Ky}_c(1\text{-}\mathrm{PercentW}_w)$. Since crop production for each crop on farm f can be expressed as the yield multiplied by acreage, we can express this constraint in summation notation as:

$$\sum_{a=1}^{3} \mathrm{FeedCrop}_{c,f,a,d} + \mathrm{SellCrop}_{c,f,d} \leq \sum_{i=1}^{8} \sum_{w=1}^{17} \mathrm{Acres}_{c,f,w,i,d} * \mathrm{Yield}_{c,f,w}$$

Operator production decisions are also constrained by agronomic factors that limit the acreage of many crops. If crops are not properly rotated on a field, yields for many crops will decrease and certain crops will become much more susceptible to disease. Soil quality may also be negatively affected by inappropriate crop rotations. Additionally, since many of the crops are harvested at different times and require different equipment, planting a mix of crops can often help producers best utilize their equipment and labor. The model incorporates these agronomic constraints by limiting the total acreage that can be planted in certain crops. Sugarbeets and potatoes are limited to a once-in-five-year rotation, onions are limited to a four-year rotation, wheat to a three-year rotation, and corn to a two-year rotation. In summation form, this constraint was written:

$$\sum_{i=1}^{8} \sum_{w=1}^{17} \text{Acres}_{c,f,w,i,d} \leq 1/\text{Rotation}_c * \text{FarmAcres}_f$$

where $\text{Rotation}_c$ = number of rotation years required for crop c

Additionally, to maintain soil quality, an additional constraint required that alfalfa be planted on at least 20% of the row crop and feedlot acreage.

The baseline model also incorporates constraints on irrigation, limiting irrigation technology to current sprinkler and drip levels.

$$\text{Acres}_{c,f,w,\text{'CP'},d} + \text{Acres}_{c,f,w,\text{'SS'},d} + \text{Acres}_{c,f,w,\text{'WL'},d} = 5500$$

$$\text{Acres}_{c,f,w,\text{'D'},d} = 300$$

Since the baseline model assumes that irrigators have no information about water supplies other than the historical probability of different water years, irrigators are constrained to plant the same crop mixture using the same irrigation technology every water year using the following equation form:

$$\sum_{w=1}^{17} \text{Acres}_{c,f,w,i,\text{'normal'}} = \sum_{w=1}^{17} \text{Acres}_{c,f,w,i,\text{ 'under'}}$$

This constraint is necessary since to optimize returns the model will choose a different crop acreage mixture for different water allocations. Irrigators, however, since they have no information about the upcoming allocation other than historical probabilities when they plant, cannot choose an optimal mixture. Given their water supply information, irrigators can best maximize returns by choosing the crop mixture that will maximize expected profits given the probability of the four different water allocations.

Finally, the model constrains irrigators by requiring that the feed needs of all VOID animals must be met either through farm crop production or purchase of feed. The model only incorporates the feed crops that are grown in the VOID: alfalfa hay, native hay, grain corn, silage corn, and pasture. Since there is some flexibility in the rations that producers feed their livestock, the model enables some substitution in feed rations. Feed rations were set based on information provided by local producers and enterprise budgets. The general, summation form for all feed constraints is:

$$\sum_{c=1}^{11} 1/\text{FeedReq}_a{*}\text{FeedCrop}_{c,f,d} + 1/\text{FeedReq}_a{*}\text{BuyCrop}_{c,f,d} \geq \text{numanim}_{f,a}$$

To summarize, in the baseline model irrigation technology is set at current (2004) levels. It is assumed in the baseline model that irrigators must make their crop acreage decisions prior to receiving information about the upcoming water year. As a result, it is assumed that irrigators profit-maximize by planting the same crop mixture every year (subject to crop rotation constraints) that maximizes returns based on the historical probabilities of the different water years. Once the water allocation is known, farmers adjust by optimally allocating water among crops.

In addition to the baseline model, this study utilizes three other linear programming models that relax some of the constraints present in the baseline model. For example, in order to study the effects of additional irrigation technology adoption, a longer-term model is constructed that changes the constraint on the acreage produced with sprinkler and drip irrigation. Also, a perfect information model is constructed by replacing the historical probabilities of water supplies with a probability of 1.0 for a given water allocation year. Finally, the introduction of a water market or water bank in the VOID is simulated in another model by relaxing the water constraint to enable water to be transferred between farms in the VOID.

### 3.4 Applicability of Input-Output Modeling

The first objective in this study was to estimate the on-farm effects of water supply reductions. A second objective is to investigate how these on-farm effects will be felt in the regional economy. To move from the farm-level impacts and quantitatively evaluate the effect of VOID water supply fluctuations on the Malheur County economy, this study utilizes an input-output (I-O) model. I-O models are often used to assess the importance of an economic sector in a local economy and to analyze the impacts of resource changes (Martin et al. 1988). I-O models, which are sometimes referred to as inter-industry models, are constructed using data relating industries to other industries and consumers in an economy. The foundation of the model is that linkages between economic sectors can be expressed by technical coefficients, which relate how the output of one industry either becomes the input of other industries or satisfies final use (final demand).

Purchases for final use drive the input-output model (Micro IMPLAN Group, 2000). Industries producing consumer products demand inputs from other industries, which in turn demand inputs from other industries. This process ripples through the I-O model until leakages from the region (i.e. purchases from businesses or wages to households outside the region) stop the cycle. The model reflects the fact that if production of output in one sector declines, the sector will demand fewer inputs from other sectors, thus decreasing their output. Thus, the impact of changes in one sector on all other sectors, and on the greater regional economy, can be analyzed using this model.

There are several assumptions implicit in I-O analysis (as discussed in Micro Implan Group, 2000). First, like linear programming, the I-O model is based on the assumption that there is a fixed linear relationship between factor inputs and outputs. This implies constant returns to scale, such that production parameters do not change when an industry grows or shrinks. This assumption can be particularly limiting if a resource or policy change results in a large change in industry output since this would also likely entail a change in industry structure or the industry's technical coefficients. As discussed earlier, agricultural production can be well approximated by linear production functions, so this assumption is not overly limiting for this study of the economic impacts of varying agricultural water supplies.

I-O models are also based on the assumption that the economy is always at full capacity, with no excess capacity or capacity constraints limiting the impacts of a policy or resource change. This implies that there are no supply constraints. The economy is thus completely flexible to changes in final demand; it can supply any final demand without concern for limited or excess inputs. In this study, since the exogenous change is a limitation of a primary resource input (water), the lack of supply constraints is not a problematic assumption. It is likely, however, that if water supply variations produce large effects on farm production, there will be excess inputs for agriculture produced that will not be accounted for in this model.

Finally, the I-O structure implies constant technology and consumer preferences such that prices do not change. This assumption does not overly limit the effectiveness of the input-output framework in this setting since it is assumed that agricultural commodities are priced based on a nationally competitive market. Therefore the exogenous change in water supplies should not significantly affect prices in Malheur County.

The restrictive assumptions inherent in all I-O models require that results from I-O studies be interpreted with caution. I-O models do not provide exact measures of the impacts of an exogenous change in a regional economy but rather are useful estimates of the magnitude and distribution of potential economic impacts among economic sectors. Thus, although none of the assumptions in an I-O model is overly problematic for this study, the results presented on the economic impact of Malheur County agricultural production changes should be interpreted as approximate estimates.

### 3.5 Description of the Input-Output Model

An I-O model is a static equilibrium model; it is assumed that the economy is in equilibrium before the exogenous policy or resource change (such as water supply reductions). To calculate the economic impacts of the exogenous change, a baseline, descriptive model of the economy at the initial equilibrium is first constructed. Once the economic activity at the equilibrium condition is calculated, then the exogenous change is introduced into the model and a new equilibrium is reached. The effect of the exogenous change is then calculated as the difference between the two equilibrium levels (Kraybill, 1993). Potential economic impacts of the exogenous change are measured in annual changes in income (value added), employment, and output. An I-O model provides us with a prediction of the resultant equilibrium state after an exogenous change on an economy, such as a water supply change, but does not illustrate how the transition between the two equilibrium states is reached or how long the transition period will be.

Through the use of an I-O model, an analyst can do an impact analysis of a change in a sector and obtain the sector's multipliers. A multiplier is the ratio of the change in economic activity in all sectors to the changed economic activity in the studied sector. For example, if an exogenous change causes agricultural income to increase by $0.50, which then causes total regional income to increase by $1.00, the income multiplier would be 2. Multipliers can be determined for income, output, and employment. Many input-output models enable three types of multipliers to be determined: Type I, Type II, and Type Social Accounting Matrix (SAM). The type of impacts that they include and whether they include households and institutional transactions differentiates these three types of multipliers.

As noted in Chapter 2, an economic change in one sector may produce direct, indirect, and induced types of impacts on a local economy. Direct impacts are the impacts on the studied sector caused by the exogenous change (in this case, reduced farm revenues due to water supply shortages), while indirect impacts refer to economic impacts on sectors providing inputs to the studied sector, and induced impacts are effects due to changes in income caused by the direct and indirect impacts. Type I multipliers include only the direct and indirect, inter-industry effects of an exogenous change, while Type II multipliers also include the induced effects of the resultant change in household income and expenditures of households. Type SAM multipliers also incorporate information about transactions between institutions such as government payments to households and business and household taxes to governments.

Although I-O models can be constructed using survey data for a specific study area, this process can be prohibitively expensive and time-consuming. The U.S. Forest Service, in cooperation with several other federal agencies and a private company Minnesota Implan Group (MIG), has developed a set of regional I-O models that aggregates to a national I-O model, IMpact analysis for regional PLANning (IMPLAN), which can be utilized to construct regional economic models. Since IMPLAN is an inexpensive model that has been shown to provide results consistent with models based on primary data (Radtke, Detering, and Brokken, 1985), this study utilizes a regional I-O model constructed from the 2001 IMPLAN data set.

IMPLAN is a system of I-O models that includes 528 sectors. The IMPLAN regional models, such as the Malheur County model, combine national technical coefficients with data on local sectoral output for each of the 528 sectors. The Malheur

County IMPLAN model indicates economic activity in 163 of the possible 528 sectors. To improve the accuracy of the IMPLAN employment data, the employment data for each sector in the Malheur County IMPLAN model was compared with data from the Bureau of Economic Analysis. All sectors with discrepancies in employment of 5% or more between the two data sources were examined to determine the best employment estimate to utilize in the IMPLAN model. Based on data from the Malheur County Economic Development Department, the Oregon Labor Market Information System, the Census of Agriculture, and the Oregon Agricultural Information Network, 41 of the IMPLAN sectors were adjusted (25% of Malheur County sectors). Of these, 22 sectors were adjusted upwards and 19 adjusted downwards for a total increase of 21 jobs (less than 1% of total employment).

The IMPLAN model was aggregated from 163 sectors to 25 sectors. The aggregation of sectors, particularly of sectors directly impacted by the exogenous change, can reduce the accuracy of the input-output model results. When sectors are aggregated, the individual production functions of each original, disaggregated sector are combined to form one new production for the aggregated sector. This reduces the precision of the inter-industry linkages, which are the basis of the input-output model, and thus reduces the precision of the impact analysis. For example, error could be introduced in the Malheur input-output model if the agricultural sectors were aggregated since the employment and output impact of a change in a crop's revenue differs by crop type. To reduce the potential for this aggregation problem, all nine of the agricultural sectors in the model were preserved such that water supply impacts could be entered into the input-output model as single crop revenue impacts, instead of as aggregated crop revenue impacts.[4]

The employment and output effects of VOID water supply variations on the Malheur County economy are estimated by conducting an economic impact analysis with the edited IMPLAN input-output model. In this analysis, the LP model estimates of the crop revenue losses at each water allocation are used in the IMPLAN model as the water supply-induced exogenous impacts. The economic impact from each reduced water allocation is estimated by comparing the employment and output from the pre-impact, full-water supply Malheur economy compared with employment and output from the post-impact (i.e. water supply reduction) Malheur economy for each of the three reduced water scenarios. The employment and output impacts of more sprinkler and drip irrigation adoption and the implementation of water markets are similarly examined.

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[4] The remaining sixteen sectors were: Forestry, Hunting and Fishing; Mining; Utilities; Construction; Food Manufacturing, Other Manufacturing; Wholesale Trade; Transportation and Warehousing; Retail; Information; Finance and Insurance; Real Estate and Leasing; Services; State and Local Government; Federal Government, and Other (inventory valuation adjustment and owner-occupied dwellings.)

## Chapter 4: Malheur County Economy

Malheur County is one of the most economically depressed counties in the state of Oregon. According to the Bureau of Economic Analysis, 2002 per capita annual income in Malheur County was the second lowest in the state at $18,608. This is just 64.6% of state per capita income and 60.2% of national per capita income. The 2000 census estimate of the poverty rate in Malheur is 18.6%, the highest of any county in the state of Oregon. (The state poverty rate is 11.6%.) Malheur has not always had such relatively low income; in 1990, Malheur County per capita income was 81.2% of state per capita income. Since 1990, however, while most of Oregon has experienced economic growth, the Malheur economy has not: 2002 per capita real income remains at approximately 1990 levels.

The Malheur County economy is heavily dependent on natural resource industries. As seen in Table 6, of the approximately 19,000 jobs in Malheur County, agriculture, agricultural services, hunting services, forestry, and mining comprise 3,600, or almost 20%. Within natural resource employment, agriculture is the primary industry, comprising approximately 3,500 jobs. The other key employment sectors in Malheur are services and government, which each contributes another 20% of total Malheur employment.

## Table 6: Malheur County Employment, 2001

(Standard Industrial Classification, one-digit level)

| | Malheur Employment | % Total |
|---|---|---|
| **Total full-time and part-time employment** | 18,752 | 100.0 |
| Wage and salary employment | 14,990 | 79.9 |
| Proprietors employment | 3,762 | 20.1 |
| Farm proprietors employment | 1,405 | 7.5 |
| Non-farm proprietors employment | 2,357 | 12.6 |
| Farm employment | 2,856 | 15.2 |
| Non-farm employment | 15,896 | 84.8 |
| **Private employment** | 12,526 | 66.8 |
| Agricultural services, forestry, fishing | 661 | 3.5 |
| Mining | 75 | 0.4 |
| Construction | 586 | 3.1 |
| Manufacturing | 1,477 | 7.9 |
| Transportation and public utilities | 589 | 3.1 |
| Wholesale trade | 724 | 3.9 |
| Retail trade | 2,442 | 13.0 |
| Finance, insurance, and real estate | 2,044 | 10.9 |
| Services | 3,860 | 20.6 |
| **Government and government enterprises** | 3,439 | 18.3 |
| Federal, civilian | 240 | 1.3 |
| Military | 0 | 0.0 |
| State and local | 3,199 | 17.1 |
| State government | 918 | 4.9 |
| Local government | 2,281 | 12.2 |

Source: Bureau of Economic Analysis, IMPLAN, Oregon Labor Market Information System, Oregon Agricultural Information Network

Malheur County agriculture is diverse; it ranks among the top five Oregon counties in producing cattle, grains, hay, onions, potatoes, and sugarbeets. It ranks fifth among Oregon counties in terms of total agricultural production value, with over $200 million in 2001 agricultural sales. With just under $11 million in 2001 agricultural sales, the VOID contributes approximately 6% to Malheur County agricultural value. According to the 2002 Census of Agriculture, there were approximately 1,062 farms in Malheur County with 269,000 acres of cropland, of which 223,000 acres were irrigated and 189,000 harvested. With 35,000 irrigable acres, VOID farmland therefore represents 16% of total irrigated land in Malheur County.

**Table 7: Acreage and Value of Agricultural Production in Malheur County, 2001 ($000)**

| Commodity | Acreage | Value | Production Value (%) |
|---|---|---|---|
| Cattle and Beef Cows | 246,800 | 65,681 | 32.8 |
| Onions | 11,000 | 28,380 | 14.2 |
| Alfalfa Hay | 49,500 | 23,389 | 11.7 |
| Potatoes | 9,500 | 18,050 | 9.0 |
| Sugarbeets | 9,790 | 11,174 | 5.6 |
| Vegetables, Sweet Corn, and Melons | 50 | 9,800 | 4.9 |
| Wheat | 29,700 | 9,106 | 4.5 |
| Dairy | 4,300 | 8,955 | 4.5 |
| Corn (Grain and Silage) | 17,900 | 7,148 | 3.6 |
| Other Hay | 40,000 | 6,400 | 3.2 |
| Alfalfa Seed | 6,060 | 4,887 | 2.4 |
| Sheep, Lambs, and Wool | 23,500 | 676 | .3 |
| Other | 32,640 | 6,580 | 3.3 |
| Total | 480,740 | 200,226 | 100.0 |

Source: Oregon Agricultural Information Network.

The importance of the agricultural industry in the Malheur County economy is suggested by its location quotient, which is a measure of the relative size of an industry. In Table 8, location quotients are calculated to compare the relative size of each industry in Malheur County with the size of the industry in Oregon. The mathematical formula for the location quotient for each industry i is:

$$LQ_i = \frac{\text{Industry}_i \text{ Employment in Malheur / Total Malheur Employment}}{\text{Industry}_i \text{ Employment in Oregon / Total Oregon Employment}}$$

## Table 8: Location Quotients and Structural Change in Malheur County 1970- 2001

| | 1970 | | | 2001 | | | |
|---|---|---|---|---|---|---|---|
| | Malheur Employment | Oregon Employment | LQ | Malheur Employment | Oregon Employment | LQ | 1970-2001 LQ % Change |
| Total full-time and part-time employment | 12,751 | 925,933 | 1.00 | 18,752 | 2,108,465 | 1.00 | .00 |
| Wage and salary employment | 8,781 | 767,695 | 0.83 | 14,990 | 1,693,654 | 1.00 | 19.82 |
| Proprietors employment | 3,970 | 158,238 | 1.82 | 3,762 | 414,811 | 1.02 | -44.03 |
| Farm proprietors employment | 2,147 | 31,861 | 4.89 | 1,405 | 39,077 | 4.04 | -17.41 |
| Nonfarm proprietors employment | 1,823 | 126,377 | 1.05 | 2,357 | 375,734 | 0.71 | -32.66 |
| Farm employment | 3,486 | 51,467 | 4.92 | 2,856 | 66,691 | 4.82 | -2.10 |
| Non-farm employment | 9,265 | 874,466 | 0.77 | 15,896 | 2,041,774 | 0.88 | 13.78 |
| Private employment | 7,441 | 714,814 | 0.76 | 12,526 | 1,764,071 | 0.8 | 5.62 |
| Agricultural services, forestry, fishing | 290 | 8,606 | 2.45 | 661 | 36,320 | 2.05 | -16.37 |
| Mining | 18 | 1,797 | 0.73 | 75 | 3,463 | 2.44 | 234.79 |
| Construction | 389 | 41,190 | 0.69 | 586 | 121,057 | 0.54 | -20.63 |
| Manufacturing | 1,710 | 179,080 | 0.69 | 1,477 | 227,763 | 0.73 | 5.16 |
| Transportation and public utilities | 416 | 53,441 | 0.57 | 589 | 67,390 | 0.98 | 73.85 |
| Wholesale trade | 439 | 46,089 | 0.69 | 724 | 81,758 | 1.00 | 43.95 |
| Retail trade | 2,012 | 146,314 | 1.00 | 2,442 | 238,995 | 1.15 | 15.05 |
| Finance, insurance, and real estate | 559 | 69,173 | 0.59 | 2,044 | 208,404 | 1.10 | 87.92 |
| Services | 1,608 | 169,124 | 0.69 | 3,860 | 778,921 | 0.56 | -19.30 |
| Government and government enterprises | 1,824 | 159,652 | 0.83 | 3,439 | 277,703 | 1.39 | 67.84 |
| Federal, civilian | 161 | 25,519 | 0.46 | 240 | 29,064 | 0.93 | 102.66 |
| Military | 138 | 15,252 | 0.66 | 0 | 12,241 | 1.00 | -100.00 |
| State and local | 1,525 | 118,881 | 0.93 | 3,199 | 236,398 | 1.52 | 63.34 |
| State government | 256 | 35,378 | 0.53 | 918 | 60,891 | 1.70 | 222.09 |
| Local government | 1,269 | 83,503 | 1.10 | 2,281 | 175,507 | 1.46 | 32.46 |

If the LQ for an industry is larger than one, then this industry provides a higher proportion of Malheur County employment than Oregon state employment. Location quotients are often viewed as indicators of the ability of an industry in a local economy to supply local industry inputs and final demands (Miller and Blair, 1985). Location quotients less than one often indicate that the local economy must import this industry's goods or services, while location quotients larger than one often signify that the local economy is exporting this industry's goods or services. Export industries are particularly important to economies since they bring external income into the area that will then be circulated through the local economy until it is "leaked" through imports or payments to households outside the region. The 2001 location quotients presented in Table 8 indicate that the only significant exports from Malheur County are from the agricultural and mining sectors. This suggests that while agriculture accounts for 20% of the employment, it likely indirectly contributes a greater share of the Malheur County economy.

In the period 1970 to 2001, reflecting national trends, the proportion of Malheur jobs in agriculture dropped from 27% to 15%. However, the relative importance of agriculture to the Malheur economy, as measured by the location quotient, has remained relatively constant, declining only 2%. The relative importance of several other sectors has dramatically increased, however. Transportation and public utilities, finance and real estate, wholesale and retail trade, and government have all increased in relative importance in the Malheur County economy compared to the state economy. Additionally, as a proportion of Malheur jobs, the combined sectors of services, finance, insurance, real estate, and trade have increased from 36% to almost 48%. Thus, while the Malheur economy continues to rely on agriculture, recent employment growth has been predominantly in the service and trade sectors.

## Chapter 5: Results and Discussion

This chapter presents and discusses results from the linear programming and input-output models regarding the farm and county-level economic impacts of different VOID water supplies. First, results from the linear programming model are presented on the effects of varying water supplies on farm crop revenue and farm profit. Second, LP model results concerning the value of improved forecasts, adoption of additional irrigation technology, and the implementation of a water market to mitigate costs of water supply fluctuations are discussed. Finally, results from the input-output model depicting the county-wide impacts of VOID farm production changes are examined.

### 5.1 Farm-Level Economic Impacts

To estimate the economic impacts of water supply variations on VOID farmers, a baseline linear programming model representing historical VOID crop acreages was created. Given the historical probabilities of four different water allocations, the model maximizes returns to land, management, and capital subject to resource, irrigation technology, and livestock feed requirement constraints. It is assumed that farmers must plant crops before the water allocation for the year is known, so crop acreage for each water year is constant in this model. (Planting the same crop mix each year is the profit-maximizing behavior since each year the farmers have the same water supply information regarding the historical water allocation probabilities.) The acreage allocation in the base model is compared with the historical allocation of VOID acreage in Table 9. Total modeled acreage is close to the historical acreage (differs by only 2.5%), while modeled acreage of individual crops differed from the historical acreage by an average of 15%. Additionally, acreages of many of the key crops are even more similar to the historical pattern: alfalfa differs by 9%, corn by 6%, pasture by 7%, and wheat by only 3%. Based on this performance, the model is therefore judged to provide a reasonable representation of actual cropping patterns.

## Table 9: VOID Acreage Allocation and LP Model Acreage Allocation

| | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | '92 - '02 Average | LP Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alfalfa Hay | 7,871 | 8,579 | 9,925 | 10,039 | 8,953 | 9,356 | 11,305 | 11,159 | 11,441 | 13,285 | 14,413 | 10,575 | 11,542 |
| Barley | 2,890 | 1,590 | 1,765 | 1,409 | 942 | 940 | 760 | 790 | 1,994 | 516 | 379 | 1,270 | 0 |
| Corn | 3,608 | 5,788 | 4,696 | 5,274 | 5,704 | 5,731 | 5,110 | 5,375 | 4,775 | 4,004 | 4,150 | 4,928 | 4,639 |
| Native Hay | 1,286 | 2,989 | 1,536 | 1,547 | 1,000 | 910 | 1,352 | 1,258 | 2,047 | 2,568 | 2,099 | 1,690 | 1,932 |
| Onions | 278 | 412 | 449 | 377 | 353 | 348 | 234 | 436 | 394 | 462 | 351 | 372 | 300 |
| Pasture | 6,448 | 7,825 | 8,603 | 8,623 | 9,237 | 9,059 | 9,263 | 9,634 | 9,931 | 10,070 | 9,202 | 8,900 | 9,538 |
| Potatoes | 433 | 755 | 960 | 883 | 1,151 | 1,078 | 1,002 | 988 | 720 | 644 | 643 | 841 | 980 |
| Sugar Beets | 827 | 681 | 772 | 871 | 658 | 495 | 821 | 678 | 874 | 879 | 702 | 751 | 980 |
| Winter Wheat | 3,706 | 3,234 | 3,266 | 3,306 | 5,303 | 5,406 | 3,437 | 2,052 | 2,045 | 1,676 | 1,513 | 3,177 | 3,092 |
| Other | 791 | 1,933 | 2,679 | 1,350 | 1,076 | 1,022 | 1,710 | 2,624 | 773 | 306 | 365 | 1,330 | 0 |
| Total Acreage | 28,136 | 33,786 | 34,652 | 33,678 | 34,376 | 34,345 | 34,993 | 34,993 | 34,993 | 34,410 | 33,816 | 33,834 | 33,002 |

Source: Vale Irrigation District

The baseline LP model results for VOID crop revenue, calculated as the revenue from all crops grown on VOID irrigated land, whether fed to livestock or sold, are presented in Table 10 for the four water allocation scenarios. Revenues depicted in Table 10 are higher than the crop revenues reported by the VOID. This is primarily due to a difference in the calculation of pasture revenue: the VOID calculates pasture revenue using the price of a unit of pasture in the VOID ($7.33 per AUM), while the model calculates pasture revenue using the price of the cheapest replacement feed crop of one half ton of hay, which results in a pasture price of $22.50 per AUM.

**Table 10: Modeled Farm Sector Revenue of Four Water Allocations (Water allocations are in Acre-Feet Per Acre)**

| | 3.5 | 3 | 2.5 | 1.67 |
|---|---|---|---|---|
| Dairy | 634,005 | 634,005 | 634,005 | 634,005 |
| Large Ranch | 1,240,273 | 1,221,993 | 1,190,822 | 1,138,871 |
| Ranch | 1,044,634 | 1,044,634 | 1,018,718 | 973,712 |
| Small mixed | 1,087,392 | 1,087,392 | 1,069,035 | 996,067 |
| Row Crop | 5,919,608 | 5,919,608 | 5,919,608 | 5,431,828 |
| Feedlot | 3,641,812 | 3,641,812 | 3,641,812 | 2,778,939 |
| Totals | 13,567,724 | 13,549,445 | 13,474,000 | 11,953,421 |
| *Weighted Avg Revenue | 13,059,492 | | | |

*Weighted Average Revenue is calculated as the revenue of each water allocation year multiplied by the historical probability of that water year occurring.

The weighted average revenue is the expected annual crop revenue from the VOID project under current resource, production technology, and historical water allocation conditions. As Table 10 illustrates, total crop revenue remains fairly stable at approximately $13.5 million for the three highest water allocations and then drops substantially to just under $12 million (12% decline) with the lowest water allotment of

1.67 acre-feet of water. The weighted average indicates that the annual expected revenue losses due to water shortages in the VOID are \$500,000 (4%). The economic effects of water supply changes can be more clearly seen in Table 11, which presents the loss of VOID crop revenue due to lower water allocations.

**Table 11: VOID Revenue Difference from 3.5 Acre-Feet Allotment**

| | 3.5 | 3 | 2.5 | 1.67 | *Weighted Avg |
|---|---|---|---|---|---|
| Farm Sector | | | | | |
| Dairy | 0 | 0 | 0 | 0 | 0 |
| Large Ranch | 0 | -18,280 | -49,451 | -101,402 | -42,079 |
| Ranch | 0 | 0 | -25,916 | -70,923 | -24,964 |
| Small mixed | 0 | 0 | -18,357 | -91,325 | -30,186 |
| Row Crop | 0 | 0 | 0 | -487,780 | -148,431 |
| Feedlot | 0 | 0 | 0 | -862,873 | -262,572 |
| Totals | 0 | -18,280 | -93,724 | -1,614,303 | -508,233 |

*Weighted Average Revenue is calculated as the revenue of each water allocation year multiplied by the historical probability of that water year occurring.

While farm operators in the baseline model are constrained to plant the same crop mix every year using the current (2004) adoption level of sprinkler and drip irrigation technologies, the baseline model does enable operators to respond to water supply fluctuations by varying the water applied to each crop. When allocated 3 acre-feet of water, large ranch operators are the only irrigators incurring economic losses (-\$18,000, or approximately 0.1% of total revenue) as they begin to deficit irrigate their pasture. When the water allocation drops to 2.5 acre-feet of water per acre, large ranch operators increasingly deficit irrigate their pasture, while hobby and small ranch operators also begin deficit irrigating of pasture, resulting in total farm revenue losses of \$94,000 (0.7%). Finally, in the lowest water allocation scenario of 1.67 acre-feet per acre, total revenue declines by over \$1.6 million (12%) as all farms except dairy deficit irrigate their lowest-valued crops. The expected annual farm revenue losses due to lower water allotments, as measured by the weighted average of losses, is $508,000, or 4% of total revenue.

Although crop revenues are useful in determining the community-wide impacts of water fluctuations, farm profit is a better measure of farm-level impacts. The losses in profit do not equal the losses in farm revenue since profits are based not only on crop yields and prices but also on irrigation labor (which declines with deficit irrigation) and on the cost of buying more livestock feed as feed crop production declines. Table 12 illustrates the baseline model's prediction of total profit impacts on each farm sector for water allocations less than the full 3.5 acre-feet per acre. While the first five columns present figures for all of the farms in a sector, the last column indicates the expected annual profit decrease for each individual representative farm.

**Table 12: Profit Difference from 3.5 Acre-Feet Allotment**

| | 3.5 | 3 | 2.5 | 1.67 | *Weighted Avg | Individual Farm *Weighted Avg |
|---|---|---|---|---|---|---|
| Farm Sector | | | | | | |
| Dairy | 0 | 0 | 0 | 0 | 0 | 0 |
| Large Ranch | 0 | -58,466 | -158,164 | -324,326 | -134,587 | -16,823 |
| Ranch | 0 | 0 | -80,853 | -215,761 | -76,207 | -1,494 |
| Small mixed | 0 | 0 | -51,883 | -150,879 | -52,683 | -309 |
| Row Crop | 0 | 0 | 0 | -305,187 | -92,868 | -13,267 |
| Feedlot | 0 | 0 | 0 | -556,330 | -169,291 | -14,108 |
| Totals | 0 | -58,466 | -290,900 | -1,552,483 | -525,637 | |

*Weighted Average Revenue is calculated as the revenue of each water allocation year multiplied by the historical probability of that water year occurring.

Table 12 provides an overview of the relative economic impacts of water supply fluctuations on the different types of farms in the VOID. The expected annual farm profit losses due to lower water allotments is $525,000, or 11% of total farm profit. As seen in the individual farm weighted average column, feedlot and large ranch operators have the highest expected annual profit losses from water shortages, followed by row crop farmers. The lack of an impact on dairy farm profits is likely an underestimation. This baseline model predicts crops grown on only 62% of total dairy farmland for the average year. This is due to two assumptions about dairies: they are primarily located on bench farmland which has lower yields, and they are the only bench farms that do not grow native hay, which provides yields even at low water levels. Since the assumptions about each representative farm type do not always apply, these economic impacts on each farm type must be viewed with caution as estimates of the relative economic impacts on each agricultural sector.

In the above baseline model, it is assumed that when farmers plant their crops they have no information on water supplies other than historical probabilities, resulting in their planting the same crop mix every year. In reality, however, farmers do have some knowledge about the water allocation before they plant their spring crops and can vary their crop mix based on this knowledge. By changing the probability of a specific water year occurrence to 1.0 and allowing the crop mix to change every year, a perfect information model was created. This model simulates the case in which farmers have perfect information about water supplies before planting spring crops and can choose the optimal crop mix for each water year. However, since wheat is planted in the fall, and the perfect information about the water supplies is assumed to only become available in the spring, wheat acreages are set for all water allocations at the optimal baseline level of

3,092 acres. Optimal spring crop acreages for the four water allocations, given the wheat acreage of 3,092, are depicted in Table 13.

**Table 13: Optimal Crop Mix for Each Water Allocation**

| | Water Allocation Per Acre (Acre-Feet) | | | |
|---|---|---|---|---|
| Crop | 3.5 | 3 | 2.5 | 1.67 |
| Alfalfa | 13,825 | 12,760 | 9,056 | 4,752 |
| Corn | 4,639 | 4,639 | 4639 | 2,642 |
| Hay | 1,647 | 1,647 | 1647 | 528 |
| Pasture | 9,538 | 9,801 | 10743 | 11,825 |
| Potatoes | 980 | 980 | 980 | 980 |
| Onions | 300 | 300 | 300 | 300 |
| Sugarbeets | 980 | 980 | 980 | 297 |
| Wheat | 3,092 | 3,092 | 3092 | 3092 |
| Total | 35,000 | 34,198 | 31,437 | 24,417 |

As seen in Table 13, the perfect forecast model predicts that farmers will maximize revenue by changing their crop mix for different water allocations. They plant all of their land in full water years and begin fallowing land as water is reduced. Alfalfa acreage in particular declines as water supplies decline. As water becomes more scarce, it is expected that farmers will use less water on crops with the lowest marginal product values of water. This explains why alfalfa, which has a relatively low marginal product of water (high water demand, but only medium valued product), is planted on fewer acres as water supplies decrease.

The true economic losses caused by water supply fluctuations likely fall in between the losses predicted by the baseline model and the perfect forecast models. Tables 14 and 15 below illustrate the decline in VOID revenue and farmer profit (difference from the full, 3.5 water allocation revenue and profits) predicted by the perfect information model in which irrigators plant the ideal crop mix for each water year. As indicated in the tables, district crop revenue losses are greater in the perfect forecast scenario, while profits are generally higher.

**Table 14: Revenue losses with Perfect Knowledge**

| | Water Allocation Per Acre (Acre Feet) | | | |
|---|---|---|---|---|
| Farm Sector | 3 | 2.5 | 1.67 | Wt. Avg |
| Dairy | 0 | -126,207 | -425,318 | -145,894 |
| Small Mixed | -125,694 | -474,010 | -1,054,535 | -415,547 |
| Large Ranch | -114,916 | -525,332 | -948,419 | -387,142 |
| Row Crop | 0 | 0 | -956,287 | -290,998 |
| Ranch | -193,712 | -798,894 | -1,185,235 | -515,462 |
| Feedlot | 0 | -22,995 | -1,022,059 | -314,014 |
| Total | -434,323 | -1,947,438 | -5,591,855 | -2,069,057 |

**Table 15: Profit Losses with Perfect Knowledge**

| | Water Allocation Per Acre (Acre-Feet) | | | |
|---|---|---|---|---|
| Farm Sector | 3 | 2.5 | 1.67 | Wt Avg |
| Dairy | -25,723 | -38,948 | -71,954 | -33,689 |
| Small Mixed | -13,172 | -49,673 | -110,509 | -43,547 |
| Large Ranch | -2,075 | -112,335 | -296,149 | -105,319 |
| Row Crop | -17,111 | -17,111 | -174,695 | -59,857 |
| Ranch | -3,073 | -83,719 | -177,294 | -65,678 |
| Feedlot | 0 | 19,230 | -242,560 | -71,301 |
| Total | -61,154 | -282,558 | -1,073,161 | -379,392 |

The weighted average of total crop revenue losses is predicted to be $1.5 million greater in the perfect forecast scenario than in the baseline model (losses of $2 million versus $.5 million as indicated in Tables 11 and 14). This is chiefly due to the difference in acreage planted in high water years and low water years in the perfect information model (10,583 acres), while the baseline model is constrained to plant the same acreage every year. Since the baseline model must plant the same acreage every year, there is less revenue in high water years because fewer acres are planted than would maximize profit, and there is more revenue in low water years because more acres are planted than would maximize profit. Similarly, since the crop mix is not constrained in the perfect information model, this model does not predict the steep profit losses of lower water years seen in the baseline model, but rather predicts a weighted average of profit losses that is $155,000 less than the baseline model (losses of $379,000 versus $534,000, as indicated in Tables 12 and 15). The predictions from these two models, the baseline and the perfect information, suggest that the current, expected annual crop revenue losses in the VOID due to water shortages fall in the range of $0.5 million (4%) to $2.1 million (14%), while the annual expected profit losses fall in the range of $379,000 (9%) to $525,000 (11%).

## Value of Forecasts

The value of better water supply information to farmers was clear in the above section; perfect information led to lower profit losses due to water shortages. However, such perfect forecasts are not possible. Thus, to examine the value of less than perfect forecasts, a two-stage model was created. In the first stage of this model, the annual per acre water allocation is forecast and farmers are assumed to plant the optimal crop mix based on the forecast. In the second stage, the farmers receive the true water allocation (which differed from the forecast allocation according to the accuracy of the forecast) and apportion it among their crops to maximize profit.

To ascertain the value of forecasts of different accuracy levels, the two-stage model was solved to obtain the revenues and profits for sixteen possible forecasting and outcome scenarios. For example, for the acreage planted based on a forecast of a 3.5

acre-feet per acre allotment, the model was solved for actual allotments of each of the four possible water years. This was done for forecasts for each of the four water years.

Using these 16 possible profit and revenue outcomes, the value of each accuracy level of forecast was determined in the following manner. First, it was assumed that it was equally likely that the forecast was too high or too low. For example, for the 50% accuracy forecast it was assumed that 25% of the time the actual allocation was lower by one allotment level, and 25% of the time the actual allocation was higher by one allotment level. (If the forecast was for the highest (lowest) water year, it was assumed that a higher (lower) water year would have similar revenue or profit as the highest (lowest) water year since the historical probabilities and averages for the highest (lowest) water year included events that were outside the range of the four states of nature in this model.) Using this probability distribution, expected values of profit and revenue were calculated for a forecast for each water year. Finally, the expected profit and revenue for each level of forecast accuracy was calculated by weighting the expected profits and revenues for each forecast water year by the probability of that water year being forecast, which was assumed to be the same as the historical probability of that water year occurring: 0.30 for 3.5 acre-feet, 0.26 for 3 acre-feet, 0.13 for 2.5 acre-feet, and 0.30 for 1.67 acre-feet. To obtain the value in increased revenue and profit due to the forecast information on water supplies, the weighted average profit and revenue from the baseline (naive) model was then subtracted from these weighted average results. The difference in revenue and profits due to the varying accuracy forecast information is presented in Table 16.

## Table 16: Value of Different Accuracy Forecasts

| | 50% | 60% | 70% | 80% | 90% | 100% |
|---|---|---|---|---|---|---|
| Profit Change | 118,288 | 140,979 | 163,671 | 18,6362 | 209,054 | 231,746 |
| Revenue Change | -1,394,266 | -1,378,398 | -1,362,531 | -1,112,499 | -1,007,054 | -978,787 |

As Table 16 indicates, even a 50% accurate forecast would increase VOID profits by $118,000 (2%). For each 10% incremental increase in forecast accuracy, total VOID profits increase by $23,000 (0.5%). When forecast accuracy reaches 100%, total profits are increased from baseline profits by $232,000 (5%). As Table 17 indicates, the farm types that benefit the most from improved water supply information are the row crop and feedlot operations. At the 100% forecast accuracy, 58% of the profit increases accrue to row crop and feedlot operators; total row crop profits increase by $45,000 ($6,500 per individual row crop farm), and total feedlot profits increase by $106,0000 ($8,800 per individual feedlot operation).

## Table 17: Expected Annual Profit Increase at 100% Forecast Accuracy by Farm Type

(Difference between perfect forecast and baseline model profits)

| Farm Sector | Sector ($) | Individual Farm ($) | Percentage Increase from Baseline (%) |
|---|---|---|---|
| Dairy | 18,167 | 1,514 | 1.8 |
| Large Ranch | 22,717 | 2,840 | 3.7 |
| Ranch | 42,718 | 838 | 15.5 |
| Small Mixed | 25,991 | 153 | 33.6 |
| Row Crop | 45,443 | 6,492 | 2.4 |
| Feedlot | 105,581 | 8,798 | 2.2 |
| Total | 260,617 | N/A | 5.4 |

In contrast to the response of farm profits to additional water supply information, VOID farm revenue decreases with all forecast accuracy levels. As forecast accuracy improves from 50% to 100%, farm revenue losses drop from $1.4 million (10%) to

$979,000 (7%). Expected farm revenue drops with increasing forecast accuracy since in the lower water years farmers plant much less acreage; this leads to higher profits but lower farm revenue. These results suggest that improved water supply forecasting in the VOID would benefit farmers by increasing total farm profits by 2% to 5%, but would lead to lower expected overall economic activity (as indicated by decreased farm revenues) and negatively impact the Malheur County economy.

## Value of Irrigation Technology Change

Another potential strategy for mitigating economic losses from water shortages is further adoption of water-conserving technologies such as sprinkler and drip irrigation. As seen in Table 18, the VOID has slowly adopted more sprinkler technology over the last ten years. Additionally, drip technology appeared in 2002.

**Table 18: VOID Acreage Irrigated by Sprinkler and Drip 1992 – 2002**

| | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sprinkler | 3,979 | 4,298 | 4,401 | 4,714 | 4,715 | 4,715 | 4,810 | 4,905 | 5,504 | 5,504 | 4,177 |
| Drip | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 |

In both the original, baseline model and the perfect information model, sprinkler irrigation was limited to 5500 acres and drip was limited to 300 acres to correspond with the estimated 2004 level of irrigation technology. To examine the effects of increased sprinkler and drip usage, a longer-term model was created which differed from the baseline model by allowing irrigation technology to increase. As in the baseline model, information on water supplies in this longer-term model was limited to information on the historical probabilities of water years and did not include any forecast information.

Since further irrigation technology adoption in the VOID is limited by several factors not included in the model (such as access to electricity lines, slope of the land, and capital constraints), the levels of sprinkler and drip irrigation technology in this new model were only allowed to double in the model to 11,000 and 600 acres, respectively.

The increased use of irrigation technology resulted in a change in the crop mix planted in the VOID. As in the baseline model, it is assumed that the only available information about water supplies is the historical probability of different allocations, so irrigators plant the same acreage every year. As illustrated in Table 19, total planted acreage in the long-term model increased by 615 acres from the acreage planted in the baseline model. Alfalfa and onions, both relatively water-intensive crops, increased in acreage while wheat, a relatively low-valued, low-water-usage crop, decreased in acreage.

**Table 19: Crop Acreage Comparison: Long Term and Baseline Models**

| | Long Run | Baseline | Difference |
|---|---|---|---|
| Alfalfa | 12,562 | 11,542 | 1,020 |
| Corn | 4,639 | 4,639 | 0 |
| Hay | 1,932 | 1,932 | 0 |
| Onions | 600 | 300 | 300 |
| Pasture | 9,538 | 9,538 | 0 |
| Potatoes | 980 | 980 | 0 |
| Sugarbeets | 980 | 980 | 0 |
| Wheat | 2,386 | 3,092 | -706 |
| Total | 33,617 | 33,002 | 615 |

The model results indicate that VOID farmers can increase profits by adopting more water-conserving irrigation technology. By increasing irrigation technology to the limit of 11,000 acres of sprinkler and 600 acres of drip, the model indicated an increase from the baseline model in expected annual profits (the weighted average over the four water years) of $264,000 (5%). Additionally, the model predicted revenue increases of $744,000 (6%). Furthermore, by increasing irrigation technology, farmers can reduce economic losses due to water shortages: the average weighted profit and revenue losses due to water shortages declined, respectively, by $32,000 (6%) and $53,000 (10%).

### Value of a Water Market or Water Bank

By enabling water to flow to its highest-valued use, water markets can limit the economic impacts of water shortages. Currently, water transfers between farmers are allowed in the VOID but are costly and difficult to transact due to the lack of an established market and the lack of a streamlined transfer process. Since the soil quality and crops grown in the VOID are heterogeneous, the VOID is particularly well-suited to implement a water market. Heterogeneity in soil quality and crop value increases the value of a water market since farmers that use water on low quality land or low-valued crops can often profit from selling the water to farmers irrigating high-valued crops on high quality land. By such a transfer, both farmers can profit, and the overall economic consequences of a water shortage are lessened.

As seen in Table 20, marginal water values in the VOID for each operation type do differ substantially. As expected, the highest marginal water values are on the operations with higher-valued crops, such as the row crop farms and feedlots, or high livestock feed replacement costs, such as the dairies.

### Table 20: Marginal Water Values Per Acre-Foot: Baseline With Water Trading Model

| | 1.67 | 2.5 | 3 | 3.5 |
|---|---|---|---|---|
| Dairy | 89.38 | 0 | 0 | 0 |
| Large Ranch | 28.49 | 28.49 | 28.49 | 0 |
| Ranch | 20.16 | 19.14 | 19.14 | 19.14 |
| Small Mixed | 20.16 | 19.14 | 19.14 | 0 |
| Row Crop | 70.656 | 70.66 | 0 | 0 |
| Feedlot | 149.928 | 91.92 | 0 | 0 |

In the most severe water shortage year (1.67 acre-foot per acre allotment) the marginal water values in the VOID are estimated to range from $20 per acre-foot to $150 per acre-foot of water. Although the difference between the marginal value of water on different farm types lessens as the per-acre water allotment increases, for every water allotment level there is a difference in the marginal water values. The disparity in marginal water values across farm types indicates that a water market would enable mutually beneficial water transfers between project farmers and lessen the economic consequences of water shortages.

The marginal values of water are lower when irrigators had perfect information about the water supply. For example, when irrigators knew before spring planting that the water allotment would be 1.67 acre-feet, the marginal water values ranged from $51 per acre-foot to $14 per acre-foot. This suggests that as irrigators have more information, they are better able to manage their resources. As expected, in both the baseline and the perfect information models, marginal water values increased with increasing water scarcity.

Using the baseline model (current irrigation levels, only historical information on water supplies) and the longer-term model in which irrigation levels are allowed to double, a perfectly competitive water market was simulated in both the short-run and the long-run by allowing all available VOID water to be used in its highest-valued use anywhere in the district. This water-trading model assumed that the water could be traded on an annual basis and that there were no transaction costs or other impediments to water transfers. In both the baseline (short-run) and the longer-term models with water trading, acreage planted increased as seen in Table 21.

**Table 21: Effects of Water Market on Long-Term and Baseline Model Acreages**

| | Long-Term Model | | Baseline Model | |
|---|---|---|---|---|
| | No Trading | Trading | No Trading | Trading |
| Alfalfa | 12,562 | 10,313 | 11,542 | 8,654 |
| Corn | 4,639 | 4,639 | 4,639 | 4,639 |
| Hay | 1,932 | 6,869 | 1,932 | 6,869 |
| Onions | 600 | 600 | 300 | 300 |
| Pasture | 9,538 | 9,538 | 9,538 | 9,538 |
| Potatoes | 980 | 980 | 980 | 980 |
| Sugarbeets | 980 | 980 | 980 | 980 |
| Wheat | 2,386 | 1,082 | 3,092 | 2,264 |
| Total | 33,617 | 35,000 | 33,002 | 34,223 |

In the lowest water year allotment, the farm operators with the highest-valued crops (and the highest marginal value of water), specifically the row crop and the feedlot operators, purchased the most water. The dairy and large ranch operators also purchased water, while the ranch and small mixed crop farms sold water. As the water allocation increased, however, the water-trading pattern shifted. While the feedlot and large ranch operators still purchased water, the row crop farmers began selling water as the marginal value of water on row crop farms declined relative to the value of water on other operations. In the baseline model, total water traded annually increased from 12,900 acre-feet (12% of total VOID water) to 16,700 acre-feet (29% of total VOID water) as the water allocation decreased from 3 acre-feet per acre to 1.67 acre-feet per acre. Water trading in the longer-term model was slightly lower than in the baseline model: water-trading volume increased from 12,600 acre-feet (12%) to 15,700 acre-feet (27%) as water allotment declined.

**Table 22: Acre-Feet of Water Traded Under Each Allocation***

| | 1.67 | | 2.5 | | 3 | |
|---|---|---|---|---|---|---|
| | Long Term | Baseline | Long Term | Baseline | Long Term | Baseline |
| Dairy | -1,630 | -604 | 370 | 1,396 | 1,570 | 2,596 |
| Large ranch | -2,172 | -3,560 | -11,980 | -13,368 | -9,980 | -11,368 |
| Ranch | 11,685 | 11,685 | 9,548 | 9,548 | 5,147 | 5,147 |
| Small mixed | 4,005 | 5,021 | 2,867 | 3,883 | -2,582 | -1,566 |
| RowCrop | -3,703 | -5,275 | 381 | -1,192 | 2,831 | 1,258 |
| Feedlot | -8,185 | -7,267 | -1,185 | -267 | 3,015 | 3,933 |
| Total Traded | 15,690 | 16,706 | 13,165 | 14,826 | 12,562 | 12,933 |
| % Total Water Used | 26.9% | 28.6% | 15.0% | 16.9% | 12.0% | 12.3% |

*Positive Figure Indicates Selling, Negative Number indicates Buying

While expected annual profits increased, expected annual revenue actual decreased with water trading. This is due to hay acreage increasing at the expense of alfalfa acreage. This reduces the revenue but increases the profit since farms on lower quality soils that produced alfalfa traded some water to irrigators with higher-valued uses and instead produced hay, a lower water usage and lower revenue crop, with their remaining water. Trading increased expected annual profits in the baseline model by $229,000 (5%) and in the longer-term model by $241,000 (5%). Trading decreased expected annual revenue in the baseline model by \$958,000 (-7%) and in the longer-term model by \$394,000 (-3%).

## Summary of Farm-Level Impacts

The LP baseline model results indicate that under existing probabilities of annual water allotments, production technology, and crop rotations, the expected annual profit losses in the VOID due to water supply fluctuations range from \$.5 million (4%) to \$2.1 million (14%), while the expected annual profit losses fall in the range of \$379,000 (9%) to \$534,000 (12.3%). Although profits and revenues begin to decline when the per-acre water allotment drops below 3.5 acre-feet, revenue and profits stay fairly stable until the water allotment decreases from 2.5 acre-feet to 1.67 acre-feet. At the 1.67 acre-feet per acre allotment, profits drop by 25 to 36% and revenues by 12 to 39%, depending on assumptions about farmer knowledge of water supply allotment.

Of the three potential strategies to mitigate the economic consequences of water fluctuations explored in this study, it appears that adoption of additional irrigation technology most successfully reduces profit and revenue losses due to water shortages. By doubling current levels of sprinkler and drip irrigation technology, expected annual revenues increase from the baseline by \$744,000 (6%) and expected annual profits rise by \$264,000 (5%), which is slightly more than profit increases due to a water market / water bank or improved accuracy water supply forecasts. Although both improved forecast accuracy and implementation of a water market or a water bank increased farm profits, these two strategies also resulted in a decrease in farm revenues of 5 to 7% from the baseline. Since farm revenues indicate the total economic activity in the agricultural sector and its contribution to the regional economy, a decrease in farm revenues would negatively impact the Malheur County economy.

## 5.2 Community-Level Impacts

In addition to investigating farm-level impacts, this study investigated the employment and income effects of VOID water supply variations on the Malheur County economy. The county-level impacts were estimated by conducting an economic impact analysis with an edited IMPLAN input-output model. Employment impacts were measured as changes in county jobs (both part-time and full-time) while income impacts were measured as the combined changes in employee income, proprietor income, property income, and indirect business taxes, or the 'total valued added' of economic activity in Malheur County. Economic impacts of the four water allocation levels were estimated for the baseline scenario as well as for each of the mitigating strategies of additional irrigation technology adoption and implementation of a water market or water bank.

The impact of a change in agricultural production on the Malheur County economy depends on the strength of the linkages between the agricultural industry and other economic sectors. The magnitude of inter-industry linkages can be measured by multipliers, which indicate how a change in one industry affects all of the sectors in an economy. For example, in Table 23, grain farming has a Type SAM employment multiplier of 1.37. This means that when one job is created in grain farming, total

Malheur County employment is raised by 1.37 jobs. Income multipliers for Malheur County agriculture (presented in Table 24) indicate that for each $1.00 increase in VOID crop farming income, total county value added will increase by of $2.10 to $2.35, depending on the crop.

### Table 23: Malheur County Employment Multipliers by Sector

(Employment effects of a $1million change in sector output)

| | Direct Effects | Indirect Effects | Induced Effects | Total Effects | Type I Multiplier* | Type SAM Multiplier** |
|---|---|---|---|---|---|---|
| Oilseed farming | 24.80 | 3.96 | 6.92 | 35.68 | 1.16 | 1.44 |
| Grain farming | 32.50 | 6.00 | 5.86 | 44.36 | 1.18 | 1.37 |
| Vegetable and melon farming | 9.32 | 5.33 | 7.62 | 22.27 | 1.57 | 2.39 |
| Fruit farming | 5.83 | 6.99 | 7.13 | 19.95 | 2.20 | 3.42 |
| Sugarcane and sugar beet farming | 18.40 | 6.75 | 6.58 | 31.73 | 1.37 | 1.72 |
| All other crop farming | 16.98 | 5.85 | 6.39 | 29.23 | 1.34 | 1.72 |
| Cattle ranching and farming | 13.55 | 14.51 | 4.81 | 32.87 | 2.07 | 2.43 |
| Animal production, except cattle and poultry | 12.32 | 7.15 | 4.97 | 24.44 | 1.58 | 1.98 |
| Forestry, Hunting & Fishing | 3.24 | 5.31 | 8.89 | 17.45 | 2.64 | 5.38 |
| Agriculture and forestry support activities | 25.27 | 2.09 | 9.62 | 36.98 | 1.08 | 1.46 |
| Mining | 5.80 | 2.57 | 6.76 | 15.13 | 1.44 | 2.61 |
| Utilities | 1.91 | 2.99 | 6.00 | 10.90 | 2.56 | 5.69 |
| Construction | 12.67 | 5.44 | 6.24 | 24.35 | 1.43 | 1.92 |
| Other Manufacturing | 6.49 | 3.09 | 4.88 | 14.47 | 1.48 | 2.23 |
| Food Manufacturing | 3.92 | 7.14 | 4.77 | 15.84 | 2.82 | 4.04 |
| Wholesale Trade | 13.32 | 3.42 | 10.37 | 27.12 | 1.26 | 2.04 |
| Transportation and Warehousing | 13.28 | 4.66 | 7.78 | 25.72 | 1.35 | 1.94 |
| Retail | 23.97 | 4.62 | 9.39 | 37.97 | 1.19 | 1.58 |
| Information | 3.77 | 4.71 | 5.33 | 13.81 | 2.25 | 3.66 |
| Finance and Insurance | 11.38 | 2.36 | 8.44 | 22.19 | 1.21 | 1.95 |
| Real Estate and Leasing | 30.57 | 3.20 | 9.22 | 42.99 | 1.10 | 1.41 |
| Services | 15.29 | 3.79 | 8.18 | 27.25 | 1.25 | 1.78 |
| State and Local Government | 23.07 | 0.10 | 11.11 | 34.28 | 1.00 | 1.49 |
| Federal Government | 13.69 | 0.02 | 11.18 | 24.89 | 1.00 | 1.82 |

*Type I Multiplier: (Indirect + Direct Effects) / Direct Effects

**Type SAM Multiplier: (Induced + Indirect + Direct + Inter-Institutional Effects) / Direct Effects

## Table 24: Malheur County Total Value Added Multipliers by Sector

(Total value added effects of a dollar change in sector output)

| | Direct Effects | Indirect Effects | Induced Effects | Total Effects | Type I Multiplier | Type SAM Multiplier |
|---|---|---|---|---|---|---|
| Oilseed farming | 0.525 | 0.129 | 0.276 | 0.930 | 1.246 | 1.772 |
| Grain farming | 0.312 | 0.185 | 0.235 | 0.732 | 1.595 | 2.349 |
| Vegetable and melon farming | 0.533 | 0.174 | 0.305 | 1.012 | 1.326 | 1.898 |
| Fruit farming | 0.399 | 0.219 | 0.286 | 0.904 | 1.548 | 2.264 |
| Sugarcane and sugar beet farming | 0.348 | 0.212 | 0.264 | 0.824 | 1.609 | 2.368 |
| All other crop farming | 0.409 | 0.184 | 0.255 | 0.849 | 1.450 | 2.074 |
| Cattle ranching and farming | 0.044 | 0.326 | 0.194 | 0.565 | 8.488 | 12.947 |
| Animal production, except cattle | 0.207 | 0.205 | 0.200 | 0.612 | 1.992 | 2.959 |
| Forestry, Hunting & Fishing | 0.561 | 0.201 | 0.356 | 1.118 | 1.358 | 1.992 |
| Agriculture and forestry support activities | 0.705 | 0.060 | 0.387 | 1.152 | 1.085 | 1.635 |
| Mining | 0.495 | 0.083 | 0.271 | 0.849 | 1.168 | 1.716 |
| Utilities | 0.377 | 0.104 | 0.241 | 0.723 | 1.277 | 1.917 |
| Construction | 0.314 | 0.167 | 0.251 | 0.733 | 1.533 | 2.334 |
| Other Manufacturing | 0.297 | 0.123 | 0.196 | 0.616 | 1.412 | 2.071 |
| Food Manufacturing | 0.217 | 0.187 | 0.192 | 0.596 | 1.861 | 2.744 |
| Wholesale Trade | 0.653 | 0.122 | 0.420 | 1.195 | 1.187 | 1.831 |
| Transportation and Warehousing | 0.492 | 0.175 | 0.312 | 0.979 | 1.355 | 1.990 |
| Retail | 0.575 | 0.153 | 0.379 | 1.107 | 1.266 | 1.925 |
| Information | 0.272 | 0.184 | 0.214 | 0.670 | 1.675 | 2.460 |
| Finance and Insurance | 0.685 | 0.106 | 0.337 | 1.129 | 1.155 | 1.646 |
| Real Estate and Leasing | 0.687 | 0.110 | 0.369 | 1.166 | 1.160 | 1.697 |
| Services | 0.550 | 0.129 | 0.329 | 1.008 | 1.234 | 1.832 |
| State and Local Government | 0.987 | 0.003 | 0.445 | 1.436 | 1.003 | 1.454 |
| Other | 0.781 | 0.074 | 0.376 | 1.231 | 1.094 | 1.576 |
| Federal Government | 0.998 | 0.001 | 0.448 | 1.447 | 1.001 | 1.450 |

As the VOID water supply declines, the direct effect is a decline in agricultural production while indirect and induced effects result in less economic activity in other economic sectors as indicated by the multipliers in Tables 23 and 24. Table 25 summarizes the effects of lower VOID water allocations on employment and output in Malheur County. As water allocation declines from 3.5 acre-feet per acre to 2.5 acre-feet per acre, employment and output each decrease by only about 0.01%. Only when the VOID water allocation drops to 1.67 acre-feet per acre does the county economy experience a more significant impact: a decline in employment of 54 jobs (0.3%) and a decline in income of $1.3 million (0.2%). These estimates reflect the county impact of a water shortage in the VOID alone; if drought were to affect all irrigation districts in Malheur County, the employment and income impacts would be much greater.

Although the influence of VOID water allocations on county employment and income appears relatively small, it is important to note that much of the employment and income impact could be localized in the Vale area, resulting in greater local economic distress than indicated by the 0.2% decline in county income. Since the direct impact is occurring in the Vale area, the percentage decline in the Vale area income would be greater than the percentage income decline for the entire county. Also, the Vale area is relatively more dependent upon agriculture than the rest of the county: according to the 2000 Census, approximately 20% of employed individuals living in the Vale zip code area work in farming occupations, while 15% of employees in Malheur County work in farming occupations.

**Table 25: Summary Baseline County Employment and Income Effects**
(Difference from pre-impact, 3.5 Acre-Foot Allotment using Type SAM multipliers)

| | Employment Change | | Income Change | |
|---|---|---|---|---|
| Water Allocation | Jobs | Percent | Dollars | Percent |
| 3 | -0.5 | -0.00300 | -15,517 | -0.00223545 |
| 2.5 | -2.7 | -0.01400 | -79,558 | -0.01146151 |
| 1.67 | -54.6 | -0.29100 | -1,312,708 | -0.18911504 |

Of the estimated 55 jobs lost as a result of a 1.67 acre-feet allotment per acre, 35 are direct employment effects in agricultural production, 10 are indirect employment effects (primarily in agricultural support, trade, real estate and service sectors), and 10 are induced employment effects (primarily in trade, services, and government sectors). Of the county income decline due to a VOID water allocation level of 1.67, 47% ($613,000) are direct income effects in the agricultural sectors. The sectors linked to agriculture for which the model predicted the highest employment and income declines are government (3.7 jobs, $181,000), services (3.1 jobs, $110,000), real estate and leasing (2.8 jobs, $62,000), retail (1.6 jobs, $39,000), and wholesale trade (1.1 jobs, $55,000).

One strategy to mitigate the economic consequences of water shortage is to implement a water bank or water market. Results from the LP model indicate that short-term transfers in the VOID would result in increased farm profits, but lower farm revenues. This is due to a different crop mix being planted in the presence of a water market or bank. Since lower crop revenues signify less total economic activity, these results indicate that county employment and income would decline in Malheur County if a water bank or market were implemented in the VOID.

### Table 26: Summary Baseline with Water Trading County Employment & Income Effects

(Decrease from pre-impact, 3.5 Acre-Foot Allotment using Type SAM multipliers)

| | Employment Change | | Income Change | |
|---|---|---|---|---|
| Water Allocation | Jobs | Percent | Dollars | Percent |
| 3.5 | -26.5 | -0.14132 | -615,575 | -0.0886827 |
| 3 | -26.5 | -0.14132 | -615,575 | -0.0886827 |
| 2.5 | -32 | -0.17065 | -777,124 | -0.11195623 |
| 1.67 | -47.4 | -0.25277 | -1,223,554 | -0.17627108 |

The IMPLAN model estimates that if water trading is implemented in the VOID and there are no water shortages, employment would decline by approximately 25 jobs and annual income would decline by $615,000. The direct effects on the agricultural sectors account for approximately 17 jobs (65%) and $285,000 (46%) of the lost income. As the water allocation decreased, employment and income would continue to decline. When the per-acre water allocation drops to 1.67 acre-feet, the model estimates that employment and income would respectively decrease by almost 50 jobs and $1.2 million. Although water trading decreases the total income and employment for per acre water allocations of 3.5, 3, and 2.5 acre-feet, it reduces the negative effects of a severely reduced water allocation of 1.67; water trading results in 7 fewer job losses (47 jobs versus 54 jobs) and $90,000 less in income losses ($1.22 million versus $1.31 million) under the severest water reduction scenario.

The county employment and income effects of a second mitigating strategy, increased irrigation technology adoption, are also examined. Results indicate that this strategy (which in the LP model resulted in a doubling of both drip and sprinkler technology) increases both profits for farmers and county employment and income. As seen in Table 27, with a full water allocation the effect of increasing sprinkler and drip irrigation technology in the VOID is an increase in employment of over 20 (0.1%) jobs and a rise in income of over $1.1 million (0.2%). Even with a per acre water allotment of 2.5 acre-feet, additional irrigation technology results in more employment and more income than a full water allotment at current technology levels. Although employment and income declined at an allotment of 1.67 acre-feet, the decrease in employment and income is substantially less than in the short-run baseline model in which there was no additional irrigation technology adoption: approximately 30 fewer jobs are lost (decrease of 55%) and income losses decreased by $1.2 million (decrease of 90%) under increased irrigation technology.

**Table 27: Summary Long Term County Employment and Income Effects**

(Difference from Pre-Impact, 3.5 Acre-Foot Allotment using Type SAM multipliers)

| | Employment Change | | Income Change | |
|---|---|---|---|---|
| Water Allocation | Jobs | Percent | Dollars | Percent |
| 3.5 | 23.6 | 0.125853242 | 1,168,956 | 0.168405433 |
| 3 | 23.3 | 0.124253413 | 1,161,548 | 0.167338201 |
| 2.5 | 21.1 | 0.112521331 | 1,097,507 | 0.158112146 |
| 1.67 | -26.5 | -0.141318259 | -137,516 | -0.019811217 |

Finally, the joint implementation of additional irrigation technology and a water bank or water market is examined. Joint implementation reduced the decline in county employment caused by the water market implementation at the higher water allocation levels and results in positive income impacts for all of the water allocation levels. Although employment losses are still higher under joint implementation for the highest three levels of water allocation than in the baseline case with no mitigation strategy, the employment losses are minimal (2 –8 jobs). Additionally, while income for the three highest water allocation levels is lower than when additional irrigation technology alone is implemented, it is higher by $0.6 to $0.7 million than in the base case. Finally, joint implementation results in the lowest employment and income impacts at the lowest water allocation level (1.67 acre-feet) of any of the strategies, with a decline in only 22 jobs and an increase in income of $66,000. Thus, for years of severe drought, mitigation by the use of water banks and irrigation technology is beneficial not only to irrigators but also to the community.

**Table 28: Summary Long Term**
**with Water Trading County Effects**
(Difference from Pre-Impact, 3.5 Acre-Foot Allotment using Type SAM multipliers)

| | Employment Change | | Income Change | |
|---|---|---|---|---|
| Water Allocation | Jobs | Percent | Dollars | Percent |
| 3.5 | -1.8 | -0.009599 | 673,678 | 0.097053 |
| 3 | -1.8 | -0.009599 | 673,678 | 0.097053 |
| 2.5 | -7.4 | -0.039463 | 512,129 | 0.073780 |
| 1.67 | -22.7 | -0.121054 | 65,700 | 0.009465 |

## Summary of Community-Level Impacts

The input-output results suggest that the county economic losses of VOID water supply fluctuations, even in the most severe water shortage scenario, are limited to less than 1% of county employment and income. The baseline (short-term) input-output model indicates that with no mitigating strategy, the current economic impacts of VOID water supply fluctuations range from employment losses of 1 to 50 jobs (0.003-0.03%) and income losses of $15,000 to $1.3 million (0.002-0.2%) depending on the severity of the water supply fluctuation. Although county economic impacts appear to be small, both employment and income impacts are likely concentrated in the Vale area, potentially causing much stronger local economic distress than indicated by the county estimates.

Table 29 provides an overview of the county income and employment effects under each mitigation strategy at each of the water allocation levels.

**Table 29: Summary of Income and Employment Changes by Mitigation Strategy**
(Difference from Baseline, 3.5 acre-foot allotment using Type SAM multipliers)

| | 3.5 | | 3 | | 2.5 | | 1.67 | |
|---|---|---|---|---|---|---|---|---|
| | Income | Emp | Income | Emp | Income | Emp | Income | Emp |
| Baseline | 0 | 0 | -15,517 | -0.5 | -79,558 | -2.7 | -1,312,708 | -54.6 |
| Baseline with Water Trading | -615,575 | -26.5 | -615,575 | -26.5 | -777,124 | -32 | -1,223,551 | -47.4 |
| Long Term (Additional Irrigation) | 1,168,956 | 23.6 | 1,161,548 | 23.3 | 1,097,507 | 21.1 | -137,516 | -26.5 |
| Joint Implementation (Additional Irrigation and Water Trading) | 673,678 | -1.8 | 673,678 | -1.8 | 512,129 | -7.4 | 65,700 | -22.7 |

These input-output model results indicate that two strategies to mitigate the economic impacts of water supply fluctuations on agricultural economies, additional irrigation adoption and water markets or water banks, would have very different effects on the Malheur economy. While a VOID water market or bank would increase farm profits, it would decrease farm revenue at all water allocation levels, and consequently negatively impact the Malheur County economy. Additional irrigation technology adoption, however, would actually increase income from the baseline, full water allocation level of 3.5 acre-feet per acre by $1.2 million (0.17%) and increase employment by 20 jobs (0.1%) for all water allocation levels except the lowest of 1.67 acre-feet per acre. Finally, joint implementation of a water market and additional irrigation technology would result in slightly higher declines in employment than either the baseline or irrigation technology adoption scenario for the three highest water allocation levels, but would result in higher incomes than in the baseline case for all of the water allocation levels (though the income increases are less for the highest three water levels than if additional irrigation technology alone were implemented). While on average the joint implementation results in lower county employment and income gains than solely adopting additional irrigation technology for the three upper water allocation levels, the combined strategies most successfully mitigates the employment and income impacts of the most severe water shortage years.

Although approximately 20% of Malheur county employment and 10% of county income are agriculturally related, changes in the VOID water supply appear to have only slight impacts on county employment and income. This is partly due to the VOID being just one of three major irrigation districts in the county (it comprises only 16% of total irrigated land in Malheur County) and partly due to strategies employed by farmers to reduce water supply impacts. Additionally, since over 30% of VOID acreage is planted in low-valued crops such as pasture and hay, the VOID contributes proportionately less to the county income than other irrigation districts (only 6% of county farm income on 16% of county irrigated land).

## Chapter 6: Summary and Conclusions

As the predominant water user in the western United States, irrigated agriculture is facing less certain water supplies due to increasing competition for water from urban populations, legal protection of endangered species, and potentially, climate-induced hydrological changes. Since many rural areas in the west depend economically on agriculture, reduced water supplies for irrigation can significantly impact not only agricultural producers, but also local economies. Although many studies have examined the economic effect of reduced water supplies on irrigated agriculture, few studies have examined the specific effects of water supply reductions on different farm types and on regional economies. Through a case study of the Vale Oregon Irrigation District (VOID) located in Malheur County, Oregon, this study investigated both the farm-level and the regional-level economic impacts of water supply fluctuations on an agriculturally-dependent economy.

The farm-level impacts of fluctuating water supplies were examined through the development of a linear programming (LP) model that simulated VOID agricultural production. Since the VOID includes a diversity of farm types, the model included six representative farms grouped by acreage, crops grown, and type and number of livestock animals raised: dairy, large ranch, ranch, small mixed crop, row crop, and feedlot. The LP model maximized farm returns to land, capital, and management subject to annual water availability, farmland resources, certain agronomic constraints, and the necessity to provide feed for livestock. Additional constraints concerning the level of irrigation technology, the availability of water supply information, and the ability of project irrigators to trade water were varied in different versions of the baseline model in order to estimate the value of additional irrigation technology adoption, improved accuracy of water supply forecast information, and implementation of a water market or water bank.

The county-level impacts were estimated by conducting an economic impact analysis with an edited IMPLAN input-output model. The LP model estimates of farm revenue changes due to water supply variations were utilized as the exogenous change in the input-output model. The employment and income (as measured by total value added) effects were estimated by comparing the pre-impact, full water supply (3.5 acre-feet per acre) employment and income with the post-impact lower water supply employment and income. Economic impacts of three lower water allocation levels (3, 2.5, and 1.67 acre-feet per acre) were estimated for the baseline scenario as well as for each of the mitigating strategies of additional irrigation technology adoption and implementation of a water market or water bank.

Results from the LP models indicate that profit-maximizing farmers in the VOID can mitigate profit losses due to water shortages in the short-term by fallowing land, deficit irrigating, and, if provided with water supply information before spring planting, by adjusting their crop mix. Despite these adjustments, with the current level of irrigation technology and water allotment probabilities, the expected annual profit losses to project irrigators due to water supply fluctuations are between 9 and 12% of full water year profits, while the annual expected revenue losses due to water shortages range from 4 to 14% of full water year revenues. Seventy-five percent of expected annual farm profit losses are on the large ranches, feedlot operations, and row crop farms. As a percentage of profits, however, expected profit losses were highest on small mixed crop farms (213%) and small ranches (38%).

Although approximately 20% of county employment and 10% of county income are agriculturally related, Malheur county employment and income declines due to water supply variations in the Vale Irrigation District, even in the most severe water shortage scenario, are limited to less than 1%. The sectors linked to agriculture for which the model predicted the highest employment and income declines are government, services, real estate and leasing, retail, and wholesale trade. While county-level economic losses remain fairly small at all water allotment levels, losses do decline at a much higher rate when water allotment levels drop to the lowest modeled water allotment of 1.67 acre-feet per acre.

The low magnitude of the county impacts is likely due to the VOID's relatively small contribution to Malheur County agriculture: the VOID comprises only 16% of irrigated land in the county and contributes only 6% of total county agricultural revenue. Impacts are expected to be much greater if all three of the major irrigation districts in the county were affected by drought. Additionally, although county impacts from water shortages limited to the VOID were relatively small, it is important to note that much of the employment and income losses could be localized in one community, Vale, resulting in greater local economic distress than indicated by the small percentage decline in county income and employment. Furthermore, since many agricultural producers operate with very small profit margins, even small declines in farm profits may cause some producers to exit and fewer producers to enter the farming business. If this were the case, small declines in farm profits could lead to large declines in total VOID farm revenues and much more significant county economic impacts.

Three commonly discussed strategies to mitigate farm-level and community-level impacts of irrigation water shortages were investigated: improved accuracy of water supply forecasts, additional irrigation technology adoptions, and implementation of a water bank or water market. Results suggest that of the three mitigating strategies, additional irrigation technology adoption most successfully reduces farm and community-level economic losses. While all strategies reduced expected annual profit declines due to water shortages by approximately 5%, only additional irrigation technology reduced revenue declines. Due to crop mix changes, both more accurate forecasts and the use of water bank or water market actually led to greater declines in expected farm revenues than in the baseline scenario, and therefore greater declines in county-level employment and income. The joint strategy of additional irrigation technology and implementation of a water bank or water market resulted in the greatest mitigation of farm profit losses due to water shortages (5%), and resulted in only a 3% loss in revenues (as compared to a 7% loss when only a water market or bank is implemented).

As water supplies become less certain for western irrigators, agriculture is under increasing pressure to reduce its water usage. Results from this study indicate that the various mitigating strategies should be examined not only for their impact on farm profits, but also for their effect on revenues since these impact community employment and income. While the decrease in farm revenues due to improved water supply forecasting and a water market or water bank found in this study might be peculiar to the VOID and Malheur County, other communities may be similarly affected. This is an area for further investigation.

Additionally, this study did not address the longer-term effects of less certain water supplies. Since many agricultural producers operate with very small profit margins, even small reductions in expected profits may make farming unprofitable and result in significant agricultural sector declines. Studies that include all costs and returns are needed to ascertain how resilient the agricultural sector will be in the long-term to increased water supply uncertainty.

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