AN ABSTRACT OF THE THESIS

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Agronomic research documents a strong correlation between the level of irrigation water applied and the level of farm chemicals leached into water bodies. Consequently, policies that cause farmers to alter irrigation water management practices are likely to influence water quality. Water markets are a potentially attractive method of addressing agriculturally induced water quality concerns because they provide an economic incentive to reduce agricultural effluent which is less costly to farmers and society than command and control or tax policies.

This research focuses on quantifying key economic and environmental implications of changes in institutional rules defining terms of water trade. At the heart of this dissertation is an empirical hydrologic-economic simulation model of the Treasure Valley area of eastern Oregon. The economic component of the model consists of 8 subregional mathematical programming models. The models vary across subregions with differences in soil productivity, production technology and irrigation cost specification. The hydrologic component of the model consist of two parts. A nitrate leaching model describes how changes in crop choice, irrigation and nitrogen input influence the level of nitrate leaving the root zone. A finite difference model describes the process of nitrate dilution in the aquifer.

Five impacts of water trade are predicted: 1) water supplied to water markets, 2) profits from water market participation, 3) local groundwater quality effects, 4) local economic effects of water markets, and 5) effects of water markets on third party water rights holders.

Significant conclusions drawn from the study include: 1) in large portions of the study area, the annual returns to selling water rights exceeds returns to continued irrigated crop production, even at very moderate water prices ($20 an acre foot); 2) at current water prices, the parts of the study area most likely to supply water to markets are areas used for extensive cultivation of hay, pasture and grain which contribute little to the loading of the underlying aquifer with nitrates; 3) a well developed water market in the area would not likely lead to full compliance with EPA groundwater quality standards; 4) the Oregon Statute allowing sale of conserved water is unlikely to induce much trade in conserved water in the Treasure Valley.

Market Water Transfers as a Water Quality Policy: A Case Study of the Malheur River Basin, Oregon

by

Jeffery D. Connor

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

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Jeffery D. Connor, Author

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CHAPTER 1: INTRODUCTION

1.1 Background

While federal laws have effectively reduced industrial and municipal water pollution, high rates of agricultural non-point effluent loading of surface and groundwater persist (Gianessi and Peskin). Formulating effective policies to control such pollutants has proven particularly difficult. One source of difficulty are the often large differences in the marginal damages per unit of effluent loading across heterogeneous watersheds. In such settings targeted policies offering specialized incentives to areas where marginal damages are greatest tend to be much more efficient than undifferentiated incentives (i.e. Braden et. al.). However, differentiated policies tend to be expensive and difficult to administer. Furthermore, the disperse spatial distribution and the stochastic temporal nature of agricultural effluent loading makes direct monitoring of effluents extremely costly. As a consequence, effluent-based incentives which are consistent with economic efficiency criteria are generally infeasible (Griffin and Bromley).

This research focuses on quantifying key economic and environmental implications of changes in institutional rules defining terms of water trade. Institutional rules are the laws and administrative procedures defining what portion of an existing diversionary water rights may be transferred, to whom it may be transferred, for what purposes and how third party effects are treated. Such rules are the variables effected by the judges, legislators, federal state and local agencies who collectively define water transfer policy.

Special emphasis is on the potential of water markets as a policy to control effluent loading of water bodies from agricultural non-point sources. Many studies conclude that when other crop management practices are held constant, there is a strong correlation between the level of irrigation water applied and the level of farm chemicals leached into water bodies (Timmons and Dylla; Linderman; Hergert; Watts and Martin; McNeal and Carlie). Consequently, policies in the arid western United States that cause farmers to alter irrigation water management practices are likely to influence water quality.

Water markets are a potentially attractive method of addressing agriculturally induced water quality concerns because they provide an economic incentive to conserve water and thus reduce agricultural effluent externalities with minimal government command and control (Dinar and Letey; Weinberg, Kling and Wilen). By contrast best management practice mandates, effluent or input tax schemes may be quite costly to farmers (Johnson, Adams and Perry; Taylor, Adams and Miller) and costly to government agencies charged with regulating these practices.

This dissertation is a detailed exploration of the agronomic, economic, hydrologic and technological factors which jointly determine the technical, economic and political feasibilty of water markets as a water quality policy.

1.2 Research Objectives

This research is designed to illuminates the way in which underlying economic, technological and hydrologic conditions interact with rules defining term of water trade to define a set of economic and water quality outcomes.

The specific research goals are to quantify the impact that institutional rules governing water trades are likely to have on:

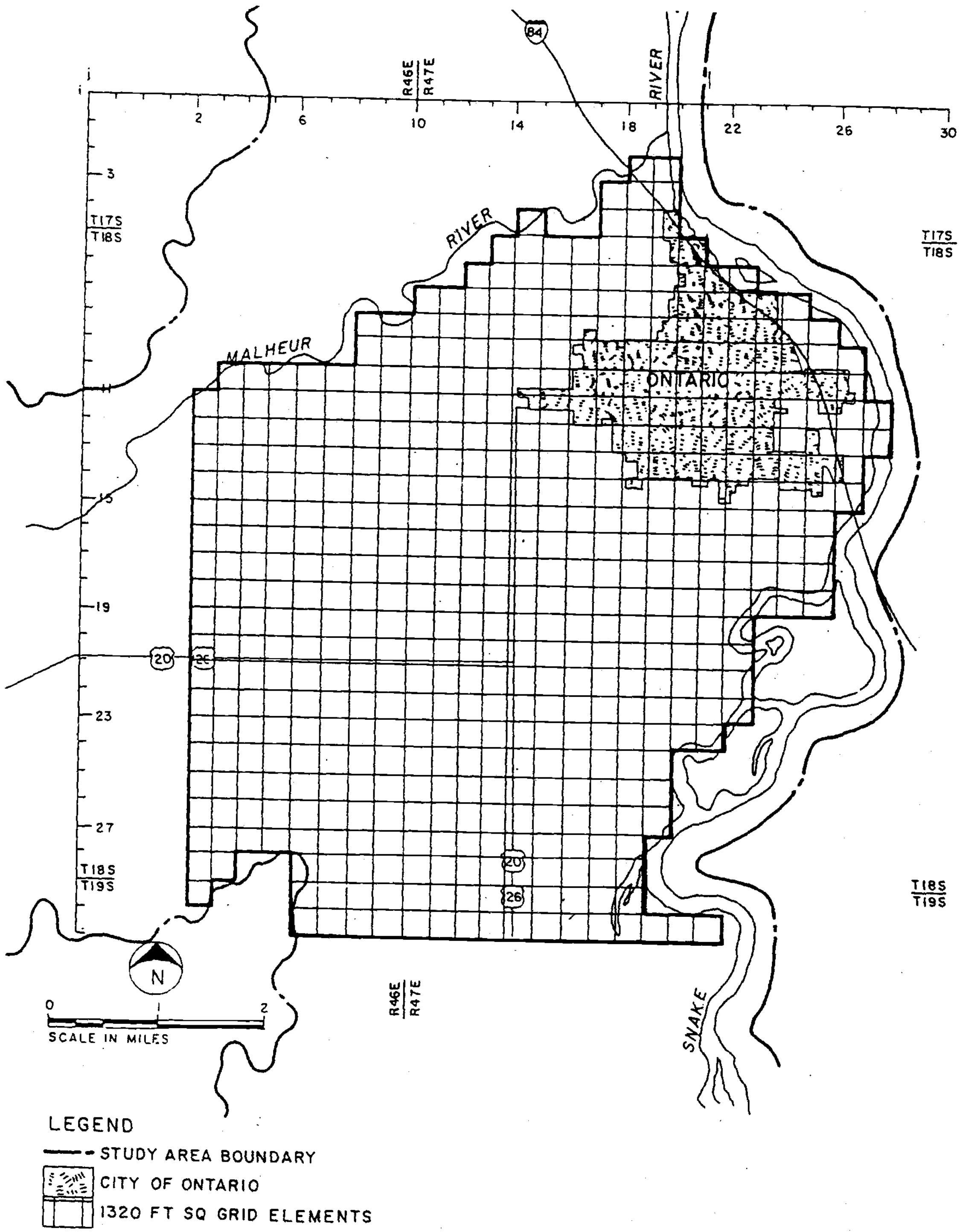
1) the amount of water supplied to water markets
2) the profits from water market participation accruing to water rights holders,
3) local groundwater quality effects of water markets,
4) local economic effects of water markets,
5) effects of water markets on third party water rights holders downstream from the study area.

1.3 Study Area

The Malheur and Owyhee river drainages of eastern Oregon constitute a semi-arid region containing over 250,000 irrigated acres of row crops, small grains, alfalfa and pasture. This study focuses on the sub-area of this region comprised of the irrigated alluvial flood plain soils and bench lands between Ontario, Nyssa and Vale, Oregon, as well as the underlying shallow sand-gravel aquifer. For research purposes, the study area is treated as the 536 element block grid portrayed in figure 1.1. Each square element has a length of 1320 feet and thus represents 40 acres. The grid representation is useful as it allows accounting for the heterogeneity of naturally occurring hydrologic and soils features in the study area. The grid provides a convenient basis for parameterizing individual grid elements or groups of elements in the economic, agronomic and hydrologic models used in the research.

Water in the area is provided by a Bureau of Reclamation irrigation project. Annual water supplied to area irrigators by the Owyhee Irrigation District averages 3.96 acre feet per acre (Owyhee Irrigation District).

Figure 1.1: Study Area



Soils in the region vary from deep alluvial silt loams with flat topography to hilly or alkali soils with impermeable layers a foot or two below the surface (US Soil Conservation Service). Better land is used for intensive production of onions and potatoes, sugar-beets and other row crops in rotation with grains and/or hay (often with furrow irrigation). Lower quality land is used for pasture, grain and hay production (US Soil Conservation Service).

Recently, part of the watershed has been designated as a critical groundwater area by the State of Oregon (Malhuer County Groundwater Management Committee, 1991).
Nitrate concentrations exceed the EPA standard of 10ppm in over 30% of area test wells (Malheur County Groundwater Management Committee, 1991).

Several studies have assessed the economics of nitrate leaching abatement in the area (Connor, Perry and Adams; Vermilyia; and Kim et. al.). One key finding emerging from these studies is that achieving large reductions in nitrate leaching would involve significant cost. However, water supplies in the area are relatively plentiful and current water pricing policies offer little incentive to conserve water through investment in water conserving technology. Liberalized rules governing market transfers of water could provide such incentives. As the result of recently enacted federal mandates to increase Columbia-Snake River flows for the purpose of restoring diminished native salmon stocks, and recent changes in Oregon water laws, increased water trade is likely in the near future (Huffaker et. al.; Landry). The results of this research contribute to an understanding of the key benefits and tradeoffs implicit in alternative water market policy specifications.

1.4 Modelling Scenarios

Four scenarios representing alternative sets of water transfer rules are evaluated. In the first and second scenarios, the potential impact of a market for water involving transfer in place and purpose of water use is analyzed. Such transfers are the most prevalent form of trade in Oregon (Landry). Transfers in place and purpose of use require cessation of irrigation on the land from which the water right is transferred. Consequently irrigators contemplating transferring water rights from a given field must evaluate a discrete choice: continue irrigated farming on the field or sell the water and retire the land from irrigated production. The difference between the two scenarios modelling transfers in place and purpose of water use involves interpretation of non-impairment conditions governing such trade. As is the case in most western states, Oregon law requires that a proposed transfer not harm any third party by reducing return flows. Scenario 1 represents a conservative interpretation of non-impairment provisions. In this scenario it is assumed that only the portion of water which has historically been used consumptively by the water rights holder may be sold. Historic return flows must remain instream. In scenario 2, impairment is ignored and it is assumed that water rights holder may transfer their entire diversionary water right.

Scenarios 3 and 4 involve trade of conserved water. Such transfers do not require that land be taken out of irrigated production. The Oregon conserved water law (ORS 537.455 to 537.500) allows water rights holders to sell, lease or gift a portion of the water that they save through implementation of water saving practices. The law envisions water use reductions through such practices as installation of high efficiency irrigation systems, adoption of irrigation scheduling, or reducing irrigation canal seepage through ditch lining (Oregon Water Resources Department).

The difference between scenarios 3 and 4 involves interpretation of non-impairment conditions governing conserved water sales. In scenario 3 it is assumed that only conservation savings which reduce consumptive water use can be sold. In scenario 4 it is assumed that any reductions in diversion can be sold.

1.5 Organization of the Dissertation

The dissertation consists of six chapters. Chapter 2 is a literature review providing an overview of current economics knowledge regarding the opportunities and trade-offs implicit in alternative existing and proposed water transfer policies. The review emphasizes studies treating the relationship between market water transfers and water quality. In chapter 3, a conceptual model of water trade in a watershed with impaired groundwater quality is introduced. The model provides a framework for determining water quality and economic outcomes of liberalized water in a way that can be generalized across settings.

The manner in which the conceptual model developed in chapter 3 is specified as an empirical hydrologic-economic simulation model of the Treasure Valley area of eastern Oregon is discussed in chapter 4. The model consists of distinct economic and hydrologic components. The economic component of the model consists of 8 sub-regional mathematical programming models. Each sub-regional model is a profit maximization problem which can be used to impute a shadow value of water. The models vary across subregions with differences in soil productivity, production technology and irrigation cost specification. The hydrologic component of the model consist of two parts. A nitrate leaching model describes how changes in crop choice, irrigation and nitrogen input influence the level of nitrate leaving the root zone. A finite difference model describes the process of nitrate dilution in the aquifer.

Simulation model results are presented in chapter 5. The chapter summarizes the influence that water prices and water trade rules have on 1) water supply, 2) producer profits, 3) the local study area economy, 4) groundwater quality, and 5) third party water rights in the Malheur and Snake Rivers.

The final chapter of the dissertation, chapter 6, includes a discussion focussed on key policy implications of the research results. The discussion centers on: 1) assessing the economic feasibility of water markets in the study area, 2) assessing of the economic-technical feasibility of water markets as a water quality policy in the study area, and 3) assessing key trade-offs between four groups influencing the political feasibility of water markets in the study area (water right sellers, those interested in water quality, local economic interests and down stream water rights holders). The chapter concludes with a discussion of the limitations of this research and suggestions for further research.

CHAPTER 2: LITERATURE REVIEW

This chapter contains a survey of literature examining water transfers, particularly the economic opportunities and trade-offs implicit in these transfers. Four themes are discussed: (1) regional economic impacts of water transfers, (2) water transfers and return flow externalities, (3) instream water and water trade, and (4) the influence of water trade on water quality. The body of the literature reviewed suggests that reforming water transfer policies to increase social welfare will be challenging because of the complex third party effects involved. However, it appears that there are opportunities to improve water quality outcomes with water marketing mechanisms.

2.1 Introduction

The theory of induced innovation posits that scarcity of a resource often motivates innovations in the societal rules and organizations governing how the resource is used (Ruttan and Hayami). Presently, in the western United States a process of institutional innovation is underway as competing interests struggle to alter water laws to deal more appropriately with increasing quantitative and qualitative demands on limited water supplies (Livingston).

The key tenant of water law in all western states is the prior appropriations doctrine. The doctrine arose as a method to allocate seasonally scarce stream-flows among competing placer mines during the California gold rush. Prior appropriations guarantee the water rights of the first party to use water beneficially. Secure water rights for those who first developed water resources encouraged investment to improve the productivity of the water right. An institutional arrangement guaranteeing secure water rights tenure was consistent with the social objectives of the era as it encouraged large scale irrigation project investment and spurred regional growth (National Research Council).

By the mid 1960's water resource scholars recognized that the marginal costs of supplying water through new projects were rising rapidly (Young). Many of the most productive project sites had already been exploited and the environmental costs of controlling wild rivers was receiving increasing recognition (e.g. Krutilla). Throughout the ensuing decades growing populations and shifts in societal preferences have generated increased demands for municipal and industrial water supplies, as well as increased desire for improved water quality and instream flows (Saliba and Bush; Colby).

Water transfers are increasingly seen as the most appropriate means of meeting growing demands. Pressure is increasing to change water laws that make water transfer difficult and expensive (Shupe, Weatherford and Checchio). The movement toward a new definition of water rights is an imperfect and contentious process, largely because outcomes are of fundamental importance to affected parties. Water rights institutions determine "who has access to resources, how resources may be used, the incidence of externalities, rules for entry and exit" (Livingston and Miller) and "who has access to benefits streams and which costs will be reckoned with by which entity" (Bromley).

Several economists have developed frameworks for evaluating water rights systems which are useful in identifying key issues. Cirancy-Wantrup recognized "security" and "flexibility" as desirable attributes of a water rights system. As discussed in reference to the prior appropriations doctrine, security of water rights tenure ensures that the rights holder can realize returns to investment which are dependent on continued exercise of the right. Flexibility in the place and purpose of water rights use ensures that, as alternative demands for water grow over time, water can be reallocated to higher value uses.

In addition to security and flexibility, other authors emphasize the desirability of minimizing uncompensated third party effects (e.g. Young; and Howe et. al.). Because there is pervasive interdependence among water users, externalities are an almost inevitable result of changes in water allocation rules (Randall; Howe et. al.). Most water users return a considerable portion (often 50% or more) of the water they divert to the stream where it is reused by downstream parties. Because changes in water rights influence the quantity and quality of these "return flows", the welfare of down stream parties is affected.

The extensive potential for externalities creates an essential problem in defining efficient and equitable water rights. On the one hand, more highly differentiated and regulated property rights systems facilitate protection of third party interests. On the other hand, such elaborate institutions tend to drive up transactions cost and contribute to persistent differentials in water use values.

Institutional changes governing water transfers are likely to influence present water rights holders, irrigation dependent communities, instream water flow and water quality. The specific influence of institutional change depends on situation specific economic, environmental, institutional and physical conditions. This chapter summarizes current understanding of water market third party implications. It is a survey of literature that provides an overview of current economics knowledge regarding the opportunities and trade-offs implicit in alternative existing and proposed water transfer policies.

2.2 Regional Economic Impacts of Water Transfers

In numerous small communities across the western United States irrigated agriculture is a key sector of the economy. Water markets could influence these communities significantly. As noted by Howe and Easter, the magnitude of economic impact a water transfer will have on an irrigation dependent community is a function of three factors: (1) the mobility of the local work-force, (2) the alternative use value of capital resources currently employed in irrigated production and related industries, and (3) the time-frame of reference.

Immobility of a specialized agricultural work-force is quite likely, at least for some transition period. Furthermore, if a large water transfer idles considerable acreage, some capital assets previously used in irrigated production would likely have little salvage value (i.e. divergence and conveyance structures, certain types of specialized farm equipment).

Howitt recently assessed the regional economic effects of a California state dry year water lease program. In 1991 farmers in Yolo and Solano counties, California provided the state Drought Water Bank with 196,000 acre feet of water. In exchange the farmers were required to fallow their land and they received $125 per acre foot of consumptive water use. Howitt found that although the amount of acreage idled was considerable (15% and 11% of total acreage in Yolo and Solano counties respectively), the overall magnitude of secondary economic effects were not particularly large. "As a proportion of the county agricultural economy the reduction was no greater than changes experienced due to past commodity and farm program fluctuations" (Howitt, p. 273).

Secondary economic effects were rather limited because leases were concentrated on lands usually cropped with small grains and field corn. These crops require relatively little labor, inputs and processing. Fallow soils were concentrated in one area shared by the two counties. The incidence of secondary economic impact was strongest in this area.

Some scholars argue that the social welfare attained from a community which is tied to irrigated agriculture is greater than the value of the purely economic benefits created in the community (Maas and Anderson; Mumme and Ingram). Given the present set of institutional rules, adverse local secondary economic effects can limit water transfers and(or) increase transactions costs (Colby, Crandall and Bush). In some cases, such considerations have been interpreted by courts as public interests that override the economic interests of direct parties to trade (Shupe et. al.). In other cases, irrigation districts or county commissions have enacted restrictions on trades outside the basin of origin (Saliba and Bush).

In a new variant of the traditional regional economic analysis, Rosen and Sexton analyzed the type of water transfer most likely to be chosen by voting members of The Imperial Irrigation District in Southern California. Voters in the district have diverse interests because some own land and some rent. The authors concluded that the form of water transfer chosen, transferring water to the Municipal Water District in exchange for conservation investments (including ditch lining and tail-water recovery systems) represented a stable equilibrium given the interest of the strongest coalition in the district (renters). Hahn, in a recent criticism of the standard methods of evaluating externality abatement cost, advocates inclusion of analysis like that of Rosen and Sexton. In his view, such analysis is policy relevant because it helps clarify the political feasibility of proposed abatement control measures.

2.3 Return Flow Externalities: Interdependence Among Water Rights Holders

Hartman and Seastone developed a useful framework for analyzing the efficiency implications of prevailing water law. The authors were interested in cases where there are significant return flows from upstream diverters which can be reused downstream. The analysis is framed in terms of a river with n diversions for various agricultural, municipal and industrial uses. Each user consumes a portion of the water he diverts (i.e. through crop water uptake) and returns the remaining water to the river. Thus the returned flow from user i-1 can be diverted by user i. Hartman and Seastone used the notation

db_i = direct benefits per unit water use at diversion i.

r_i = portion of water user i-1 returns to the river.

A stream of benefits resulting from user i's diversions (in the form of return flows) are captured by successive down stream diverters. The total benefits of i's diversions can be written

$$DB = db_1 + r_2*db_2 + r_2*r_3*db_3 +..+ r_2*r_3* \ldots *r_n*db_n \quad (2.1)$$

Thus, the total benefits resulting from diversion i depends on: (1) the portion of diversion returned to flow by i (larger return flows create a larger stream of reuse values downstream), and (2) the position on the stream diverter i occupies (return flows from upstream water rights holders will be reused more often than first time diversions by downstream water rights holder).

A central finding of the analysis was that prevailing water transfer law is inefficient. The inefficiency arises because most western states make water trade contingent on

There are, however, rarely possibilities for third parties who would benefit from a positive return flow externality to compensate the party who generates the externality[1].

Hartman and Seastone concluded that market efficiency could be approached if water trade was facilitated in a two segment market. If both diversions and positive return flow externalities were tradeable, third parties would offer compensation to water rights purchasers who generated appropriable return flow.

Issues related to return flow timing and position were discussed by Howe and Easter. The authors noted that the value of return flows to irrigators will be reduced if supplies first become available late in the irrigation season. The problem is most intensive when most diversions are for irrigation. Return flow generated by municipalities usually returns directly to the river. Part of agricultural return commonly begins as leachate moving into the groundwater. Some of this water re-emerges later in the season and increases surface water flows down river.

2.4 Interdependence Among Water Rights Holders and Instream Water Use Values

Most western states grant limited protection against the effects of water transfers on water quality and instream flow. Although many states are beginning to grant instream flow water rights, most rights granted to date are junior and afford little meaningful protection (Colby). However, it seems likely that third party environmental and amenity effects of water transfers will gain increasing legal status over time (Colby). There is a growing body of recent

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[1] New Mexico state law allows for parties petitioning a water rights transfer to negotiate settlement for third party effects (Saliba and Bush).

over time (Colby). There is a growing body of recent literature addressing related issues.

Research by Griffin and Hsu characterized the first best water pricing system which would be necessary when both consumptive water use and instream water provide utility. The efficient pricing rules which the authors derive are quite complex. They involve markets for diversions and return flows as well as subsidies or charges to facilitate user recognition of instream benefits and costs resulting from water transfers. The authors recognize that informational and transactions cost associated with a complex multiple price mechanism make practical implementation rather infeasible[2]. Nevertheless, the study does provide an upper-bound estimate of attainable efficiency in policies designed to protect instream water rights.

Several researchers suggest that legal recognition of instream water rights is likely to complicate transfer of traditional diversionary rights (Livingston and Miller; Anderson). Livingston and Miller analyze the consequences of insuring no instream flow damage results from a transfer of diversionary water rights. The authors conclude that guaranteeing secure tenure to instream water rights would reduce the flexibility of diversionary water rights. Diversionary water rights would generally be less valuable in exchange as the set of admissible trades would be reduced.

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[2]Similar pricing schemes have been discussed in the tradeable air quality literature (McGartland and Oates). In a recent article, Hahn critiques the methods commonly used by economists to assess the relative efficiency of command and control versus incentive based environmental regulations. One source of analytical error Hahn emphasizes is ignoring the informational and transactions costs associated with linked markets in location-specific air quality. This criticism would also apply to water trade co-payments related to location specific instream effects of water trade.

The authors note that the influence of instream flow rights on the transferability of diversion rights is site specific. If stream flow is protected in a headwaters area or where few diversions take place or at the end of a stream beyond most diversions, impact will be minimal. "Impacts are greatest when the relevant water course is fully appropriated and a large number of individuals holding rights below the instream flow right wish to transfer them above or within the reach of the instream right." (Livingston and Miller).

Colby noted that improved instream flow can arise as a result of consumptive water rights exchange under current water law. The prerequisite condition is that the direction of trade is downstream. Colby also questioned the decisions by most states to preclude private parties from attaining instream water rights.

An example of the conflicts surrounding changes in instream flow rights can be found in the Pacific Northwest. Return flow impacts on instream flow are important in Columbia River water management. Currently at issue is the survival of native salmon species stocks. The federal Endangered Species Act requires changes in river management to aid salmon survival. A northwest research panel known as the Salmon Task Force is analyzing related issues.

In a task force publication, Peterson, Hamilton and Whittlesey argue that increasing the efficiency of irrigated agriculture will not necessarily yield increased stream flow for salmon. Their analysis is based on a small scale hydrologic-economic model and a larger scale computer simulation (Frazier, Whittlesey and Hamilton). The argument presented is based on two key premises: (1) junior water rights holders will capture and consume a portion of the water left instream when senior irrigators increase efficiency, and (2a) water not consumed ultimately becomes available as river flow and (2b) the amount of this ultimately available water at the mouth of the river basin in question is the flow relevant to fish stocks.

The authors note that net water savings over the whole river basin take place only when consumptive use is reduced. They concluded that increases in irrigation efficiency can likely aid in augmenting flow on some important river stretches during critical time periods.

2.5 Water Trade and Water Quality

Water has the capacity to dilute pollution and the capacity to carry pollutants down rivers or into aquifer sand and gravel. Consequently, water transfers can create both positive and negative water quality externalities. The conceptual research on how water transfer laws and site specific characteristics influencing water quality is less well developed than similar literature relating to return flow and instream flow issues.

The potential impact of water transfers on water quality has been recognized in principal since at least the 1960's (Hartman and Seastone). Howe, Schurmeier and Shaw elucidate the essential nature of the problem with a simple externality model. The model assumes a river basin with two parties diverting water, one upstream and one downstream. Each party (which may be thought of as a collective of river users) has a net benefits function related to water quantity and water quality. These benefits functions are denoted as: $B_1(W_1,Q_1)$ and $B_2(W_2,Q_2)$ where W_i and Q_i represent water quantity and quality respectively. However, water quality downstream is generally a function of upstream quantity and quality. Thus, $Q_2 = f(Q_1,W_1)$. The authors demonstrate that water allocation decisions that result from the current priority rights system diverge from an economically efficient allocation because upstream users generally have no incentive to consider downstream users welfare.

Two recent studies report that water markets could reduce damage to the Kestorson Wildlife Refuge from San Joaquin Valley agricultural drainage (Dinar and Letey; Weinberg, Kling and Wilen). Dinar and Letey examine the incentives of a single irrigator producing one crop (cotton). The irrigator's decision variables are water application rate and irrigation technology choice given yield and drainage (modelled with agronomic and hydrologic simulations). The irrigator can lease his water rights (presumably to a municipal water district) or pay the cost of saline drainage disposal. By parametrically varying water market price, drainage disposal cost and water endowments, the authors simulated resultant producer profit, water use and drainage.

Major findings were that water markets stimulate increased irrigation efficiency, decreased water use, decreased drainage and increased producer profit. Drainage, water use and profit were all quite sensitive to water market price and water endowments. The elasticity of water supply and drainage reduction were greatest among irrigators with the largest water endowments, because irrigators with large water endowments generally had inexpensive opportunities to substitute irrigation capital for water. Irrigators with poorer endowments generally exhaust inexpensive technology substitutes for water even in the absence of water markets, as water constraints were more limiting for such irrigators. Although drainage reduction could also be achieved with drainage disposal charges, the policy was found to be less desirable than water markets. A major advantage of water markets was that they were associated with increased producer profit. In contrast drainage charges decrease irrigators' profits.

Weinberg, Kling and Wilen modelled farm profit and drainage response to a water market in a major part of the San Joaquin Watershed. The model included spatial variation in water endowment and soil productivity allowing irrigators to choose among multiple crops and yield levels and use multiple alternative irrigation technologies.

The analysis suggested that the amounts of water supplied to the markets and the level of drainage reduction were responsive to water market price, spatial variation in water endowments and spatial variations in soil productivity. One interesting finding was that at water prices of less than $60 per acre foot, irrigators with small water endowments and highly productive soils found it attractive to buy water. As a result, drainage actually increased in some parts of the watershed at water prices of less than $60 per acre foot. The study concluded that in order to achieve a 30% reduction in drainage, the water market equilibrium price received by producers would have to be $96 per acre foot.

Booker and Young modelled the hydrology and economics of water allocation in the Colorado River Basin. They assessed the impact of alternative institutional arrangements governing water transfer on the producer surplus of consumptive water users, as well as hydropower water use and river salinity. The approach the authors used involved placing an economic value on the benefits of river salinity reductions. The objective in each of the scenarios modelled was to maximize net social benefits. Institutional arrangements governing water transfer were modelled as constraints in transfer choices.

The influence of water transfers on river water salinity are of special interest here. Results predict that both free intrastate and interstate trade of water for consumptive uses would likely lead to increased economic damages from salinity. Most of these damages would be suffered by southern California municipal water users. When the benefits of water allocation to hydropower generation and salinity control were explicitly included in the model objective function, significant transfers of water from the Upper Colorado River Basin to the Lower Basin resulted.

Inclusion of hydropower and salinity values resulted in Upper Basin water allocation reductions of 26% and 30% respectively. The authors concluded that "down-river hydropower benefits and reductions in salinity damages by dilution each exceed marginal benefits in one-quarter of existing Upper Basin irrigation uses" (Booker and Young, p81).

2.6 Future Water Market Research Needs

The pressure for changes in western water laws is not likely to subside in the near future. Nonetheless, movement toward water law reform is likely to be slow. The pervasive interdependence among water users and the usufructuary nature of water rights makes reaching consensus over public water policy goals difficult.

The challenge to applied economists wishing to provide relevant input to water marketing policy reform initiatives is to provide research which clarifies relationships between: 1) water market transfer laws, 2) underlying hydrologic, economic and technological conditions and 3) the multiple objectives of water resource policy. Several of the analyses cited in this literature survey conclude that the outcome of water transfers with respect to a specific objective is often dependent on site specific hydrologic, technological and economic parameters. These findings suggest that meeting water market policy research needs will require case specific studies.

CHAPTER 3: CONCEPTUAL MODEL OF NON-POINT SOURCE WATER POLLUTION IMPACTS OF LIBERALIZED WATER TRADE IN AN IRRIGATED WATERSHED

Existing theoretical models characterizing the influence of water trade on water quality focus primarily on instream flows (Livingston and Miller; Griffin and Hsu). While instream flow is important to fish populations and recreationists (Colby), there are other important dimensions of water quality which are influenced by market water reallocation. For example, changes in the spatial pattern of water use are likely to change the pattern of effluents entering surface and groundwater with return flows.

This chapter describes a comparative static approach useful in assessing the influence of water trade on water pollution from disperse non-point sources. The approach draws on concepts and notational conventions originally used in the economic literature treating air pollution permit trade (Baumol and Oates; Krupnick, et. al.). The focus is on a watershed where the primary water use is irrigation. This is appropriate because irrigators own over 85% of all water rights in every western state (National Research Council)

The framework forms a conceptual basis for the specification of the hydrologic-economic simulation model described in chapter 4. The framework also offers a general way of clarifying expectations regarding the influence of water markets on groundwater water quality, *a priori* without explicit modelling. This chapter ends with a discussion of some general conclusions.

3.1 Modelling a Heterogeneous Watershed

Understanding the economic and water quality outcomes of liberalized water trade rules at a watershed level requires an understanding of the spatial differences in natural resource endowments across the watershed. Specifically, the geographic distribution of soils and hydrologic endowments are likely to be key determinants of these outcomes when water rights are held by irrigators. The endowment of soil characteristics (i.e. texture, rooting depth, pH, etc) tend to be a dominating determinant of feasible crop rotations, per acre profits and the value of water and chemical inputs in production. Poorer quality soils tend to be farmed at lower input intensity levels, resulting in lower rates of effluent loading (i.e. Taylor, Adams and Miller). In general, irrigators are more likely to retire water from such lands to supply a regional water market (Zilberman et. al.; Howitt et. al.).

From an environmental perspective the spatial distributions of hydrologic endowment are important because they determine how a marginal change in effluent loading at a given point in a watershed influences pollution concentration at other points in the watershed. At points in a watershed where drainage water mixes quickly with large volumes of fresh water and becomes very dilute, the influence of incremental effluent is likely to be minimal. At points of little dilution the influence of incremental loading is likely to be more significant.

A useful way to model spatial heterogeneity is to represent a watershed as a set of discrete geographic subregions or 'cells' (i.e. Baumol and Oates; Krupnick, et. al.). In this analysis the watershed of interest is represented as a two dimensional M by N cell plane with each cell indexed by a unique set of i,j coordinates. It is further assumed that within each cell, naturally determined endowments of soils and hydrologic characteristics, institutionally determined water rights endowments, as well as individual production unit attributes such as human capital endowments are identical.

The problem is somewhat simplified by assuming that the focus of water quality concern is a single 'hot spot' in a water body where the pollutant of concern accumulates. Concentration of the pollutant at this point is a function of loading which occurs at upgradient points and water transport of the pollutant loads. Extending the analysis to consider multiple "hot spots" would substantially complicate exposition without significantly increasing the explanatory power of the framework. Although the framework is applicable to any pollutant spreading through groundwater, surface water or an airshed, the focus here is on nitrates reaching groundwater from agricultural non-point sources.

3.2 Technologically Joint Output Production and Pollution Processes

The presence of a pollution externality implies technical interdependence among the processes generating pollution and the processes for producing economic goods. In this model crop output and nitrate in groundwater are modelled as the joint product of irrigation water and irrigation efficiency inputs.

3.2.1 Crop Production Functions

The crop production process assumed unique to each cell is described functionally as

$$Y_{i,j} = Y_{i,j}(W_{i,j}, IE_{i,j}) \qquad (3.1)$$

In words, equation 3.1 states that crop yield in cell i,j, $Y_{i,j}$ is a function of water applied $W_{i,j}$, and irrigation efficiency, $IE_{i,j}$ input levels in the cell. The irrigation efficiency input is assumed to be a combination of capital inputs (i.e. high efficiency irrigation equipment) and labor inputs (i.e. time spent measuring soil moisture and computing irrigation schedules) which can be used as a substitute for water. Yield is assumed to increase with increases in both water and irrigation efficiency up to a maximum yield YM_i, after which yield decreases in response to incremental inputs. Mathematically stated, these assumptions about functional form are:

$$\frac{\delta Y_{i,j}}{\delta W_{i,j}} > 0, \quad \frac{\delta Y_{i,j}}{\delta IE_{i,j}} > 0 \; for \; Y_{i,j} \leq YM_{i,j} \qquad (3.2a)$$

$$\frac{\delta Y_{i,j}}{\delta W_{i,j}} < 0, \quad \frac{\delta Y_{i,j}}{\delta IE_{i,j}} < 0 \; for \; Y_{i,j} \geq YM_{i,j} \qquad (3.2b)$$

Variants of this functional representation have proven useful in analyzing the economics of irrigation technology choice, water use and irrigation-induced water quality externalities (Caswell and Zilberman; Feinerman et. al.; Dinar and Letey). The particular functional representation is appropriate here for two key reasons: (1) It allows for water conservation through both yield reduction and substitution of water conserving inputs, (2) It represents the eventually diminishing crop yield response to water.

3.2.2 Contaminant Loading and Transport Functions

The process determining the concentration of pollution at a cell of critical groundwater quality is described functionally as:

$$NC = \sum\sum\nolimits_{i,j} d_{i,j}(W_{i,j}) * NL_{i,j}(W_{i,j}, IE_{i,j}) \qquad (3.3)$$

In words, the equation states that the concentration of a pollutant (nitrate) in groundwater at the cell of critical groundwater quality, (NC) is a function of two factors, loading at upgradient cells ($NL_{i,j}$) and the process of dilution ($d_{i,j}$). The loading at each cell is denoted $NL_{i,j}$.

Generally, the loading rate of a water soluble water pollutant, as well as sediments suspended in runoff, is an increasing function of irrigation water, and a decreasing function of irrigation efficiency. Commonly, the function describing loading has an exponential form, increasing slowly at first and then more quickly once the reservoir capacity of a soil to hold water and water carried pollutants is exceeded. More detailed discussion of the nitrate loading model used in this study can be found in chapter 4, section 2.

Dispersion effects are represented here as an M by N matrix of dispersion (or transfer) coefficients, $d_{i,j}$. Each element in this matrix represents the rate of change in concentration at the point of critical groundwater quality per unit increase in loading at cell i,j. In the environmental economics literature on air pollution (i.e. Baumol and Oates), dispersion effects are treated as exogenous to the decisions of polluters. This is justified as the release of air pollutants does not generally influence the direction or velocity of prevailing winds. However, dispersion or the rate at which a mass of pollutant spreads through an aquifer is determined by both:

1) effects exogenous to water rights holder decisions: i.e. aquifer thickness and permeability, and

2) effects endogenous to water rights holder decisions: i.e. volume of water applied as irrigation, irrigation technology and crop choices.

In general, it is to be expected that dispersion will be an increasing function of water application rate. The empirical literature suggests that decreased irrigation water application results in decreased deep percolation (Timmons and Dylla; Linderman; Watts and Martin). Further, it follows from the governing equation of groundwater flow that this reduced infiltration of water below the root zone will result in a decreased rate of dispersion in downgradient areas of the underlying aquifer (Wang and Anderson).

3.3 Liberalized Water Transfer Rules and Water Quality

The analytical framework developed above is fleshed out with empirical models of water use economics and groundwater pollution processes in the next chapter. However, even in the absence of empirical specification, the theoretical model developed here can be useful. Specifically, it is useful in identifying the economic and hydrologic parameters which are likely to be key determinants of water quality if water trade rules are liberalized. It is also useful in drawing *a priori* inferences regarding the influence that a movement toward liberalized water trade is likely to have on water quality.

3.4 The Influence of Key Economic and Technological Variables on Water Quality in Emerging Water Markets

Water markets in most western states are poorly developed, lacking key conditions necessary to the functioning of efficient, competitive market exchange mechanisms. Specifically, water markets are commonly characterized by small numbers of buyers and sellers, heterogenous commodities, high cost of searching out trading partners and negotiating price and costly engineering and legal fees required to prove legal title and non-impairment of third party water rights (Colby, Crandall and Bush; Brown et. al.; Landry). The result is a low volume of water transfer, as well as a divergence between present use value of water and its alternative use value.

This section focusses on the influence that key hydrologic and economic parameters may have on water quality if well functioning water markets were to develop. The methodology used to illuminate the key determinants of water quality in a well functioning water market involves comparison of two polar cases. One polar extreme is the total absence of water trade. The other is a perfectly competitive market for water rights. If this model was used for quantitative estimation, it would tend to overstate gains to trade and water quality outcomes. However, there is no *a priori* reason to suppose that the model would be biased in determining the directional effects of key parameters.

In the absence of a water market, each cell i,j's profit is constrained by the fixed water endowment available in the cell, $WA_{i,j}$. Under these circumstances profit functions ($\Pi_{i,j}$) can be represented as

$$Maximize\ \Pi_{i,j} = P*Y_{i,j}(W_{i,j},IE_{i,j}) - C_{i,j}(IE_{i,j}) \qquad (3.4)$$
$$s.t. \quad W_{i,j} \leq WA_{i,j}$$

where $C_{i,j}(IE_{i,j})$ is a continuous, twice differentiable function describing the cost of increased irrigation efficiency and P is the price of output. It follows from empirical estimates (Chen and Wallender) and from the law of diminishing marginal returns that $C_{i,j}$ is increasing in $IE_{i,j}$ at an increasing rate. Assuming that equation 3.4 is continuous and twice differentiable, Kuhn-Tucker optimization conditions can be represented as

$$P*\frac{\delta Y_{i,j}}{\delta W_{i,j}} - \lambda w_{i,j} = 0 \qquad (3.5a)$$
$$P*\frac{\delta Y_{i,j}}{\delta IE_{i,j}} - \frac{\delta C_{i,j}}{\delta IE_{i,j}} = 0 \qquad (3.5b)$$
$$(W_{i,j} - WA_{i,j}) \ *\lambda w_{i,j} = 0, \qquad (3.5c)$$

where λw_i represents the shadow price of water in cell i,j. The resultant product supply and input demand functions can be represented as

$$Y^*_{i,j}(\ P,C_{i,j}(IE_{i,j}),WA_{i,j}\ ) \qquad (3.6a)$$
$$W^*_{i,j}(\ P,C_{i,j},(IE_{i,j}),WA_{i,j}\ ) \qquad (3.6b)$$
$$IE^*_{i,j}(\ P,C_{i,j}(IE_{i,j}),WA_{i,j}\ ) \qquad (3.6c)$$

Assuming that over time perfectly competitive trade in water arises and results in an equilibrium price of water, PW, the profit function for cell i,j can be represented as

$$Maximimize\ \Pi_{i,j} = P*Y_{i,j}(W_{i,j},IE_{i,j}) - C_{i,j}(IE_{i,j}) - PW*(W_{i,j} - WA_{i,j}) \qquad (3.7)$$

with resultant first order conditions,

$$P*\frac{\delta Y_{i,j}}{\delta W_{i,j}} - PW = 0 \qquad (3.8a)$$
$$P*\frac{\delta Y_{i,j}}{\delta IE_{i,j}} - \frac{\delta C_{i,j}}{\delta IE_{i,j}} = 0 \qquad (3.8b)$$

and product supply and input demand functions

$$Y'_{i,j}(\ P,C_{i,j},PW\ ) \qquad (3.9a)$$
$$W'_{i,j}(\ P,C_{i,j},PW\ ) \qquad (3.9b)$$
$$IE'_{i,j}(\ P,C_{i,j},PW\ ) \qquad (3.9c)$$

The essential nature of irrigator response to a transition from fixed water endowments to free water trade can be understood through comparison of first order conditions 3.5a,b,c with first order conditions 3.8a,b. In the absence of a water market, the value of water for each cell, $\lambda w_{i,j}$, is determined by the fixed allotment of water and its marginal productivity, $P*\delta Y_{ij}/\delta W_{ij}$, given the soils endowment, production technology and prices faced by producers in the cell. In the presence of a water market the value of water to irrigators is determined by the equilibrium water price, PW. Subregions in which the marginal value of allotted water exceeds equilibrium price ($\lambda w_{i,j} > PW$) will wish to purchase water ($w_{i,j}' < w_{i,j}^*$). Subregions in which the marginal value of allotted water is less than equilibrium price ($\lambda w_{i,j} < PW$) will wish to sell water ($w_{i,j}' > w_{i,j}^*$).

Although free trade maximizes gains experienced by direct parties to trade (the sum of producer and consumer surplus), the impact of trade on nitrate concentration at the point of critical groundwater quality may or may not be positive.

Mathematically, the change in concentration, (ΔNC) resulting from liberalized water trade can be expressed as the full differential,

$$\Delta NC = \sum\sum_{i,j} \left(d_{i,j} * \left[\frac{\delta NL_{i,j}}{\delta W_{i,j}} * \frac{\delta W_{i,j}}{\delta PW} + \frac{\delta NL_{i,j}}{\delta IE_{i,j}} * \frac{\delta IEi,j}{\delta PW} \right] + \left[\frac{\delta d_{i,j}}{\delta W_{i,j}} \frac{\delta W_{i,j}}{\delta PW} * NL_{i,j} \right] \right) * \Delta PW_{i,j} \qquad (3.10)$$

where $\Delta PW_{i,j} = PW - \lambda w_{i,j}$.

In words, the equation states that ΔNC can be described as a function of eight factors: 1) the change in the effective price of water in each cell, $\Delta PW_{i,j}$, 2) the marginal influence of a price change on water demand, $\delta W_{i,j}/\delta PW$, 3) the marginal influence of a change in water demand on nitrate loading, $\delta NL_{i,j}/\delta W_{i,j}$, 4) the marginal influence of an effective change in water price on irrigation efficiency demand, $\delta IE_{i,j}/\delta PW$, 5) the marginal physical productivity of a change in irrigation efficiency demand on nitrate loading, $\delta NL_{i,j}/\delta IE_{i,j}$, 6) the marginal influence of a change water demand on the rate of dispersion, $\delta d_{i,j}/\delta W_{i,j}$, 7) the initial rate of loading in each cell, $NL_{i,j}$, and 8) the initial rate of dispersion in each cell.

It is more realistic to assume that crop output and nitrate leaching are also functions of nitrogen ($N_{i,j}$) and nitrogen substitute ($NS_{i,j}$) inputs. Generalizing the technologically joint crop output, pollution process production framework to accommodate four inputs is straight forward. Equation 3.11 expresses the influence of free water trade on groundwater quality.

$$\Delta NC = \sum\sum_{i,j} \Big(d_{i,j} * \Big[\frac{\delta NL_{i,j}}{\delta W_{i,j}} * \frac{\delta W_{i,j}}{\delta PW} + \frac{\delta NL_{i,j}}{\delta IE_{i,j}} * \frac{\delta IEi,j}{\delta PW} + \frac{\delta NL_{i,j}}{\delta N_{i,j}} * \frac{\delta N_{i,j}}{\delta PW} + \frac{\delta NL_{i,j}}{\delta NS_{i,j}} * \frac{\delta NSi,j}{\delta PW} \Big] + \frac{\delta d_{i,j}}{\delta W_{i,j}} * \frac{\delta W_{i,j}}{\delta PW} * NL_{i,j} \Big) * \Delta PW_{i,j} \qquad (3.11)$$

Probable signs of each argument in expression 3.11 are summarized in table 3.1.

3.5 Interpretation of the Results

The results of this comparative static analysis suggest that water quality outcomes of liberalized water trade are likely to depend on case specific economic, agronomic and hydrologic conditions. Positive water quality externalities are likely to result from transition to free water trade when: 1) water in its current use has large physical productivity in externality production, and 2) the value of water in alternative uses is high. Several case studies report the potential for precisely such conditions.

Table 3.1: Probable Signs of Key Arguments Effecting Groundwater Quality Outcomes of Liberalized Water Trade

Term	Sign	Explanation/Comment
1. $\Delta PW_{i,j}$	+	in cells where water market price exceeds water shadow value in current use
		in cells where water shadow value in current use exceeds water market price
2. $d_{i,j}$	-	The level of pollutant concentration is inversely related to dispersion rate in upgradient cells
3. $\delta W_{i,j}/\delta PW$	-	own price elasticity of demand negative for a normal good
4. $\delta IE_{i,j}/\delta PW$	+	cross price elasticity of substitute good, therefore positive
5. $\delta N_{i,j}/\delta PW$	-	nitrogen and water are complementary inputs. However, this effect is likely small compared to 3&4
6. $\delta NE_{i,j}/\delta PW$	?	no strong a priori basis for supposing strong relationship. Any effect is likely small.
7. $\delta NL_{i,j}/\delta W_{i,j}$	+	follows from empirical agronomic study results
8. $\delta NL_{i,j}/\delta IE_{i,j}$	-	follows from empirical agronomic study results
9. $\delta NL_{i,j}/\delta N_{i,j}$	+	follows from empirical agronomic study results
10. $\delta NL_{i,j}/\delta NE_{i,j}$	-	follows from empirical agronomic study results
11. $\delta d_{i,j}/\delta W_{i,j}$	-	decreased water application tends to decrease aquifer recharge rates and consequently reduce groundwater flow rates

One example is the simulation of the potential for interstate water transfers along the Colorado River by Booker and Young. Results suggest that water in the upper Colorado Basin tends to load the river with salinity as a result of current irrigated agricultural production use. However, the alternative use value of the water downstream is considerable and a free water market would tend to reduce irrigation in the upper basin and thus decrease salt loading. Other examples are studies by Dinar and Letey; and Weinberg et. al., which conclude that liberalized water trade in the San Jocquin Valley would likely decrease leaching of salts into the Kesterson Wildlife Refuge.

Free water trade can also lead to increased externality incidence. A negative water quality externality is likely to result from transition to free water trade when water in valuable alternative uses has a large physical productivity in externality production. One setting in which negative water quality externality effects may arise from water markets is trade among irrigators. This negative externality occurs because the shadow value of water tends to be highest for the most chemically intensive vegetable and row crops. Transfers of water from extensive to intensive cropping activities will lead to increased contaminant loading of water bodies. The effect is likely to be enhanced in areas overlying shallow sand-gravel aquifers. Chemically intensive high value crops tend to be grown in flat alluvial soils and more extensive grain, hay and forage crops on steeper bench lands. Because such aquifers tend to follow land contours, groundwater velocity and thus dispersion tends to be less in flat areas more suited to high value crop production than in steeper areas.

Increased effluent concentrations may also result from certain forms of conserved water purchases. In general, such outcomes can occur in any setting where conservation of water significantly decreases the rate of surface or groundwater dilution but does not significantly decrease the rate of contaminant loading. The transfer of water conserved by the Imperial Irrigation District to the Municipal Irrigation District in California's Imperial Valley is a good example of a water trade resulting in water quality degradation. The conservation purchase worked out by the two parties involved the Municipal Water District financing ditch lining and irrigation capital investments by the Imperial Irrigation District in exchange for the conserved diversionary water rights but involved no reduction in consumptive use in the district (Rosen and Sexton). The arrangement caused reduced flow downstream from the irrigation district leading to reduced dispersion and increased effluent concentrations (National Research Council).

Another significant inference that can be drawn from this comparative static analysis is that employing liberalized water trade as the sole policy tool to reduce effluent loading may not always be a desirable policy. Specifically, when the effluent of concern is a farm chemical input, there may be significant low cost opportunities to reduce loading through chemical input management. The opportunity to sell water offers little incentive to undertake such activities. In some instances a mixed strategy involving policies which facilitate water trade, as well as policies which offer farm chemical management incentives, may be advisable.

CHAPTER 4: HYDROLOGIC-ECONOMIC SIMULATION METHODOLOGY

4.1. Chapter Overview

The central objective of this dissertation is to provide a policy relevant analysis of benefits and costs of alternative water market structures in a specific case study setting, the Treasure Valley of Eastern Oregon. Such analysis is difficult because the diverse goals of water resource policy are inter-related in complex, sometimes conflicting ways.

The approach taken involves quantifying five key effects influencing the potential attractiveness of water market policies: 1) water supply response to water markets, 2) profit accruing to water market suppliers, 3) secondary economic impacts, 4) groundwater quality effects and 5) down stream river flow effects. No attempt is made to measure these effects in a common money metric or compare policies using a comprehensive welfare measure. Rather, the quantification of these effects serves as basis for qualitatively analyzing: 1) the economic feasibility of alternative water market structures in the study area, 2) the technical and economic feasibility of alternative water market structures as groundwater quality improvement strategies in the study area, and 3) the magnitude and direction of third party local economic impacts and return flow effects likely to influence the political/legal feasibility of alternative water market strategies.

This chapter contains a description of the economic and hydrologic simulation models developed for this research. The simulation consists of four components:

1) An economic optimization model, WM, described in section 4.3, which estimates profits, output choices, input choices (including water use, nitrogen use and irrigation

technology choices) in response to alternative prices of water and changes in water trade rules.

2) A model of short-run local economic impact, LI, described in section 4.4 which simulates the net impact of water sales on the Malheur county economy.

3) A pollution process model consisting of two components. A nitrate leaching model, NL, described in section 4.5.1 is used to compute the rate of nitrate leaching into the aquifer based on the resource allocation decisions modelled with WM, as well as agronomy and soils parameters. A groundwater hydrology model described in section 4.5.2 is used to compute the spreading of nitrates through the aquifer with groundwater flows.

4) A return flow externality mass balance model described in section 4.6, which is used to compute the net impact of water trade on third party water rights holders.

4.2 Modelling Scenarios

A central hypothesis of this research is that the rules of water trade influence economic, hydrologic and agronomic outcomes. The four scenarios representing alternative water trade rules modelled in this research are described here. Four specialized terms are used to describe the scenarios: 1) transfers in place and purpose of water diversion, 2) conserved water trade (or conserved water sale), 3) restrictive non-impairment conditions and 4) non-restrictive non-impairment conditions.

4.2.1 Scenario 0: Base Case

In the base case, water trade is precluded and irrigators can neither sell nor buy water. The value of water in this scenario is its use value in irrigated crop production. The scenario is used as a benchmark against which the affects of alternative water trade policies can be measured.

4.2.2 Scenario 1: Transfers in Place and Purpose of Water Diversion with Restrictive Non-Impairment Conditions

Scenario 1 simulates current Oregon law governing "transfers in the place and purpose of water diversion". Such transfers require that water be made available through retiring land with attached water rights from irrigated crop production. Another characteristic of scenario 1 which approximates current Oregon water transfer law is the inclusion of "restrictive non-impairment provisions". Such provisions are the legal mechanism designed to protect down-stream parties from negative return flow externalities. These restrictive non-impairment conditions are modelled as constraints on a water rights holder giving up irrigation on land with an attached water right.

Specifically, it is assumed that water rights holders can not sell all of the water they have the right to divert. Only the portion of diversions which does not eventually returns to the stream and constitute part of the water claim of water rights holders down stream may be sold in this scenario.

4.2.3 Scenario 2: Transfers in Place and Purpose of Water Diversion with Non-Restrictive Non-Impairment Conditions

Scenario 2 is also a simulation of transfers in place and purpose of water diversion. The non-restrictive non-impairment conditions modelled in scenario 2 ignore potential negative third party impacts of water trade on downstream parties. It is assumed that all water diversions reductions gained through retiring irrigated land may be traded.

4.2.4 Scenarios 3 and 4: Trade in Conserved Water

Scenarios 3 and 4 model trade in conserved water. They simulate the Oregon conserved water trade law (ORS 537.455 to 537.500) which has existed since 1987. This law was designed to remove water conservation disincentives inherent in earlier state water laws. Conserved water transfer law allows water rights holders to reduce diversions through adaption of water management practices which increase water use efficiency. Note that conserved water trade (scenarios 3 and 4), in contrast with place and purpose of water diversion transfers (scenarios 1 and 2), does not require cessation of irrigation on land with attached water rights.

In scenario 3 "non-restrictive non-impairment provisions" are assumed. Specifically, scenario 3 simulates the Oregon conserved water law that allows trading 75% of water diversion reductions associated with water conservation practices. In accordance with the Oregon conserved water law, the remaining 25% of reductions in diversion are assumed to be returned to the stream. Non-impairment conditions are assumed to be non-restrictive in this scenario in the sense that beyond returning 25% of diversion reductions to streamflow, no effort to mitigate third party return flow effects is required.

In scenario 4 "restrictive non-impairment provisions" are assumed, meaning that water saved through conservation can only be sold if the protection of downstream water rights from negative return flow can be guaranteed. This "restrictive non-impairment provision" is modelled as a constraint allowing only trade of reductions in consumptive use (relative to historical levels) achieved through water conservation. Specifically, it is assumed that 75% of reductions in consumptive use achieved through water conservation may be sold and that 25% of reductions in consumptive must be returned to the stream.

4.3 Economic Optimization Models

The economic optimization models developed for this study are numerical approximations of the conceptual profit maximizing model of an irrigated farm as developed in chapter 3 (equation 3.1). The models were designed to represent study area irrigator responses to an increased opportunity cost of water.

In order to fully reflect the range of choices available to irrigators, the models used included three categories of response: 1) substitution of dryland or less water intensive crops for more water intensive crops, 2) deficit irrigation strategies involving reducing the depth of water applied and accepting consequent reductions in yield, and 3) increasing irrigation system efficiency by substituting labor or capital for water.

Eight sub-regional programming models were use in this research to reflect the variability in feasibility, costs and returns associated with alternative production choices across the diverse soils in the study area. Figure 4.1 shows the location of the subregions, Table 4.1 contains a brief verbal description of the soils in each subregion and Table 4.2 summarizes the assumed maximum potential yield by crop in each subregion (zero values indicate that the crop cannot be profitably produced in the subregion).

Programming model output is used to generate several important kinds of information. Water supply and irrigator

Figure 4.1: Sub-division of the Study Area by Soil Type

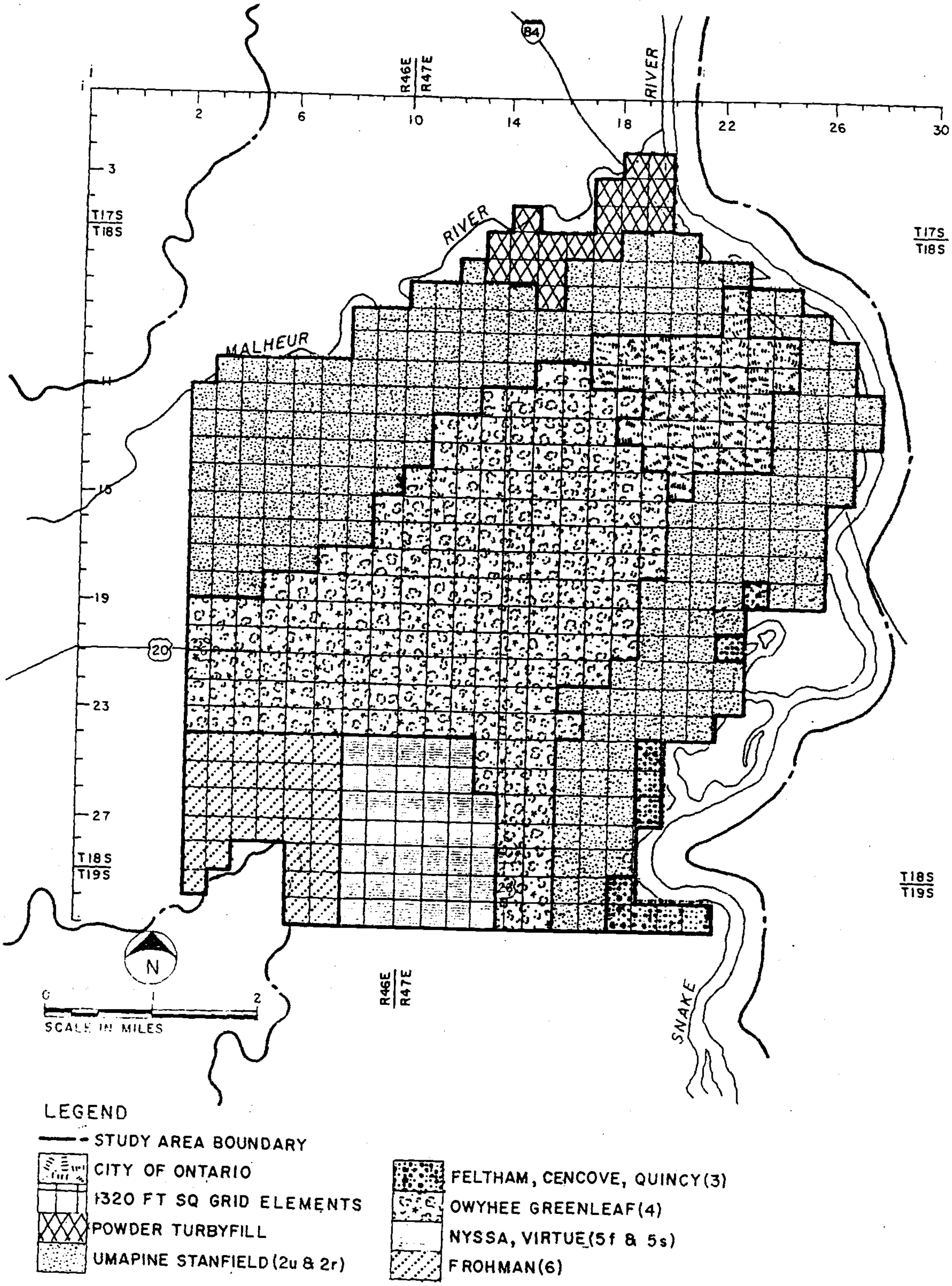


Table 4.1: Description of Sub-regional Soils

Subregion	Soil Name	Soil Description
1	Powder-Turbyfill	deep silt loams/fine sandy loams, well drained, less than 2% slopes
2U	Umapine-Stanfield unreclaimed	very strongly alkali silt loams, deep to moderately deep over hard pan, moderately to somewhat poorly drained, less than 2% slope
2R	Umapine-Stanfield reclaimed	silt loam, deep to moderately deep over hardpan, moderately to well drained, less than 2% slope
3	Feltham-Cencove-Quincy	deep loamy sands and moderately deep sandy loams over sand and gravel, well to excessively well drained, less than 2% slope
4	Owyhee-Greenleaf	deep silt loams, well drained, less than 2% slope
5f	Nyssa-Virtue flat	silt loams, moderately deep over hardpan, well drained, less than 3% slope
5s	Nyssa-Virtue	silt loams, moderately deep over hardpan, well drained, slopes of 3 to 30%
6	Frohman	silt loams, shallow over hardpan, well drained, slopes of 3 to 30%

profit curves are traced out by solving the linear programming models over a range of exogenously determined water prices. The changes in irrigator income and the value of irrigated crop production generated with these models are key inputs in the model of local economic impact. The water and nitrogen input level choices in programming model solutions are key inputs in the nitrogen and water balance models used to compute hydrologic impacts.

Table 4.2: Maximum Potential Yield by Crop and Subregion

	Subregion*							
Crop	1	2R	2U	3	4	5f	5s	6
Wheat bu/ac	104	90	0	94	106	97	92	84
Potato cwt/ac	400	0	0	360	400	360	0	0
Alfalfa tons/ac	6.2	5.2	0	5.2	6.2	5.2	5.2	2.7
Sugar-beets cwt/ac	30	26	0	0	30	27	0	0
Onion cwt/ac dry	470	0	0	0	470	425	0	0
Pasture low input AUM	12.8	10.5	9.8	11.3	13.5	12	12	9.8
Pasture high input AUM	17	14	13	15	18	16	16	13

*see figure 4.1 and table 4.1 for a description of subregions.

4.3.1 Irrigation Technology Set Specification

The range of available irrigation technologies and the associated efficiencies greatly influence the cost of conserving water and reducing effluent loading. Commonly, efficiency is described in terms of several positive fractional values which sum to 1. There are several alternative conventions for describing such fractions (Wade). In this text the irrigation efficiency fraction (IE) is described as that portion of applied irrigation water which is used consumptively by the irrigated crop (CU). The fraction of water not used by crops (NCU) consists of three components, deep percolation of water below the root zone (DP), runoff (RO) and evaporation/wind loss during application (EL). Given a measure of irrigation fractions and a measure of crop consumptive use of water necessary to maximize yield (CU_m), the total water application depth necessary to maximize yield can be computed as $W_m=CU_m/IE$. Irrigation systems that apply water more evenly are associated with larger irrigation efficiency fraction values and require less water to maximize yield.

In general, increasing irrigation efficiency involves substituting labor and (or) capital for water. In this study, the range of available irrigation efficiencies is represented with a set of five alternative irrigation technology/ management options. The three systems involving furrow irrigation vary with respect to the assumed intensity of water management. Present furrow (PF) irrigation management in the area commonly involves 12 or 24 hour irrigation sets. Scheduling is ussually based on visual inspection of crops for symptoms of moisture deficiency or is based on a fixed rotation. Typically, stream size is chosen to minimize observable runoff, a practice that tends to cause relatively large deep percolation losses (Whittlesey, Obersinner and McNeal). The improved furrow irrigation strategy (MF) modelled here involves scheduling of irrigation to meet predicted crop demands, as well as better management of stream sizes using techniques such as watermark sensor measurement of infiltration at various intervals along a furrow. The cut-back furrow management strategy (CF) modelled here involves the MF irrigation strategy plus additional labor input. Specifically, the practice involves beginning irrigations with a relatively large irrigation stream size and returning to the field later and reducing the stream size. This practice increases the uniformity of infiltration along the length of furrow by speeding advance time, thereby reducing deep percolation at the head of the furrow and reducing runoff.

Solid-set is the predominant irrigation technology used to produce row crops in the study area. Published figures suggest that irrigation efficiencies for such systems range from 60 to 85%, depending on soils, crop, wind conditions, maintenance, as well as spacing of laterals along the mainline and sprinkler heads along the laterals (Martin et. al.; Chen and Wallender). In this study two configurations of lateral and sprinkler head spacing are considered. The sprinkler activity denoted SP1 is representative of the configuration typically used in the study area in potato production. The sprinkler activity denoted SP2 involves investment in additional laterals and sprinkler heads as a water conservation strategy. Close grown crops in the rolling benchland areas of the study area are typically grown with side-roll irrigation systems. Activity SP3 represents such a system for alfalfa, wheat and pasture production.

Assumed irrigation system fractions associated with each of the alternatives are represented in table 4.3. The furrow irrigation fractions are based on estimates reported by Whittlesey, McNeal and Obersinner. The authors claim that the values are representative of silt loam soils and Snake-Columbia River Basin climatic conditions. The sprinkler irrigation system fractions are based on the Whittlesey, McNeal and Obersinner estimates as well as values from an engineering study of solid set irrigation design by Chen and Wallender.

4.3.2 Crop-Water Production Functions

In addition to possibilities to conserve water through substitution of capital and labor, irrigators facing scarce or expensive water may choose to deficit irrigate their crops. Deficit irrigation involves intentionally providing a crop less than its consumptive use requirements. Understanding the economics of deficit irrigation requires an understanding of underlying crop-water production functions. Scientific attempts to quantify crop yields as a function of water are numerous and date back more than 80 years (Vaux and Pruitt).

The most common empirical methodology for assessing crop response to water involves regression of agronomic experiment data. When statistically estimating these production functions, other factors which influence yield (such as fertilization rate, pest or disease infestation) are treated as constant and assumed not to limit yield. The consensus arising from these studies is that for a diverse set of plant species and cultivars, over varying climatic conditions, crop yield as a function of water applied can best be represented as a convex function (Vaux and Pruitt; Hexam and Heady).

A shortcoming of statistically estimated crop-water response functions based on agronomic field trial data is that results tend to be specific to soil, climate and irrigation management conditions at the experiment site. Water resource planners often wish to transfer information about crop-water response across sites. As a result, semi-empirical methodologies have arisen which combine crop-water response information available from diverse settings with information about climate, irrigation technology and other factors (Vaux and Pruitt; Letey, Knapp and Solomon).

The methodology used in this study is based on a model developed by Warrick and Yates and is similar to models developed by Feinerman et. al. and Seginer. The model is especially appropriate for this research because it accounts for the influence of irrigation efficiency as well as crop water uptake on yield as a function of water applied. Key assumptions of the model are that: 1) other cultural practices are non-limiting, 2) response is a single valued

Table 4.3: Assumed Irrigation System Efficiencies

Irrigation Efficiency

Crop	Irrigation System					
	PF	MF	CF	SP1	SP2	SP3
Alfalfa	.575	.625	.725	.80		.80
Wheat	.50	.55	.65	.75		.75
Pasture	.50	.55	.65	.75		.75
Sugarbeats	.45	.50	.60	.75		
Potatoes	.325	.375	.475	.65	.80	
Onions	.325	.375	.475	.65	.80	

Deep Percolation Fraction

Crop	Irrigation System					
	PF	MF	CF	SP1	SP2	SP3
Alfalfa	.175	.15	.125	.10		.10
Wheat	.25	.225	.20	.15		.15
Pasture	.25	.225	.20	.15		.15
Sugarbeats	.20	.175	.15	.15		
Potatoes	.325	.30	.275	.25	.10	
Onions	.325	.30	.275	.25	.10	

function of total water added, and 3) a single uniformity characterizes all water added. These assumptions are appropriate when good irrigation scheduling practices are followed (Warrick and Yates, p. 169).

Because of technological factors and soil heterogeneities, irrigation systems generally apply water non-uniformly. Thus applying sufficient water to maximize yield at the point of minimum infiltration in an irrigated field results in water applied exceeding crop requirements at other points in the field.

In conceptual terms, average yield can be expressed as

$$AY = \int_{0,\infty} Y(W)\, f(W)\, dW \qquad (4.1)$$

where AY is average yield

Y(W) is crop water response function

f(W)dW is the frequency distribution of water depth.

Implementation of the conceptual model requires specification of Y(W) and f(W)dW. A Von-Leibig type growth response to water uptake is assumed. Yield in this model is assumed to be a linear function of the rate of crop water uptake, measured as soil-plant system evapotranspiration. Beyond a threshold level of uptake, W_m, no yield increase is expected to result from additional uptake. A strong case for assuming linear yield is summarized by Vaux and Pruitt. The response function can be written as

$$Y = 0 \qquad W < W_0 \qquad (4.2)$$

$$Y = \frac{(W-W_0)Y_m}{W_m-W_0} \qquad W_0 < W < W_m$$

$$Y = Y_m \qquad W > W_m$$

where Y is crop yield

Y_m is maximum yield attainable when water is non-limiting

W is water uptake

W_m is water uptake necessary to attain maximum yield

W_0 is threshold water uptake level below which yield is zero.

Several alternative statistical distributions (i.e. normal, parabolic, uniform) have been used to represent f(W)dW in applied research (Seginer). However, the choice of functional form does not appear to play a significant role in determining yield as a function of average depth (Warrick and Yates). The uniform distribution is used in this research for the sake of computational ease. Given information describing the minimum and maximum depth of water application (W^{max}, W^{min}), the assumption of a uniform distribution allows solution for average yield (Seginer),

$$ay = \frac{[2w^{max}(1-w_0) + w^{min}(2w_0-w^{min}) - 1\ ]}{[\ 2(w^{max}-w^{min})(1-w_0)\ ]} \qquad (4.3)$$

where yield and water are expressed in dimensionless units

$ay = AY/Y_m$,

$w_0 = W_0/W_m$,

$w^{max} = W^{max}/W_m$,

$w^{min} = W^{min}/W_m$.

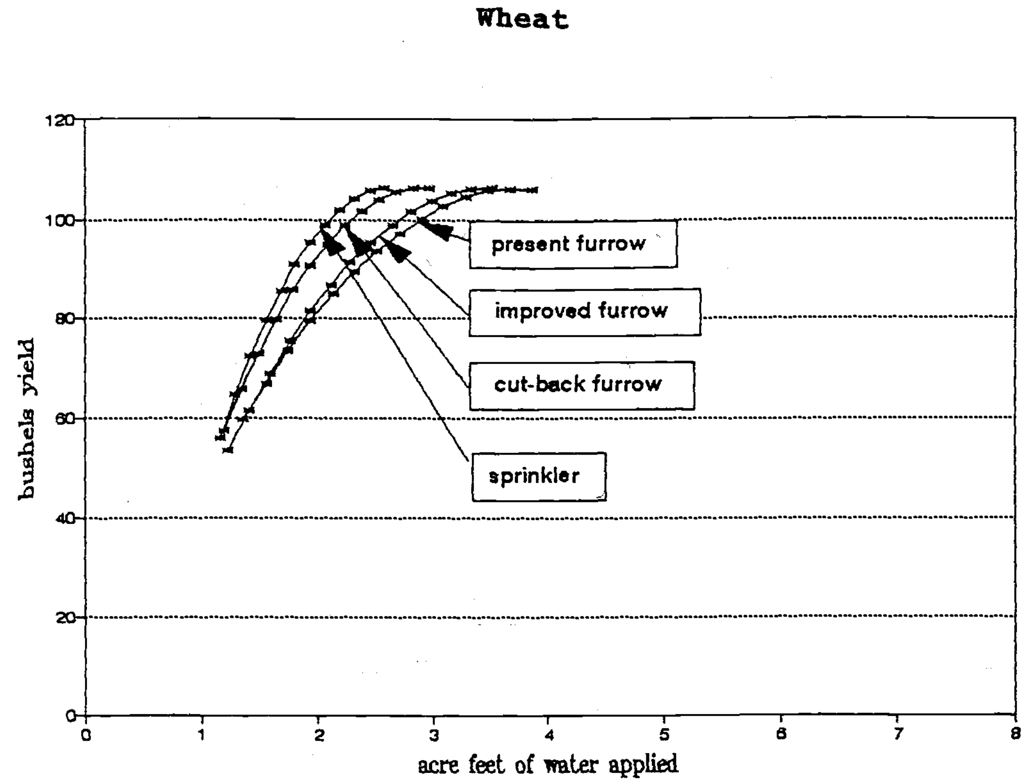
Water production functions for six crops and four irrigation technologies over a range of water application depths were generated by writing a computer algorithm in the GAMS programming language to solve equation 4.3. Yields as a function of water application depth values generated are presented in table 4.3. A regression analysis was used to characterize the relationships in quadratic form. Figure 4.2 contains a graphic representation of the family of water production functions generated for wheat and potatoes on Owyhee-Greenleaf soils.

4.3.3 Modelling Nitrogen Input Decision Making

Although the emphasis of this study is analysis of the implications of changes in the price of water, crop nitrogen input decisions cannot be ignored. The level of nitrogen application to crops is one of the most significant determinants of nitrate leaching (Linderman, Hergert, Watts and Martin) and nitrogen and water input decisions tend to be interdependent.

Several simplifying assumptions were required in this analysis as a substitute for incomplete information regarding nitrogen input decision making. Specifically, it is assumed that irrigated crop producers maintain sufficient levels of nitrogen in the soil to make it a non-limiting factor of production. The levels of nitrogen assumed to be non-limiting are based on recommendations in the Oregon State University Extension Service Fertilizer Guides and a survey of area growers (Jensen and Simko). They are assumed

Figure 4.2: Crop-Water Response Functions for Wheat and Potatoes Grown on Owyhee-Greenleaf Soils



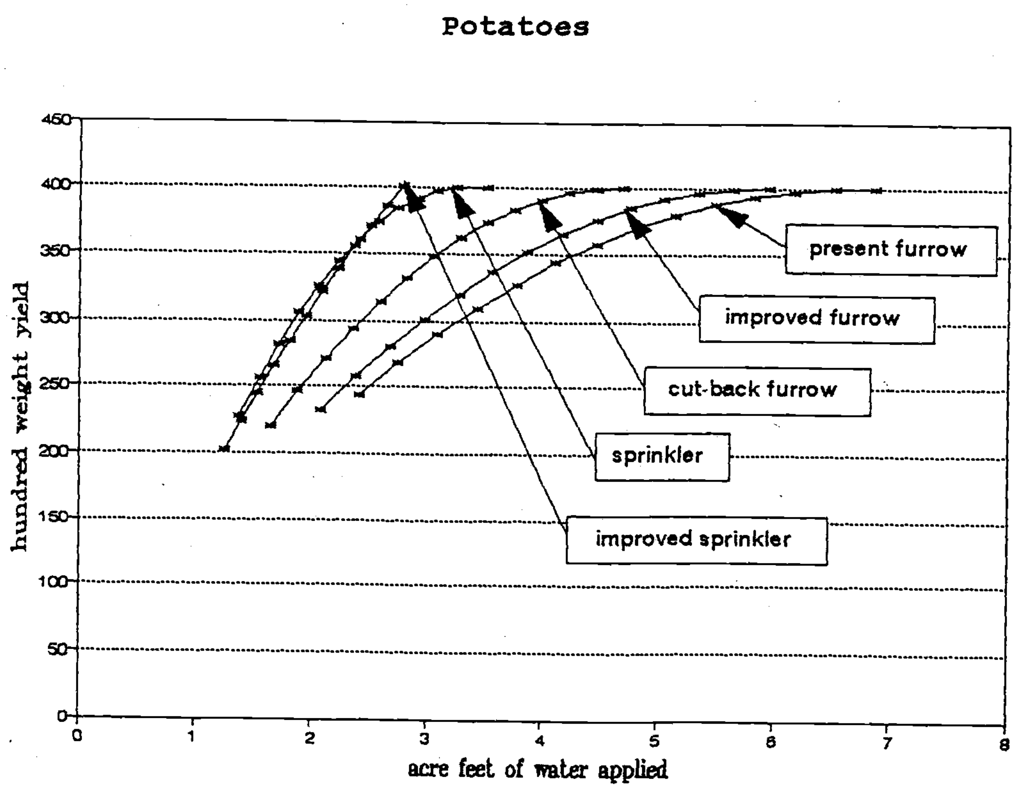


Table 4.4: Crop Yields as a Function of Non-uniformly Distributed Irrigation Water Depth

water input as fraction of crop et at maximum potential yield (W/W_m)		yield as a fraction of maximum potential yield (Y/Y_m)				
		present furrow	improved furrow	cut-back furrow	present sprink.	improved sprink.
Wheat	2	1	1	1	1	-
	1.5	0.943	0.967	1	1	-
	1.25	0.862	0.889	0.963	0.992	-
	1	0.746	0.765	0.853	0.897	-
	0.75	0.595	0.595	0.638	0.675	-
Potatoes	3	1	1	1	1	1
	2.5	0.974	0.997	1	1	1
	2	0.894	0.94	0.998	1	1
	1.5	0.762	0.812	0.913	1	1
	1	0.578	0.612	0.706	0.862	0.933
	0.75	-	-	0.557	0.633	0.675
Alfalfa	2	1	1	1	1	-
	1.5	0.982	0.998	1	1	-
	1.25	0.906	0.944	0.99	1	-
	1	0.774	0.811	0.872	0.935	-
Sugarbeet	2.25	1	1	1	1	1
	2	0.99	1	1	1	1
	1.5	0.884	0.934	0.987	1	1
	1.25	0.786	0.841	0.91	0.997	1
	1	0.658	0.706	0.762	0.897	0.935
	0.75	-	-	0.587	0.663	0.678
Onions	3	1	1	1	1	1
	2.5	0.974	0.997	1	1	1
	2	0.894	0.94	0.998	1	1
	1.5	0.762	0.812	0.913	1	1
	1	0.578	0.612	0.706	0.862	0.933
	0.75	-	-	0.557	0.633	0.675
Pasture	2	1	1	1	1	-
	1.5	0.943	0.967	1	1	-
	1.25	0.862	0.889	0.963	0.992	-
	1	0.746	0.765	0.853	0.897	-
	0.75	0.595	0.595	0.638	0.675	-

to represent the sum total of nitrogen fertilizer and residual nitrogen which must be available in the crop root zone to realize maximum yield.

When reductions in water application lead to reduced yields, the level of nitrogen fertilizer necessary to assure that nitrogen is a non-limiting factor is also assumed to be less. In the case of wheat it is assumed that 3 lbs/acre less of nitrogen are required for each anticipated bushel of reduced yield (This assumed behavior mimics OSU extension fertilizer irrigated wheat guidelines). In the case of the other crops modelled (row crops, alfalfa and pasture), the non-limiting nitrogen availability level is not assumed to vary with water application rate. This omission is likely to introduce only slight bias for two reasons. First, the marginal value of water in row crop production is high, thus strategies which involve row crop yield sacrifices are likely to be relatively uneconomical compared to the alternative water saving strategies available. Second, pasture is grown with little nitrogen fertilizer input and alfalfa is generally grown with no nitrogen fertilizer. Thus, ignoring change in fertilizer nitrogen input levels for these crops is not likely to distort results greatly.

As stated above it is assumed that plant nitrogen demand can be satisfied with nitrogen fertilizer or residual nitrogen. In other words, it is assumed that farmers view residual nitrogen as a substitute for fertilizer nitrogen. The extent of possible substitution is likely to vary with the rate of water application for two reasons. First, water application rate reductions which lead to reduced leaching losses in one year may result in higher rates of available residual nitrogen which can be substituted for fertilizer in the following year. The potential for such a response is included in this study by reducing costs of production by the value of any residual nitrogen substituted for nitrogen fertilizer. Residual nitrogen credits are included in this study when acreage is allocated to row crops (onions, potatoes and sugarbeets) grown in rotation with wheat or to wheat-wheat rotation. The depth to which residual nitrogen is treated as a fertilizer substitute varies with crop. In wheat production, any nitrogen residual left in the first five feet of soil by the proceeding crop is treated as a substitute for fertilizer. In onion production only residual nitrogen left in the first foot of soil by the proceeding crop is assumed to be a substitute for fertilizer. In potato and sugarbeet production, all nitrogen residual left in the first foot of soil and 25% of the residual left in the next four feet of soil by the preceding crop is assumed to be a substitute for fertilizer.

Second, water application reductions in a given crop year which decrease leaching losses may decrease the rate of nitrogen application necessary to maintain soil nitrogen as a non-limiting factor in that year. This possibility is not modelled here because reliable information was not available characterizing the magnitude to this response. Omitting this response may lead to overstatement of nitrogen input rates.

4.3.4 Production Cost and Revenue

When the price of water as an input in crop production changes, irrigators respond by adjusting crop rotations and crop management. Costs and revenues of alternative crop management strategies are key determinants in this adjustment process.

In this study, costs of production are broken into four components: 1) pre-harvest production costs except irrigation and fertilizer management, 2) irrigation and water related costs, 3) fertilizer application and management costs, and 4) harvesting, hauling and storage costs. Profit in this model is calculated as returns to land and water for a farm owner.

The costs of pre-harvest operations and the costs of harvesting, hauling and storage are based on Oregon State Malheur County Extension estimates. More detailed budgets for a range of irrigation and fertilizer management were developed using estimates of input requirement and cost based on farmer interviews, irrigation equipment dealer interviews and published reports. Cost estimates are summarized in appendix A.

Revenues are computed as the sum over crops of crop yield times average annual price over the period 1986-1991 (Oregon State University, Malheur County Extension Service). Price data are also summarized in appendix A. In general, no changes in yield or price are assumed to result from changes in irrigation technology used. There are two exceptions. Growing Onions under sprinkler irrigation is associated with a 10% yield reduction as the result of increased disease (Jensen). Russet potatoes grown under sprinkler are associated with a 15% price premium due to reduced incidence of dark fry ends. About half the potatoes grown in the county are Russet, the other half are Sheppity potatoes. Sheppity potato contracts pay no quality premiums (Jensen).

4.3.5 Crop Rotation Restrictions

Agronomic and soils conditions can limit the choice of crops which can be grown in a given setting as well as the sequence in which crops can be grown. In mathematical programming models such limits on cropping choices are commonly expressed as constraints.

In this study crop rotation constraints are assumed to vary across soils. The set of crop soil combinations assumed to be infeasible are summarized in table 4.2 as zero elements. An additional set of crop rotation constraints restrict potatoes, onions and sugarbeets to follow wheat in rotation. Furthermore, the total quantity of potatoes, onions and sugarbeets grown on a given soil is restricted. Specifically, total acreage dedicated to any one of these crops is not allowed to exceed 13.5% of cropped acreage.

4.3.6 Functional Representation of Optimization Models

Five variants of the basic optimization model were used in this research. Each represents one of the five alternative water trade scenarios modelled. All models share common features including the irrigation technology choice set, the crop-water response functions, crop rotation restrictions, production cost, and return specification described above. However, specifications vary with respect to the set of alternative parameter definitions or constraints included. These differences effect a) how water rights holder can make water available for sale, and b) how much of the available water they can sell. A synopsis of these functional representations is provided here.

4.3.6.1 Scenario 0: Base Case

In the base case scenario, water trade is precluded and irrigators can neither sell nor buy water. In this scenario, the model representing a profit maximizing irrigator is written:

$$MAX\ \Pi = \sum_c \sum_{ie} \sum_d (P_c Y_{c,ie,d} - C_{c,ie,d}) * A_{c,ie,d} \quad (4.4a)$$

$$s.t. \quad Y_{c,ie,d} = B0_{c,ie} + B1_{c,ie} W_{c,ie,d} + B2_{c,ie} W^2_{c,ie,d} \quad (4.4b)$$

$$\sum_c \sum_{ie} \sum_d W_{c,ie,d} * A_{c,ie,d} \leq WA*AA \quad (4.4c)$$

$$\sum_c \sum_{ie} \sum_d A_{c,ie,d} \leq AA \quad (4.4d)$$

where choice variables are defined as:

Π	profit
$Y_{c,ie,d}$	crop yield
$A_{c,ie,d}$	acreage allocation level

parameters are defined as:

$W_{c,ie,d}$	water input demand associated with an acre of activity $A_{c,ie,d}$
P_c	crop price
$C_{c,ie,d}$	production cost
$B0_{c,ie}$	quadratic water production function parameter
$B1_{c,ie}$	quadratic water production function parameter
$B2_{c,ie}$	quadratic water production function parameter
WA	water endowment (diversion allowed per acre)
AA	acreage endowment

and indexes are defined as:

c	index of crops (onions, sugarbeets, potatoes, wheat, alfalfa, pasture)
ie	index of irrigation technology choices (present, improved and cut-back furrow, present and high efficiency sprinkler)
d	index of water depth as a percent of yield maximizing water depth, d = 0,0.05,..,0.95,1.

4.3.6.2 Scenario 1: Transfers in Place and Purpose of Water Diversion with Restrictive Non-Impairment Conditions

The programming model developed for scenario 1 is described functionally with equations 4.5a-4.5d.

$$MAX\ \Pi = \sum_c \sum_{ie} \sum_d (P_c Y_{c,ie,d} - C_{c,ie,d}) * A_{c,ie,d} \quad (4.5a)$$
$$+PW * CUB * SA$$

$$s.t. \quad Y_{c,ie,d} = B0_{c,ie} + B1_{c,ie} W_{c,ie,d} + B2_{c,ie} W^2_{c,ie,d} \quad (4.5b)$$

$$\sum_c \sum_{ie} \sum_d W_{c,ie,d} * A_{c,ie,d} \le WA * (AA - SA) \quad (4.5c)$$

$$\sum_c \sum_{ie} \sum_d A_{c,ie,d} \le AA - SA \quad (4.5d)$$

The model simulates a profit maximizing irrigator with the opportunity to use water on his farm or sell water by transferring the place and purpose of his water right use to another party. The model includes a water sales activity which reflects current Oregon place and purpose of water use transfer laws requiring cessation of irrigation on the land to which traded water rights are attached. In this model, the irrigator may either allocate land to irrigated crop production activities ($A_{c,ie,d}$), or to water transfer (SA). Allocating an acre of land to water transfer yields the market price (PW) times the amount of water attached to the acre which is available for sale (CUB). Simultaneously, the land availability constraint (4.3d) forces a reduction in acreage available for cropping equal to the amount of acreage from which attached water rights have been sold. The model does not allow irrigators to sell water conserved through means other than retiring irrigated acreage. Thus for example water saved through increasing irrigation system efficiency cannot be sold in this scenario.

Restrictive non-impairment conditions are included in the model by defining the reduction in water available to the irrigator (WA) and the amount of water available for sale (CUB) differently. CUB represents that fraction of the irrigators per acre water endowment (WA) which has historically been used consumptively by the crops he grows. CUB is computed in this study as the level of consumptive water use in the base case scenario.

4.3.6.3 Scenario 2: Transfers in Place and Purpose of Water Diversion with Non-Restrictive Non-Impairment Conditions

The programming model developed for scenario 2 (equations 4.6a-4.6d) is essentially the same as the scenario 1 programming model except that no non-impairment conditions are assumed. This is reflected in the specification of objective function, equation 4.6a and the water availability constraint, equation 4.6c. Allocating an acre to the water sales activity, SA in this model results in a reduction in water available to the irrigator equal to his per acre diversion allotment. The same amount, WA becomes available for sale.

$$MAX\ \Pi = \sum_c \sum_{ie} \sum_d (P_c Y_{c,ie,d} - C_{c,ie,d}) * A_{c,ie,d} + PW * WA * SA \quad (4.6a)$$

$$s.t. \quad Y_{c,ie,d} = B0_{c,ie} + B1_{c,ie} W_{c,ie,d} + B2_{c,ie} W^2_{c,ie,d} \quad (4.6b)$$

$$\sum_c \sum_{ie} \sum_d W_{c,ie,d} * A_{c,ie,d} \le WA * (AA - SA) \quad (4.6c)$$

$$\sum_c \sum_{ie} \sum_d A_{c,ie,d} \le AA - SA \quad (4.6d)$$

4.3.6.4 Scenarios 3 and 4: Sales of Conserved Water

The scenario 3 and 4 programming models described functionally in equations 4.7a-4.7d and 4.8a-4.8d simulate the decision making of an irrigator who can allocate water to crop production or sell it in a conserved water market. Approval of a conserved water sale by the Oregon Water Resources Department is contingent upon two conditions: 1) that 25% of all reductions in diversion be returned to stream flow, and 2) that proposed conservation measures "will not cause harm to any other (water) user ... and will not adversely affect the public interest" (Oregon Department of Water Resources).

In scenario 3 it is assumed that the second of these constraints is non-binding. In other words, it is assumed that the proposed transfer of conserved water has no negative return flow effects. The model developed for this scenario includes a water conservation activity (WC). Allocation of water to this activity has two affects: 1) it influences the irrigators objective function 4.7a, increasing profit by an amount equal to the market price of an acre foot of water (PW) times the amount of conserved water eligible for transfer (75% of the conserved water), and 2) it influences the water availability constraint 4.7c, decreasing the volume of water available for crop production by WC acre feet.

$$MAX\ \Pi = \sum_c \sum_{ie} \sum_d (P_c Y_{c,ie,d} - C_{c,ie,d}) * A_{c,ie,d} + PW * WC \quad (4.7a)$$

$$s.t. \quad Y_{c,ie,d} = B0_{c,ie} + B1_{c,ie} W_{c,ie,d} + B2_{c,ie} W^2_{c,ie,d} \quad (4.7b)$$

$$\sum_c \sum_{ie} \sum_d W_{c,ie,d} * A_{c,ie,d} \leq WA * AA - WC \quad (4.7c)$$

$$\sum_c \sum_{ie} \sum_d A_{c,ie,d} = AA \quad (4.7d)$$

In scenario 4 it is assumed that the non-impairment condition is binding. In other words, it is assumed that any reduction in return flow damages downstream water rights holders or a public interest. Consequently, in this scenario the objective function (4.8a) yields the water market price (PW) for 75% of any reductions in consumptive use of water below the base case level, ($CU_{c,ie,d}*A_{c,ie,d}$ - CUB*AA). Noting that the coefficient $CU_{c,ie,d}$ represents the consumptive water use associated with allocating an acre foot of water to crop production activity, $A_{c,ie,d}$.

$$MAX\ \Pi = \sum_c \sum_{ie} \sum_d (P_c Y_{c,ie,d} - C_{c,ie,d}) * A_{c,ie,d} \quad (4.8a)$$
$$+PW * 0.75 * (cub*AA - \sum_c \sum_{ie} \sum_d (cu_{c,ie,d} * A_{c,ie,d}))$$
$$s.t. \quad Y_{c,ie,d} = B0_{c,ie} + B1_{c,ie} W_{c,ie,d} + B2_{c,ie} W^2_{c,ie,d} \quad (4.8b)$$
$$\sum_c \sum_{ie} \sum_d W_{c,ie,d} * A_{c,ie,d} \leq WA * AA \quad (4.8c)$$
$$\sum_c \sum_{ie} \sum_d A_{c,ie,d} = AA \quad (4.8d)$$

In contrast to the transfer in place and purpose of water transfer markets modelled in scenarios 1 and 2, the trade in conserved water modelled in scenarios 3 and 4 does not require taking land with attached water rights out of production. Rather, water is made available for sale through adaptation of conservation practices which decrease diversions without taking land out of irrigated production. To reflect this absence of irrigated land retirement requirements, the land availability constraints in scenarios 3 and 4 (4.7d and 4.8d) are expressed as equalities and do not require reductions in land availability to accompany reductions in water diversion.

4.4 Local Economic Impact Analysis

Residents of areas with a large irrigated farming sector are often concerned that proposals to reallocate water could have adverse secondary impacts on the regional economy. Such concerns arise because irrigated crop production, food processors, input and service suppliers and other connected economic sectors often represent a large part of the economic base in such areas.

The methodology used to assess local economic impact in this study involves combining the results of a 1992/93 input-output study of Malheur County (Obermiller, Iqbal and Stringham) with results from economic optimization model runs. Specifically, the local economic impact of water transfers is measured as the sum of all direct, indirect and induced changes in demand for goods and services. This impact is computed as

$$\Delta FD = \Delta FI * \alpha_{hh} + \Delta CO * \alpha_{ic} \qquad 4.9$$

where

ΔFD is the sum total change in county final demand for goods and services resulting from water trade

ΔFI is the change in farm income resulting from water trade. This value is computed as increases in revenue from water sales

α_{hh} is the multiplier expressing the sum of direct, induced plus indirect impacts of change in household income on final demand for all goods and services

ΔCO is the sum of changes in the value of irrigated crop production output resulting from water trade

α_{ic} is the multiplier expressing the sum of direct, indirect plus induced impacts of change in irrigated crop production output on final demand for all goods and services

One key assumption underlying this methodology for estimating local economic impact is that all labor and capital assets left unemployed as an indirect effect of water trade do not become re-employed within the county. This is a reasonable assumption when the objective of the analysis is to assess the short-run local economic impact of transferring water out of the area of origin. In the short-run, certain types of specialized assets previously employed in economic sectors with significant forward and backward linkages to crop production are not likely to realize an equal rate of return in alternative activities (i.e. water conveyance infrastructure, food processing plant capacity). Furthermore some labor previously employed indirectly as a result of crop production may leave the region.

However, the assumption that all labor and capital assets left unemployed as an indirect effect of water trade do not become re-employed limits the validity of this economic impact analysis from a long-run, national economic accounting perspective. To the extent that assets are fully employed in perfectly competitive markets, labor and capital previously employed in irrigated crop production are, in the long-run likely to earn equal returns in alternative activities elsewhere in the economy.

Another key assumption underlying the input-output methodology is that all sectors in the local economy produce goods and services using constant returns to scale production technology. The assumption is likely to represent a reasonable approximation in the case of small changes. However, the assumption may lead to distorted estimates of the local economic impact if: 1) very large volumes of water are sold away from the county, and 2) economic sectors closely linked to irrigated crop production (such as food processing or agricultural input supply) are more accurately characterized as increasing returns to scale industries. Under such circumstances, the methodology used here could lead to an under-estimation of local economic impacts. For example, reduced demand in some increasing returns to scale sectors could cause exit because it would be un-economical to operate at a significantly reduced scale.

A final critical assumption underlying the local economic impact assessment methodology used here is that returns to water sales are spent in precisely the same way that other household income in the county is spent. This is likely to be a reasonable approximation when revenues from water sales represent a small change in the income of water rights holders. However, patterns of household income expenditure, especially the portion of income spent on goods and services out of the county would likely change significantly from the present pattern for a water rights holder retiring significant irrigated acreage to sell attached water rights.

4.5 Pollution Process Models

The pollution process models developed for this research are numerical approximations of the conceptual model of contaminant loading and transport presented in chapter 3 (equation 3.3). The model receives as inputs several values attained through solution of the economic optimization model including: depths of water infiltration, nitrogen input rates, and crop yields. This information, along with data characterizing crop agronomy, soils and aquifer characteristics, is processed in a two part simulation. In the first step, a nitrate leaching model is used to compute the rate of nitrate leaching to groundwater. In the second step, the dispersion of leachate across the spatial domain of the aquifer is computed.

4.5.1 Conceptual Model of Nitrate Leaching

Attempts to scientifically estimate the nitrogen budgets of plant-soil systems date back over 100 years (Meisinger and Randall). The fundamental concept underlying all nitrogen budgets is the law of conservation of mass. This laws implies that the sum of all nitrogen inputs into the system less the sum of all nitrogen outputs must equal the change in nitrogen stored in the system.

The conceptual model used in this research accounts for the affects of dynamics and spatial variance. Functionally, this model can be written as

$$nl_{i,j}^{t} = nl_{i,j}^{t}[ni_{i,j}^{t}, wi_{i,j}, pnu_{i,j}^{t}, sn_{i,j}^{t}] \qquad 4.10.a$$

$$sn_{i,j}^{t} = sn_{i,j}^{t}[ni_{i,j}^{t-1}, pnu_{i,j}^{t-1}, nl_{i,j}^{t-1}] \qquad 4.10.b$$

$$ni_{i,j}^{t} = ni_{i,j}^{t}[sn_{i,j}^{t}, pnu_{i,j}^{t}] \qquad 4.10.c$$

where

$ni_{i,j}{}^{t}$ = mass of nitrogen fertilizer added in year t
$wi_{i,j}{}^{t}$ = depth of water infiltration during year t
$nl_{i,j}{}^{t}$ = mass of nitrogen leaching subtracted in year t
$sn_{i,j}{}^{t}$ = mass of nitrogen stored in the root zone at the beginning of year t
$pnu_{i,j}{}^{t}$ = mass nitrogen taken up by the crop in year t
$nl_{i,j}{}^{t}$ = mass of nitrogen leaching subtracted in year t
i,j are geographic coordinates.

Equations 4.10.a and 4.10.b represent the physical (agronomic, soils) processes governing nitrate leaching and storage of nitrogen in soils. Equation 4.10.c represents the decision making processes of irrigated crop producers regarding nitrogen fertilizer input levels. The dynamic nature of the processes determining nitrogen stocks and flows in this conceptual crop-soil system implies that nitrogen leaching in a given year is not just a function of inputs and outputs in that year but also a function of input and output rates in previous years.

4.5.2 Implementation of the Nitrate Leaching Model

Implementation of the conceptual nitrate leaching model involved use of a computer nitrogen process model to generate three large matrices: 1) a matrix of nitrate leaching values as a function of crop type, crop yield, irrigation system efficiency, soil residual nitrogen and nitrogen fertilizer input level, 2) a matrix of soil nitrogen residual states at the end of the crop year as a function of crop type, crop yield, irrigation system efficiency, soil residual nitrogen and nitrogen fertilizer input level.

The computer algorithm used to compute these matrices is a mass balance accounting of nitrogen inflow, outflow and storage. The model tracks nitrogen and water in two soil horizons, the first foot of soil and the next five feet. The functional relationships upon which the algorithm is based are those governing the *Nitrogen Leaching and Economic Analysis Package* (NLEAP) computer algorithm (described by Shaffer, Halvorson and Pierce). The model accounts for additions and subtractions to nitrate, ammonia, plant residue nitrogen, plant residue carbon and water accounts.

The basic functioning of the model is summarized in equations 4.11-4.14

1) <u>nitrogen mass balance</u>

$$NAL^{t=m} = N_{rsd}^{1} + \sum_{t=1}^{m} [\ N_f^t + N_n^t - N_{plt}^t - NL^t\ ] \qquad (4.11)$$

$$N_n^{m=t} = K_n^t * [\ NH_{rsd}^1 + \sum_{m=1}^{t} [K_m^t * N_V^t + NH_f^t - NH_{plt}^t - N_n^{t-1}] \qquad (4.12)$$

where

NAL^t is nitrogen available for leaching in time period t

NL^t is nitrogen leaching in time period t

N_f^t is NO_3-N added as fertilizer in time period t

N_{rsd}^1 is initial residual nitrate in soil profile

N_n^t is nitrate produced through nitrification of ammonium in time period t

N_{plt}^t is nitrate taken up by crop in time period t

NH_f^t is NH_4-N added as fertilizer in time period t

NH_{rsd}^1 is initial residual ammonia in soil profile

K_n^t the rate of nitrification of ammonium in time period t

NH_{plt}^t is ammonia taken up by crop in time period t

N_{or}^t is the pool of organic crop residue nitrogen at time t

K_m^t is the rate of transformation of organic nitrogen to ammonia in time period t

2) <u>water mass balance</u>

$$WAL^{m=t} = \sum_{m=1}^{t} [\ W^t - ET^t\ ] - (AWC - ST) \qquad (4.13)$$

where

WAL^t is water available for leaching at time t

W^t is water infiltration from irrigation and rainfall in time period t

ET^t is crop-soil evapotranspiration in time period t

AWC is initially available stored water in the root zone

ST is capacity of soil to store water

3) <u>nitrate leaching</u>

$$NL^t = NAL^t * (1 - \exp[\ -K * WAL^t / POR\ ]) \qquad (4.14)$$

where
POR is soil porosity, and
K is a leaching coefficient

4.5.3 Limitation of the Nitrate Leaching Model

Three potential sources of error are inherent in the methodology used.

1) Uncertainty with respect to nitrogen transformation rates (i.e. rate of mineralization, nitrification etc.) reduces the predictability of nitrogen leaching model estimates. An informal analysis reported by Miesinger and Randall summarizes the expected range of error associated with eight key input and rate coefficient variables driving common nitrogen leaching models such as NLEAP, EPIC or CERES. The analysis concludes that individual parameter value errors are likely to vary between +/- 5% and +/- 50% depending upon the parameter. The cumulative effect of these random errors on outcomes depends upon their joint distribution, which is not fully understood. Thus it should be noted that, while leaching predictions are treated deterministically, under- or overestimation of the true rates as a consequence of nitrogen transformation rate coefficient error is a possibility.

2) Heterogeneities across a watershed including differences in soils and topography, as well as differences in farm management skill and preferences, are likely to result in an uneven pattern of nitrate leaching. The scale of these effects is so small that adequate data characterizing underlying sources of these difference is generally not available.

Available data allowed specification of such heterogeneities only on a very broad scale in this research. Specifically, it is assumed that, for a given crop and management, rates of nitrate leaching vary across but are homogeneous within the eight subregions (summarized in section 4.1). Variations across regions are assumed to be the result of differences in soil texture, root zone depth and soil drainage. Assuming homogeneity within subregions is likely to lead to underestimation of variance in actually observed rates of leaching as it omits any accounting for smaller scale heterogeneities.

3) The net nitrogen leaching associated with incorporating alfalfa into a crop rotation is assumed to be zero. More specifically, it is assumed nitrogen additions from fixation that occur when alfalfa crops are turned under are offset through two forms of subtraction: 1) reductions in fertilizer additions in the following crop and 2) uptake of residual nitrogen left behind by the previous crop in the alfalfa establishment year. This assumption may lead to over or under estimation of nitrate leaching.

4.5.4 Modelling Nitrate in Groundwater

The ultimate objective of water quality policies is to protect human beings and natural eco-systems from dangerous levels of pollutant concentration. The level of pollution concentration which occurs at a given point within a water body is primarily determined by three sets of factors: 1) the spatial distribution of pollution sources and the rate of loading at each source, 2) the rate of pollutant mixing as a result of water flows in the water body, and 3) the rate of decay of the pollutant.

The methodology used to estimate the rate and spatial distribution of nitrate leaching into the study area aquifer was described in section 4.5.1. This section contains a description of the model used to assess the rates and directions of groundwater flow in the aquifer and the impact of these flows on groundwater pollution spreading. The computational technique used is known in the hydrology literature as the finite difference method (Wang and Anderson). The methodology involves representing a water body as a grid of blocks each containing a discrete volume of water. The rate of water flow and pollution spreading through the grid is simulated with a set of numerical algorithms representing governing equations of hydrology as well as empirically measured hydrologic parameter values and assumptions.

For the purposes of groundwater modelling the portion of the Owyhee Aquifer underlying the study area is represented as the 536 element block - center grid portrayed in figure 1.1. The coverage area is approximately 35.5 sq. miles, as each of the square cells has a length of 1320 feet and thus represents 40 acres. Conceptually, the model used in this study is a two dimensional advection model based on Fick's Law (Wang and Anderson, p. 181).
The differential equation governing this conceptual model is written (Wang and Anderson, p.182),

$$-\frac{\delta}{\delta x}(nCv_x) - \frac{\delta}{\delta y}(nCv_y) = n\frac{\delta C}{\delta t} - C'W/b \qquad (4.15)$$

where the following dimensional conventions are used (L=length, M=mass, T=time) and

- n = porosity (L^3L^{-3})
- C = solute concentration in groundwater (ML^{-3})
- C' = concentration of solute in source, sink (ML^{-3})
- v_x, v_y = average linear pore velocity (L/T)
- b = thickness of the aquifer (L)
- W = volume flow rate per unit aquifer (L)

In discrete "finite difference" form the model can be written as

$$C^{t}{}_{i,j} = C^{t-1}{}_{i,j} + \frac{VX_{i,j}}{DX} * (C^{t-1}{}_{i-1,j} - C^{t-1}{}_{i,j})$$

$$+ \frac{VY_{i,j}}{DY} * (C^{t-1}{}_{i,j-1} - C^{t-1}{}_{i,j}) + \frac{PER^{t}{}_{i,j}}{b*n} * (C^{t}{}_{i,j} - C^{t-1}{}_{i,j}) \qquad (4.16)$$

where

$C^t_{i,j}$ = nitrate concentration in aquifer cell i,j at time t

$C'^t_{i,j}$ = nitrate concentration of water leaching into aquifer cell i,j at time t

$VX_{i,j}$ = the X-direction component of the two dimensional vector describing groundwater direction and velocity of flow in cell i,j

$VY_{i,j}$ = the Y-direction component of the two dimensional vector describing groundwater direction and velocity of flow in cell i,j

DX=DY = the length of one side of a grid cell

$PER^t_{i,j}$ = the depth of water introduced as recharge into cell i,j at time.

Equation 4.16 states that the concentration of nitrate in cell i,j at time t is the weighted sum of four concentrations:

1) the concentration of water flowing into aquifer cell i,j from the cell which is upgradient in the X flow direction, $C^{t-1}_{i-1,j}$ weighted by the fraction of total cell water volume displaced by flow from this direction in one time period, $VX_{i,j}/DX$,

2) the concentration of water flowing into aquifer cell i,j from the cell which is upgradient in the Y flow direction, $C^{t-1}_{i,j-1}$ weighted by the fraction of total cell water volume displaced by flow from this direction in one time period, $VY_{i,j}/DX$,

3) the concentration of nitrate entering into aquifer cell i,j from above as leachate, $C'^t_{i,j}$ weighted by the fraction of total cell water volume displaced by flow from this direction in one time period, $PER_{i,j}/(b*n)$,

4) the concentration of nitrate in water which is not displaced in cell i,j in time t, $C^{t-1}_{i,j}$, weighted by the fraction to total cell water volume which is not displaced in one time period t, $(1 - VX_{i,j}/DX - VY_{i,j}/DY - PER_{i,j}/(b*n))$.

A GAMS computer programming language model was developed to track nitrate spreading in the study area groundwater with equation 4.16 at its heart. The program receives as input two matrices generated with the economic optimization and nitrate leaching model. One matrix describes the spatial distribution of water percolating below the root zone resulting from crop management choices of watershed irrigators, $PER_{i,j}$. The other matrix describes the spatial distribution of nitrate concentrations in this percolating water, $C'_{i,j}$.

Development of the groundwater simulation model required treatment of several issues, including: 1) treatment of aquifer dynamics, 2) treatment of study area boundaries, 3) estimation of groundwater flow rates.

4.5.4.1 Treatment of Aquifer Dynamics

While the computer program developed for this research is well suited for tracing the time path of nitrate spread in an aquifer, no dynamic analysis was conducted for this research. Instead the model was used to simulate the consequences of changes in water market conditions which, once in place, remain in place for a long period of time. Specifically, steady-state groundwater nitrate concentrations were simulated by running the dynamic model iteratively until the maximum change in concentration in any cell from one time period to the next was less than a small convergence criteria constant value.
This took between 20 and 50 years depending upon the scenario evaluated and assumed starting values.

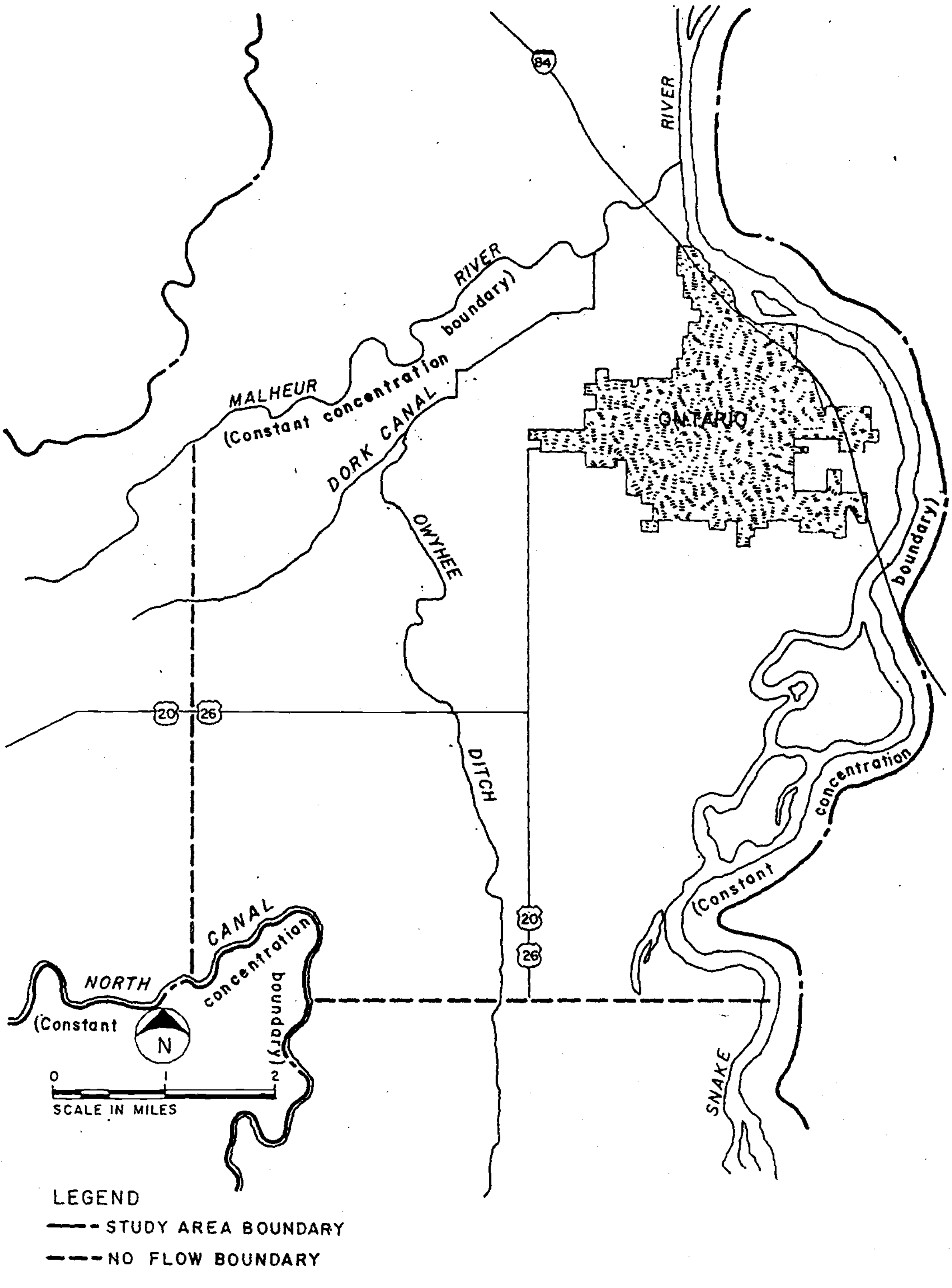
4.5.4.2 Treatment of Study Area Boundaries

Figure 4.3 illustrates the groundwater model boundaries and how each was treated. Two of the boundaries are treated as constant (zero) concentration boundaries: the upper end of studied portion of the aquifer running along the North Irrigation Canal and the lower end of the aquifer running along the Snake and Malheur Rivers. At cells along these two perimeters of the grid, the concentration is not computed with equation 4.16. Rather, concentration $C^t_{i,j}$ is set to zero in all time periods for these cells.

The assumed zero concentration boundary condition is justified in the case of the North Canal as the canal represents the upper extent of the irrigated area in the watershed. Any water entering the aquifer as groundwater flow from above this point is likely to contain negligible concentrations of nitrate. The zero concentration boundary condition is justified in the case of the Snake and Malheur Rivers because the volume of flow in these rivers with small concentrations of nitrate is large relative to the recharge with nitrate polluted groundwater.

The western and southern ends of the study area are modelled as no-flow boundaries. The no-flow boundaries implemented with the "artificial cell row method" (Wang and Anderson) treat the western and southern ends of the study area as if they were impermeable walls refracting flows back into the study area. While no-flow boundary conditions are computationally convenient, they can introduce some distortion into the analysis, especially when flow is strongly perpendicular to no-flow boundaries. The no-flow boundaries are unlikely to strongly distort results of this study as groundwater flow is almost exclusively parallel to the no-flow boundaries (Walker, Gannet).

Figure 4.3: Groundwater Model Boundary Conditions



4.5.4.3 Estimation of Groundwater Flow Rates

A key determinant of the spatial distribution of nitrate concentrations in groundwater is the rate and direction of groundwater flow. Because direct measurement to subsurface water flows is often infeasible, hydrologists have developed methods for estimating these values with information that is readily available or easily attained. The methodology used to estimate groundwater flows in this dissertation is based substantially on a model of groundwater flow in the Oywhee aquifer published as an Oregon State University Civil Engineering master thesis (Walker) and later modifications of this model (Fleming).

The basic finite difference equation governing this model can be written

$$VX_{i,j} = K_{i,j} * \frac{(H_{i+1,j} - H_{i-1,j})}{2 * DX} \qquad (4.17)$$

$$VY_{i,j} = K_{i,j} * \frac{(H_{i,j+1} - H_{i,j-1})}{2 * DX}$$

where

$K_{i,j}$ = the hydraulic conductivity of aquifer in cell i,j

$H_{i,j}$ = the elevation of the groundwater table in cell i,j

In words the equations state that velocity of groundwater in cell i,j is determined by slope of the aquifer in the vicinity of the cell and the conductivity (permeability) of aquifer material in the cell. Use of the equation to estimate groundwater flow rates requires knowledge of aquifer conductivity and groundwater table elevations.

The conductivity (or permeability) of an aquifer is commonly measured using well "draw-down" tests. These tests involve two steps: 1) pumping water from a well until the water level in the well drops and 2) measuring the time required for water in the well to return to its original elevation. The time versus elevation change data generated with such a test can be compared to empirical table values to derive point estimates of aquifer conductivity. Large conductivity values associated with quickly recovering wells are an indication of highly permeable non-compacted aquifer materials. Small conductivity values indicate finely textured, cemented or compacted aquifer materials.

In this study, groundwater conductivity is assumed to vary across four zones but be constant within each zone, as indicated in figure 4.4. The conductivity values assumed in zones 1,2 and 3 are those assumed by Walker. The fourth zone lies outside the area modelled by Walker. Fleming derived the conductivity value assumed in this zone using a computer algorithm designed to choose the zonal conductivity values that minimize the difference between observed and predicted groundwater elevations in the zone.

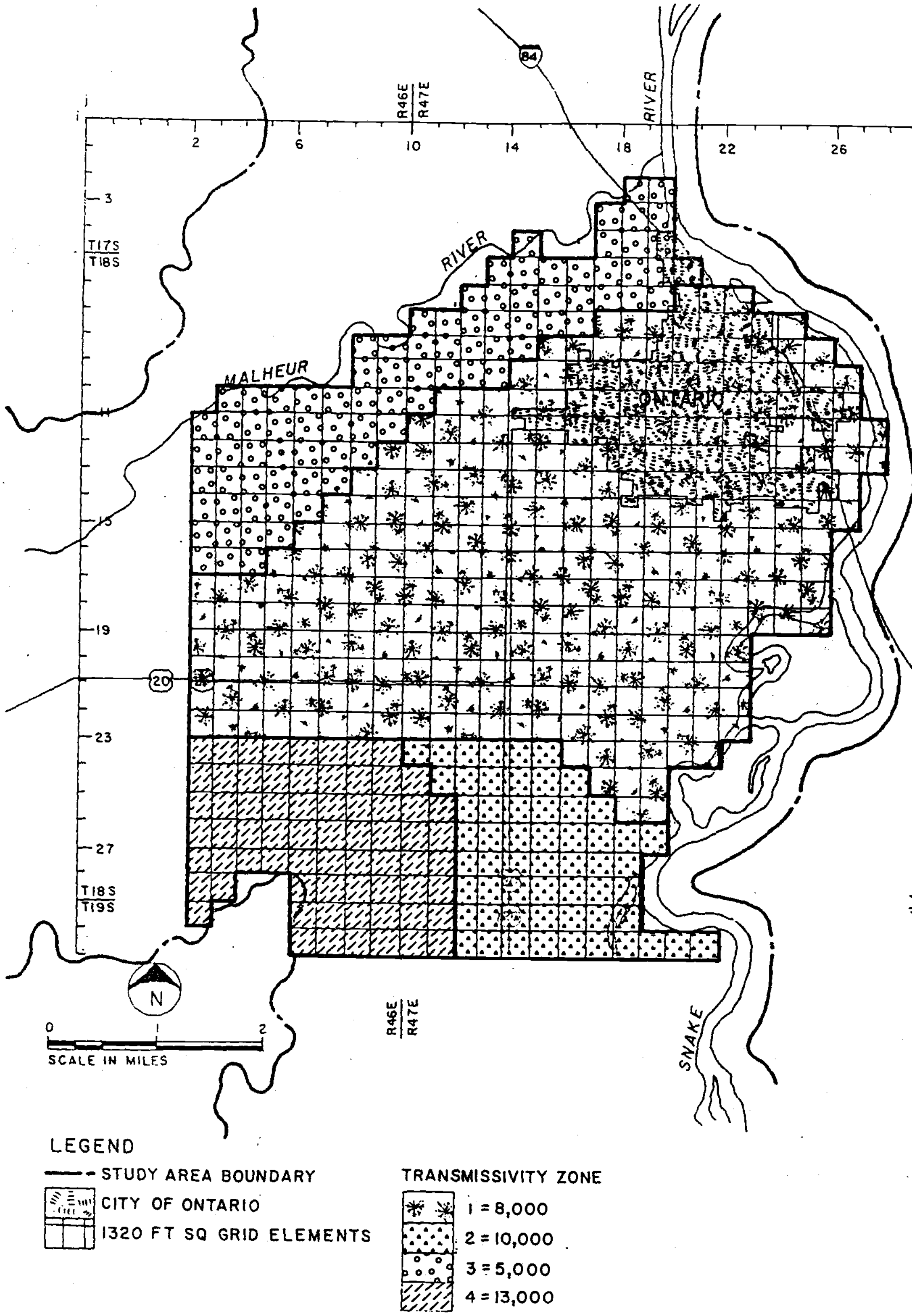
Although well log records detailing the elevation of the groundwater table are available for some cells in the aquifer grid used in this study, values at other points had to be estimated. The methodology used to estimate these unknown water elevation (or tensio-metric head) values is based on the governing equation known as the Poisson Equation (Wang and Anderson, p. 42). The Poisson Equation can be written as

$$\frac{\delta^2 h}{\delta x^2} + \frac{\delta^2 h}{\delta y^2} = - \frac{R(x,y)}{T} \qquad (4.18)$$

where

x,y = coordinates in the horizontal plane (L),
h = water level elevation (L),
T = transmissivity (L^2/T), and
r = groundwater recharge (discharge) rate (L/T).

Figure 4.4: Assumed Aquifer Zonal Conductivities



The finite difference representation of the governing differential equation of steady-state groundwater flow in a confined aquifer used in this model is:

$$H_{i,j} = 0.25 * (H_{i-1,j} + H_{i+1,j} + H_{i,j-1} + Hi,j+1) + \frac{R_{i,j}}{T} * DX*DX \quad (4.19)$$

where $H_{i,j}$ = the value of tensio-metric head in cell i,j

$R_{i,j}$ = the value of recharge in cell i,j

The use of this equation to estimate unknown groundwater level values involved three steps:

1) Groundwater elevations along three contours were set as fixed values. As indicated in figure 4.5, the three contours are the Snake-Malheur River, the North Canal and the geologic break running close to the Owyhee-Nyssa and Dork Canals. Values of fixed head along these contours were taken from well log data reported by Walker, and Gannett. Linear interpolations were made at points where well log data were not available.

2) The depth of water recharging (discharging) the aquifer from above in each time period was computed. Recharge (discharge) was assumed to consist of three components as
expressed in equation 4.20.

$$R_{i,j} = CL_{i,j} + PER_{i,j} - WD_{i,j} \quad (4.20)$$

where

$CL_{i,j}$ = canal leakage in cell i,j

$PER_{i,j}$ = deep percolation to groundwater of irrigation water and precipitation

$WD_{i,j}$ = withdrawal of well water from cell i,j

Recharge from leaky canal beds is thought to be one of most significant sources of aquifer recharge in the study (Ross). However, exact rates of canal bed leakage in the study area are not known. In this study, leakage from canals was computed on the basis of assumed canal bed permeability and known canal lengths and widths. Specifically, following Walker it was assumed that, during the irrigation season, water seeps from the major irrigation canals in the area at 2 feet per day (Walker) with the exception of a portion of the North Canal which is assumed to lose 17 feet per day. These seepage rates are converted to annual rates of recharge from canal water in cells bisected by a canal as follows:

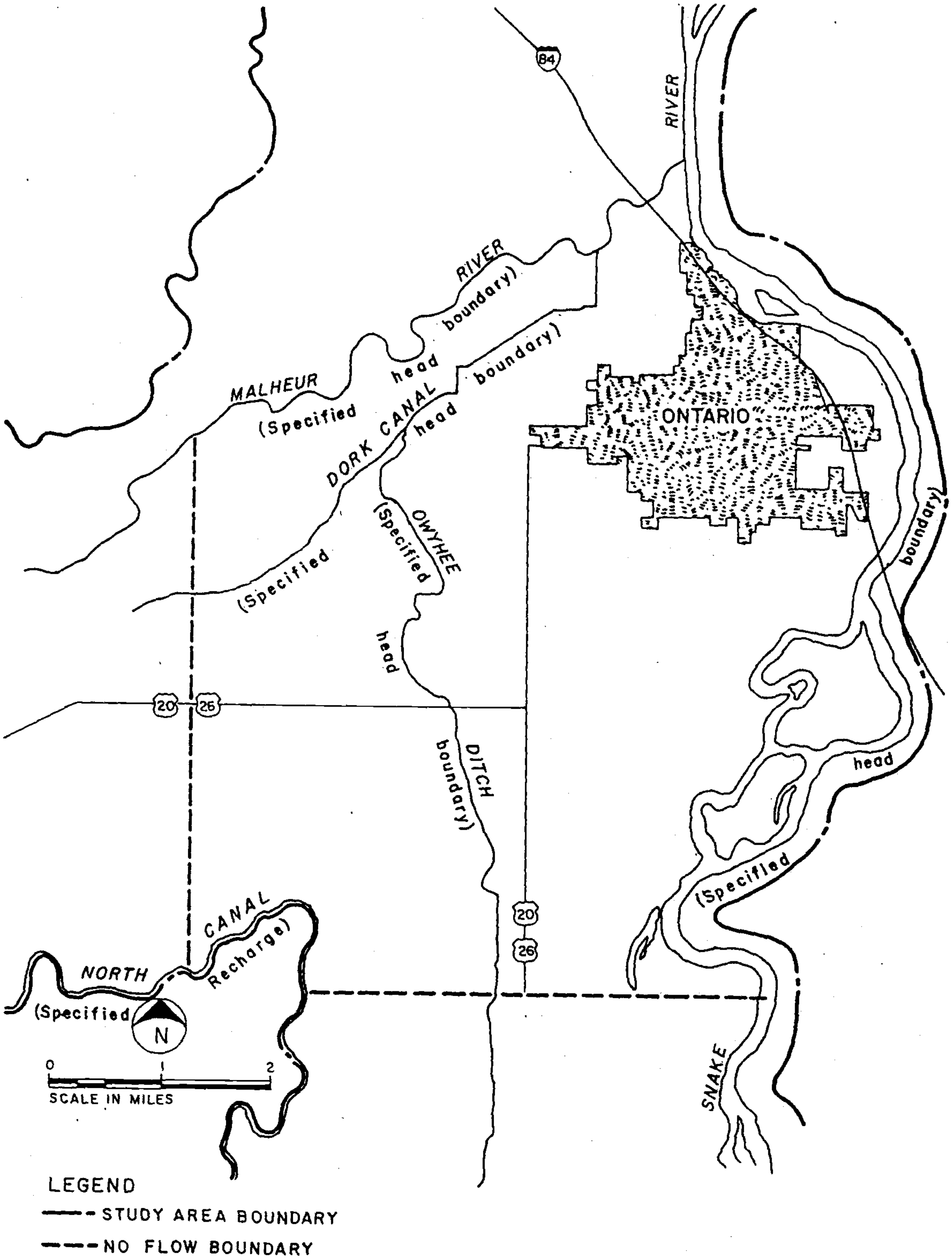
$$CL_{i,j} = \frac{CWIDE_{i,j}}{DX} * SEEP_{i,j} * IRRDAYS \qquad (4.21)$$

where $CL_{i,j}$ = annual canal leakage rate in cell i,j
$CWIDE_{i,j}$ = the width of the canal in cell i,j
$SEEP_{i,j}$ = the rate of canal seepage in cell i,j
IRRDAY = the number of days in the irrigation season.

It is assumed that the rate of leakage from canals remains constant in all scenarios. While this is probably a reasonable assumption for small volumes of water market reallocations, large transfers would likely lead to some modifications in canal operations. Thus, assuming constant canal water seepage in the simulation of large water transfer may lead to some distortion. Assumed rates of withdraw from a major production wells were based on estimates provided by Walker. It is assumed that these rates are not influenced by water reallocations.

The rate of recharge from irrigation water and precipitation is assumed to vary across scenarios in this study depending upon irrigator response to water market incentives. Specifically, a matrix describing rates of deep

Figure 4.5: Boundary Conditions Used in Estimating Groundwater Flow



percolation in each cell is generated as an output of the economic optimization model and read into the groundwater model. The deep percolation values in this matrix represent the average rate of deep percolation for crop growing activities by soil type in the solution to the economic optimization model. The rates of deep percolation associated with a given crop, irrigation technology and yield level are computed with the crop-water response function and irrigation technology coefficients described in sections 4.3.1 and 4.3.2.

3) The values of fixed groundwater elevation and recharge assumed in each scenario were used along with a computer algorithm to compute all unspecified groundwater elevation values. The GAMS computer programming language algorithm employed is based on the Gauss-Seidel type iterative algorithm described by Wang and Anderson (pp48-49). The algorithm computes and recomputes tensio-metric head values in all un-specified head value cells using equation 4.18. At the end of each iteration current tensio-metric head values are compared to tensio-metric head values estimates from the previous period. Estimates are updated until the maximum divergence between current estimates and those from the prior iteration is less than or equal to a small divergence criteria constant.

4.5.5 Assumptions Underlying the Groundwater Model

The groundwater model developed for this research is a valid representation of the study area aquifer to the extent that the following key assumptions hold:

1) Steady-state confined aquifer assumption: The Poisson Equation used to estimate ground-water elevation and the Fick's Law equation used to estimate nitrate spreading are valid governing equations for steady-state confined aquifers. In such aquifers, the level of groundwater

elevation does not vary over time and all flow is in the horizontal plane. Increased recharge in such an aquifer causes water to move horizontally through the aquifer more quickly but does not cause the water level to rise. A hydrologic investigation of the Owyhee aquifer by Walker concluded that assuming the aquifer is steady-state confined is justified for two reasons. First, nearly all observed flow in the aquifer is horizontal. Second the areal extent of the aquifer is large relative to the depth of the aquifer. Under such circumstances the horizontal flow effect tends to dominate vertical flow effects (Walker; Wang and Anderson).

2) Conservative mass assumption: Many pollutants tend to decay over time as the result of bio-chemical processes. A key assumption underlying this model is that no such degradation processes lead to a reduction in the mass of nitrate in the study area aquifer over time. This assumption is justified in most of the studied aquifer area because most of the aquifer is characterized by low carbon, low oxygen conditions and constant groundwater elevations. Such conditions are not conducive to nitrate decay (Pointke and Lowrance). The assumption is less appropriate for the small part of studied aquifer area near the city of Ontario which is characterized by a fluctuating groundwater table. Vadose zone decay through the process of denitrification can be significant under such conditions (Pointke and Lowrance).

3) Zero dispersity assumption: The velocities of groundwater flow used in this model are derived assuming that the permeability of the aquifer is constant within zones. In reality aquifer material permeability within zones is likely to vary considerably. The result is micro differences in the rate of groundwater flow which are not accounted for in this model. As a result nitrates tend to move faster through preferential flow channels and more slowly through flow barriers. The assumption of zero dispersion is likely to result in underestimation of nitrate

concentration variance in the aquifer. There is, however, no reason to assume that predictions of average zonal nitrate concentrations will be biased.

4.6 Return Flow Externality Assessment Methodology

Typically, not all water diverted by a water rights holder is consumed. Rather, a portion of the diversion is commonly returned to the stream where it may form the basis for downstream water claims. Transfers which reduce the level of return flows can reduce the water available to down stream rights holders. Such third party effects are referred to as return flow externalities in the water resource literature. Water law in most of the West grants third parties significant influence in the legal/administrative water rights transfer process if damage occurs to their water rights. Consequently, the extent of return flow externality can be a significant determinant of a proposed water transfer's feasibility. Reviewing proposed water transfers for potential return flow externalities can be a complex and expensive process. The extent of return flow associated with a given water trade depends upon several factors including: 1) the rules of water trade, 2) the source and destination of the traded water rights, 3) the location of third party water rights relative to the source and destination of water trade, 4) the degree of water allocation in the river basin where trade takes place, 5) the hydrology of the river and groundwater dictating when and where water not consumed by diverters re-emerges downstream.

The methodology used for assessing return flow externalities in this research is somewhat simplistic. It provides only an upper bound estimate of the reductions in water claims that downstream water rights holders would suffer as a consequence of the water transfer scenarios simulated. These estimates are premised on the assumptions that: 1) water rights in the Snake River downstream from the Malheur River mouth are completely allocated, and 2) traded water rights are used either to augment river flow or for alternative diversionary purposes, neither of which generate allocable return flows in the Snake River downstream from the mouth of the Malheur. A GAMS computer program was used to compute the level of return flow externality consistent with these assumptions using output from the economic optimization model. Specifically the level of return flow externality was computed as

$$RE = \sum_{i,j} (WT_{i,j} + CU_{i,j} - CUH_{i,j}) \quad (4.22)$$

where

RE = reduced third party water claims as the result of water transfers,

$WT_{i,j}$ = volume of water trades from cell i,j,

$CU_{i,j}$ = consumptive use after transfer in cell i,j,

$CUH_{i,j}$ = historic consumptive use in cell i,j.

In words, equation 4.22 states that transfering a volume of water, $WT_{i,j}$, without reducing consumptive use by an equal amount ($WT_{i,j} = CUH_{i,j} - CU_{i,j}$), will result in a return flow externality.

This methodology is likely to overstate the extent of return flow externality in years of high flow when the river is not completely allocated. The methodology may also overstate return flow externality effects when the loss of return flows generated at the source of traded water is offset by return flows generated at other destinations.

CHAPTER 5: RESULTS

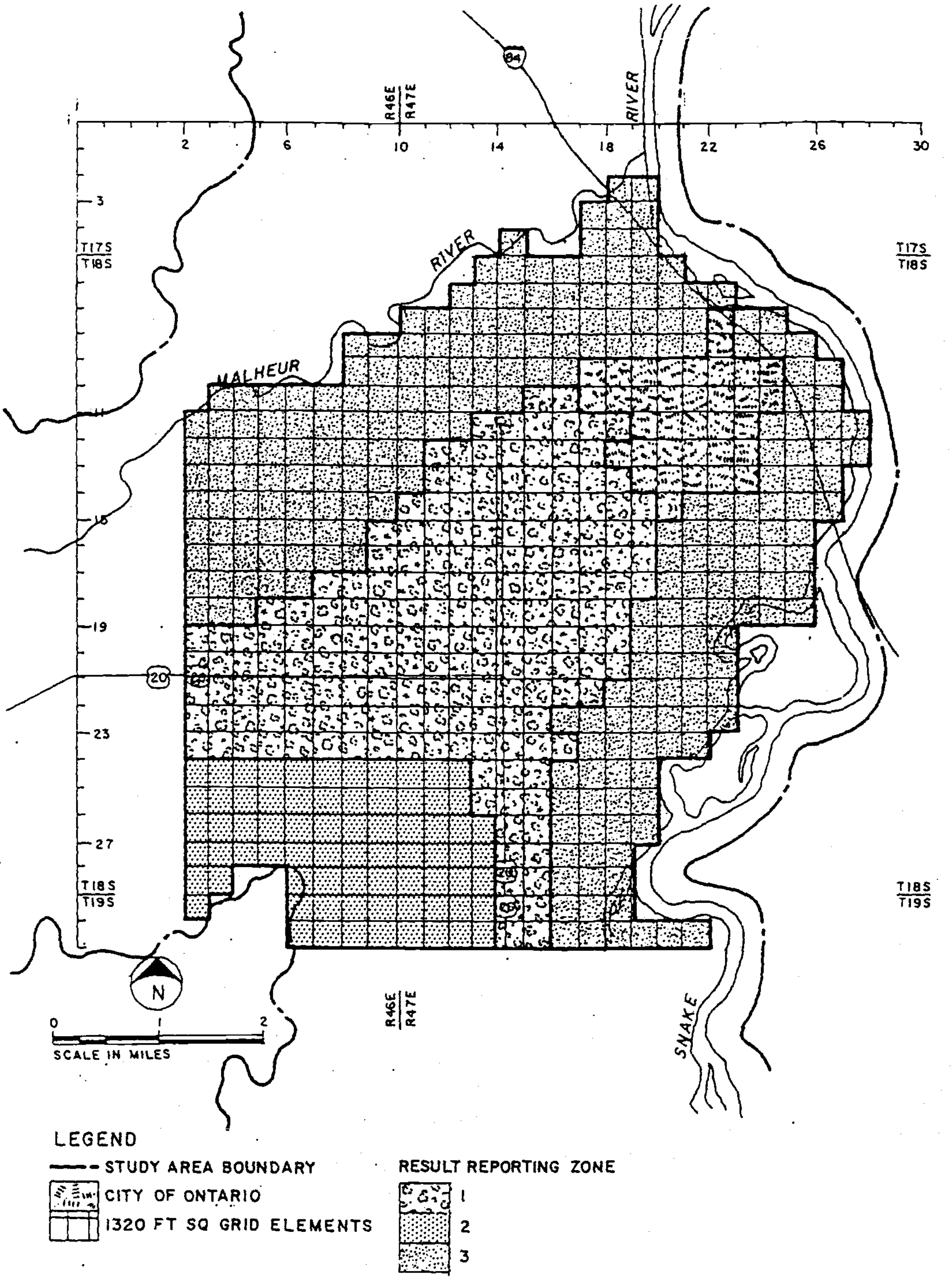
5.1 Chapter Overview

The results of several simulations implemented with the methodology outlined in chapter 4 are presented in this chapter. The chapter begins with a review of base case scenario results. Emphasis is on comparison of predicted study area economic and hydrologic conditions with observed conditions as a means of validating the model specification.

The remainder of the chapter focusses on reporting results of water market policy analyses. Perhaps the most striking finding of these policy analyses is that economic and hydrologic outcomes are strongly influenced by the rules of water trade modelled as scenarios in this research. These differences arise because the alternative rules of water trade considered here generate fundamentally different opportunity costs of water market participation. Discussion of the policy simulation results begins with a reporting of the predicted farm-level response to the modelled water trade scenarios. The chapter also reports five predicted impacts of the water trade: 1) water supply response to water markets, 2) profit accruing to water market suppliers, 3) secondary economic impacts, 4) groundwater quality effects and 5) third party water rights holder impacts.

Heterogeneity in soils and groundwater properties significantly influence agronomic and economic aspects of farming as well as processes governing dispersion of nitrates in the study area. Consequently, many outcome of this analysis can only be clearly understood with results reported at a disaggerate level. Results are reported as zonal averages in some instances to facilitate discussion of the influence that heterogeneity has on model outcomes.

Figure 5.1 Result Reporting Zones



Specifically, the study area is divided into three zones for result reporting. Three zones were chosen because a larger number would complicate discussion and a smaller number would mask significant effects of soil and aquifer heterogeneity. Figure 5.1 shows the location of the zones.

5.2 Base Case Results

Base case modelling analyses in this study established a benchmark to which policy scenario results could be compared. This section contains a summary of the base case model results and is divided into two parts, 1) a description of economic model results and 2) a description of the hydrologic model results. Reporting in this section focusses on comparing predicted outcomes to observed outcomes as a way of assessing model validity:

5.2.1 Economic Model Base Case Results

In order to check the adequacy of the base case economic optimization model specification, predicted estimates of farm profits, crop acreage, crop yields, water input levels, and nitrogen input levels from the final version of the base case economic model were compared to values reported in published reports.

Farm Profits: The *1992 U.S Census of Agriculture State and County Data Report* (U.S. Department of Commerce) found average per farm net cash returns of $45,811 in Malhuer County. In this study average farm profit is estimated at $22,229. The estimate is based on the assumption that the average county irrigated farm in the study area is 170 acres (the county average irrigated crop farm size, U.S. Census of Agriculture).

The difference between the published value and the predicted value of profit is attributable to several factors. One likely explanation is differences in the conventions used to account for owner-operator labor. In this study labor is charged at an hourly rate, even if it is provided by a farm owner-operator. Census reported profits (net farm returns) do not include charges for owner operator labor. Given the small average irrigated crop farm size in the study area (170 acres) and the large percentage of full time farmers (72%), owner-operator labor accounting conventions seem likely to be a particularly significant explanation of the low profit levels estimated in this study. Not counting owner-operator labor as a production cost could improve profit prediction. However, not charging for owner-operator labor would imply a zero opportunity cost for this factor of production in current use and consequently lead to overstatement of supply response to water market incentives.

Other potential explanations for divergence between observed and predicted profits include:

- differences between the study area and county as whole: The area studied for this research is only a small part of the area surveyed for the county census of agriculture. It is possible that detailed analysis of census survey data would reveal a different pattern of profit in the study subarea than in the county as a whole. These difference in sample could be a partial explanation for divergence in observed versus predicted profits.

- differences between the 1992 crop prices used in determining Census profit estimates and the average 1986 to 1990 crop prices used in profits estimated here.

- differences in the cost of production assumed in this study and actual production costs.

Crop Acreage and Crop Yields: Table 5.1 summarizes the frequency distribution of acreage predicted by crop in the base case scenario and reported in the Owyhee Irrigation District in 1988. Because the area considered in this study represents only about 17% of the irrigated acreage in the Owyhee Irrigation district, interpretation of the results is somewhat difficult. To the extent that interpretation of the results is reasonable, table 5.1 suggests that the linear programming models used in this study do reasonably well at predicting the allocation of acreage to crops. The models allocates more land to pasture and slightly less to onions and sugarbeets than is observed on average in the irrigation district as a whole.

Table 5.2 summarizes predicted crop yields in the base case scenario and Malheur county average crop yields (Oregon State University, Malheur County Extension Service).

Table 5.1: Observed Acreage by Crop and Base Case Predicted Acreage by Crop

Acreage Freq.	Wheat	All Grain	Past. and Sila.	Sugar-beet	Pottato	Onion	Alfalfa	Other
obs.	11%	21%	12%	10%	7%	8%	29%	13%
pred.	22%	22%	29%	7%	7%	6%	29%	0%

Table 5.2: Observed Yield by Crop and Base Case Predicted Yield by Crop

Yield /Acre	Wheat	Potato	Alfalfa	Sugar-beet	Onion	Pasture
obs.	93.8 Bu	378.5 cwt	4.72 tons	29.2 cwt	538.3 cwt	-
pred.	98.8 Bu	391 cwt	5.21 tons	28.6 cwt	551.8 cwt	9.1 AUM

note: - indicates no published observation available

This comparison suggests that the math programming model provides reasonable predictions of crop yields, with a slight upward bias (3% to 10% for all crops except sugarbeets). Again, part of the difference may be attributable to differences between average yield in the study area and average yield in the county as a whole.

Water Input Level and Nitrogen Input Level: Table 5.3 summarizes predicted water use levels in the base case scenario and average crop water use levels reported in a survey of 53 Malhuer County growers (Jensen and Simko). The predicted levels are generally slightly higher than the survey reported levels. One potential explanation for the upward bias is the difference in study area water use and water use in the county as a whole. The Jensen and Simko survey sample includes growers from the Vale Irrigation District who experienced extreme water shortage in the survey year (1991), receiving on average just 1.1 acre feet. In contrast, this model is based on the assumption that study area growers receive the average Owyhee Irrigation District water allocation in the years 1986 to 1991 (3.96 acre feet).

Table 5.3: Observed Water Input by Crop and Base Case Predicted Water Use by Crop

Acre feet/ Acre	Wheat	Potato	Alfalfa	Sugar-beets	Onion	Pasture
obs. ac ft /ac	2.4	3.64	-	3.63	3.7	-
pred.	3.09	4.20	4.08	4.69	5.59	3.96

Table 5.4 summarizes predicted nitrogen fertilizer input levels in the base case scenario and average nitrogen

fertilizer input levels reported in the Malhuer County survey (Jensen and Simko). The near exact correspondence between predicted and observed values is more an anomaly of the model specification than a reflection of model accuracy. The Jensen and Simko fertilizer input levels are specified in this model as the level of nitrogen fertilizer input necessary to realize maximum yields. Predicted base case fertilizer levels correspond closely to observed levels because average predicted yields by crop in the base case are very close to specified maximum levels.

Table 5.4: Observed Nitrogen Input by Crop and Base Case Predicted Water Use by Crop

N lbs per Acre	Wheat	Potato	Alfalfa	Sugar-beets	Onion	Pasture
obs.	137	214	-	205	284	-
pred.	136	215	0	202	284	46

5.2.2 <u>Nitrate Leaching and Groundwater Dispersion Base Case Results</u>

The methodology used to predict the groundwater quality impact of water trade in this research involved three steps: economic optimization modelling, modelling of nitrate loading and modelling of nitrate spreading in groundwater. The outcome of this methodology is an estimated spatial distribution of nitrate concentrations in the studied aquifer. This section contains a description of the spatial distribution of nitrate concentration predicted with the base case model. The section also contains a discussion of how these results compare to observed values, as well as a discussion of factors contributing to divergence of predicted and observed values.

Table 5.5 contains a description of predicted and observed mean concentrations, predicted and observed variance of concentration and mean absolute deviation between predicted and observed values. These predictions and observations are reported for each of the three zones used in result reporting, as well as, for the aquifer as a whole. The observed concentration data used in this table come from the 1991 Northern Malheur County Groundwater Management Action Plan, Appendix B (Malheur County Groundwater Management Committee). The report contains a summary of Oregon Department of Environmental Quality laboratory analyses of water taken from a network of groundwater monitoring wells in the study area. The samples were taken between the years 1983 and 1991. Multiple observations were available for some sample points as samples were taken in more than one year. In these instances, observed concentration was assumed to be the average of all reported sample values.

Table 5.5 Predicted Versus Observed Nitrate Concentrations in Groundwater

		total	zone 1	zone 2	zone 3
avg. observed concentration	=	10.45	11.17	2.74	11.94
observed std. deviation	=	10.05	10.51	3.05	9.47
avg. predicted concentration	=	10.40	14.19	4.20	6.80
predicted var.	=	5.33	4.49	1.47	1.43
avg. absolute difference	=	9.57	11.42	2.46	9.17

The results indicate that the methodology predicts aquifer average nitrate concentrations well. The average observed nitrate concentration in grid cells with monitoring wells of 10.45 ppm matches the average base case predicted value of 10.40 ppm almost exactly. The methodology is less accurate in predicting the spatial variation of nitrate concentrations in groundwater. Specifically, the results indicated an average absolute deviation between observed and predicted concentrations of 9.47 ppm.

The failure of the simulation to explain the large observed variance in nitrate concentration is likely caused by several factors. First, the economic optimization model used in this study is premised on the assumption that irrigators within each of eight soil zones face identical natural conditions, have identical risk attitudes, endowments of farm management skill capital and labor constraints etc. A result of these assumptions is prediction of identical crop rotation and input use decision for all points within each soil zone and thus identical nitrate leaching rates. In reality, output and input decisions likely vary across individual farmers and fields resulting in variable rates of nitrate loading within soil zones.

Second, the groundwater model used in this research is based on the assumption that the rate of aquifer conductivity within each of the four conductivity zones is uniform. In all likelihood, conductivity varies within each of these zones because of heterogeneities in the layers of sand and gravel carrying groundwater. The assumption of homogenous zonal groundwater conductivity is another likely reason for underestimated variance in predicted base case groundwater nitrate concentration.

Finally, there may be some bias in the predicted pattern of acreage allocation across the study area and consequent bias in estimated spatial pattern of nitrate loading. The estimated average nitrate concentrations by result reporting zone are 27% greater than the predicted level in zone 1, 53% greater than predicted in zone 2 and 43% less than predicted in zone 3.

The bias in estimated variance of predicted nitrate concentrations potentially influences the estimated impacts of water trade on groundwater quality. The issue is explored in the section describing the groundwater quality impacts of alternative water trade rules (section 5.4.4).

5.3 Farm-Level Response to Alternative Water Trade Rules and Water Prices

Irrigation water rights holders contemplating water market participation face an economic choice: a) continue using water in irrigated crop production and accept the economic return to this activity or b) reduce water use and sell the conserved water at the prevailing market price. The results presented here show that the response to water market incentives differs significantly between the place and purpose of water diversion transfers modelled in scenarios 1 and 2, and the sales of conserved water modelled in scenarios 3 and 4. Modelled response to water market incentives also differ significantly between scenarios which ignore the potential for return flow externalities (scenarios 2 and 3) and scenarios involving restrictions on trade to avoid such third party effects.

5.3.1 Farm-Level Response to Place and Purpose of Water Diversion Market Incentives

Scenarios 1 and 2 simulate markets for transfers in place and purpose of water use. Irrigators anticipating participation in such markets must compare the returns at the margin of maintaining an acre in irrigated production to the returns associated with retiring the acre from irrigated production and selling the attached water rights. The results of this research suggest that returns to retiring land and selling attached water rights exceed returns to continued irrigated crop production in large portions of the studied area. This result holds even at relatively low water prices. For example, scenario 2 estimates imply that if study area irrigators were offered a price of $20 per acre foot they would be willing to retire 9941 acres of irrigated land (more than half of the study area irrigated acreage).

As indicated in table 5.6, supplying this water involves retirement of all of the estimated 5,212 acres of irrigated pasture in the study area, as well as a 74% reduction in alfalfa acreage (from 5,173 to 1345 acres) and a 20% reduction in wheat acreage from 3833 to 3056 acres). Not surprisingly, most of this land retirement comes from zones 2 and 3 which are dedicated primarily to relatively low value grain, hay and pasture crops in the base case. The estimated profit foregone as a result of giving up irrigation on an acre in these zones is relatively low. Base case predicted average profit in zone 2(3) is $53.22 ($42.77) per acre.

Scenario 1 differs from scenario 2 in the assumed required treatment of potential return flow effects. In scenario 2 it is assumed that any return flow externality potential must be avoided. To guarantee down stream flow rights, retiring an acre from irrigated production in this scenario frees only a fraction of the water diversion right attached to the retired acre. Specifically, only that fraction of water diversion which has been historically dedicated to consumptive use may be sold. In scenario 1 it is assumed that any potential third party effects can be ignored.

The third party protection implicit in scenario 1 water trade rules reduces the quantity of marketable water attached to a water right and thus reduces the returns to water market participation. Consequently, less acreage is retired in response to a given water price in scenario 2 than in scenario 1. For example, at a price of $20 an estimated 5597 acres are retired in scenario 1 versus 9941 acres in scenario 2. Not surprisingly, the kinds of crops retired are similar in both scenarios 1 and 2. As indicated in table 5.6, all of the 5212 acres of pasture and 14% of wheat acreage are retired from irrigation in scenario 1 at a

Table 5.6: Predicted Acreage Allocation to Cropping Activities in Place and Purpose of Water Use Transfer Simulation Model Results
Scenario 1:

water price	total acres	wheat acres	potato acres	alfa. acres	sugar-beet acres	onion acres	pas-ture
0.00	17400	3833	1157	5173	1208	950	5212
10.00	16884	3314	1157	5173	1208	950	5212
20.00	11803	3314	1157	5173	1208	950	0
30.00	7452	3056	1157	1338	950	950	0
40.00	7452	3056	1157	1338	950	950	0
50.00	7452	3056	1157	1338	950	950	0
60.00	5703	2851	952	0	950	950	0
70.00	3803	1901	952	0	950	950	0
80.00	3803	1901	952	0	0	950	0
90.00	3803	1901	952	0	0	950	0
100.00	3803	1901	952	0	0	950	0

Scenario 2:

water price	total acres	wheat acres	potato acres	alfa. acres	sugar-beet acres	onion acres	pas-ture
0.00	17400	3833	1157	5173	1208	950	5212
10.00	11803	3314	1157	5173	1208	950	0
20.00	7459	3056	1157	1345	950	950	0
30.00	6114	3056	1157	0	950	950	0
40.00	6114	3056	1157	0	950	950	0
50.00	3803	1901	952	0	0	950	0
60.00	3803	1901	952	0	0	950	0
70.00	2792	1396	445	0	0	950	0
80.00	1900	950	0	0	0	950	0
90.00	1900	950	0	0	0	950	0
100.00	1782	891	0	0	0	891	0

$40 per acre foot water price. Again, the majority of these retirements take place in zones 2 and 3.

In scenarios 1 and 2 at water prices in excess of $30 and $20 per acre foot respectively, acreage remaining in production is dedicated to high value row crops, grain crops grown in rotation with row crops and a small acreage of alfalfa (see table 5.6). The opportunity cost associated with reducing acreage in the productive, zone 1 soils which allow profitable production of these crops is relatively large. The profit per acre which results from maintaining water in its current use in zone 1 is on average $218.60. Thus water supply responses at prices in excess of $30 and $20 per acre foot in scenarios 1 and 2 respectively become considerably less price elastic. This is more so in scenario 1 than in scenario 2, as a result of the more restrictive non-impairment conditions modelled in scenario 1.

5.3.2 Optimal Economic Response to Conserved Water Market Incentives

Scenarios 3 and 4 model transfers of conserved water. The scenarios are simulations of the Oregon law which allows water rights holders who increase water use efficiency and thus reduce diversions to sell a portion of resulting water savings. Water rights holders anticipating participation in a conserved water market can make water available using three strategies.

1) Water rights holders can adopt irrigation efficiency input substitution strategies. Such strategies involve the increased use of inputs which can be substituted for water without decreasing yield. An example would be moving from furrow to sprinkler irrigation. Production costs typically increase when adopting these new technologies.

2) Deficit irrigation strategies involve reducing the frequency of water application or the depth of water applied at each irrigation event. Such strategies allow crop production with reduced water input but involve some yield sacrifices. The opportunity cost of a deficit irrigation strategy is the value of the foregone yield associated with reduced water application.

3) Water rights holders can reduce diversions by increasing acreage in crops with smaller water requirement and decreasing acreage in water intensive crops.

Tables 5.7 through 5.10 describe the extent to which study area irrigators are predicted to pursue each of these strategies in response to the conserved water incentives modelled in scenarios 3 and 4. Table 5.7 summarizes irrigation technology choices in scenarios 3 and 4 programming model solutions over the modelled range of water prices. Table 5.8 summarizes the frequency of acreage dedicated to each crop. Table 5.9 describes average per acre yield by crop and table 5.10 describes average per acre water use by crop.

These results indicate that the opportunity to sell water in conserved water markets would induce considerable changes in water management. One significant response is substitution of irrigation efficiency inputs for water. The primary irrigation efficiency input based strategies adopted to reduce diversions are strategies involving increased use of labor and management inputs which increase the efficiency of present furrow irrigation systems. For example, as indicated in table 5.7, relative to the base case, a $40 per acre water price under scenario 3 water market conditions is predicted to induce the following changes in irrigation management: 1) 75% of wheat acreage will convert from present furrow management to cut-back furrow management, 2) 50% of potato acreage will change from improved furrow management to cut-back furrow management, 3) 44% of alfalfa acreage will change from present and cut-back furrow

Table 5.7 Percentage of Cropped Acreage Allocated to Alternative Irrigation Technology Choices in Solution to Conserved Water Trade Simulations

Scenario 4:

Water Price $/af	Wheat pf	mf	cf	s1	s2	Potato pf	mf	cf	s1	s2
0.00	100					1	49		50	
10.00	100					1	49		50	
20.00	100					1	49		50	
30.00	100					1	49		50	
40.00	14		86					50	50	
50.00			100					50	50	
60.00			100					50	50	
70.00			100					50	50	
80.00			100					50	50	
90.00			100					50	50	
100.00			100					50	50	

Water Price $/af	Alf-alfa pf	mf	cf	s1	s2	Sugar-beet pf	mf	cf	s1	s2
0.00	61		39				100			
10.00	61		39				100			
20.00	3	19	78				100			
30.00		20	80				100			
40.00			100				100			
50.00			100				100			
60.00			100					100		
70.00			100					100		
80.00								100		
90.00								100		
100.00								100		

Water Price $/af	Onion pf	mf	cf	s1	s2	Pas-ture pf	mf	cf	s1	s2
0.00		74	26			100				
10.00		74	26			100				
20.00		74	26			100				
30.00		74	26			100				
40.00			100			100				
50.00			100			100				
60.00			100			100				
70.00			100			100				
80.00			100			100				
90.00			100			100				
100.00			100			37	63			

Table 5.7 Percentage of Cropped Acreage Allocated to Alternative Irrigation Technology Choices in Solution to Conserved Water Trade Simulations - continued

Scenario 4:

Water Price $/af	Wheat pf	mf	cf	s1	s2	Potato pf	mf	cf	s1	s2
0.00	100					1	49		50	
10.00	100					1	49		50	
20.00	100					1	49		50	
30.00	100					1	49		50	
40.00	100					1	49		50	
50.00	100					1	49		50	
60.00	100					1	49		50	
70.00	100					1	49		50	
80.00	100					1	49		50	
90.00	100					1	49		50	
100.00	100					1	49		50	

Water Price $/af	Alfalfa pf	mf	cf	s1	s2	Sugarbeet pf	mf	cf	s1	s2
0.00	61		39				100			
10.00	61		39				100			
20.00	74		26				100			
30.00	90		10				100			
40.00	100						100			
50.00	100						100			
60.00	100						100			
70.00	100						100			
80.00	100						100			
90.00	100						100			
100.00	100						100			

Water Price $/af	Onion pf	mf	cf	s1	s2	Pasture pf	mf	cf	s1	s2
0.00		74	26			100				
10.00		74	26			100				
20.00		74	26			100				
30.00		74	26			100				
40.00		74	26			100				
50.00		74	26			100				
60.00		74	26			100				
70.00		74	26			100				
80.00		74	26			100				
90.00		74	26			100				
100.00		74	26			100				

Table 5.8: Predicted Acreage Allocation to Cropping Activities in Conserved Water Transfer Simulation

Scenario 3:

water price	total	wheat acres	potato acres	alfa. acres	sugar-beet acres	onion acres	pas-ture
0.00	17400	3833	1157	5040	1208	950	5212
10.00	17400	3833	1157	5040	1208	950	5212
20.00	17400	3314	1157	5560	1208	950	5212
30.00	17400	3314	1157	5560	1208	950	5212
40.00	17400	3314	1157	5560	1208	950	5212
50.00	17400	3314	1157	2731	1208	950	8042
60.00	17400	3056	1157	1338	950	950	9950
70.00	17400	3056	1157	1338	950	950	9950
80.00	17400	3056	1157	0	950	950	11288
90.00	17400	3056	1157	0	950	950	11288
100.00	17400	3056	1157	0	950	950	11288

Scenario 4:

water price	total acres	wheat acres	potato acres	alfa. acres	sugar-beet acres	onion acres	pas-ture
0.00	17400	3833	1157	5040	1208	950	5212
10.00	17400	3833	1157	5040	1208	950	5212
20.00	17400	3833	1157	5040	1208	950	5212
30.00	17400	3833	1157	5040	1208	950	5212
40.00	17400	3833	1157	5040	1208	950	5212
50.00	17400	3695	1157	5179	1208	950	5212
60.00	17400	3502	1157	5372	1208	950	5212
70.00	17400	3314	1157	5561	1208	950	5212
80.00	17400	3314	1157	5561	1208	950	5212
90.00	17400	3314	1157	5561	1208	950	5212
100.00	17400	3288	1157	5612	1182	950	5212

Table 5.9 Predicted Yield by Crop in Solution to Conserved Water Trade Simulations

Scenario 3:

water price	wheat bushel	potato cwt	alfa. tons	sugar-beet tons	onion cwt	pas-ture AUM
0.00	98.8	391	5.2	28.6	469	9.1
10.00	98.8	391	5.2	28.6	469	9.1
20.00	98.8	391	5.2	28.6	469	8.3
30.00	98.8	391	5.2	28.6	469	7.3
40.00	99.5	390.7	5.0	28.6	468.9	5.5
50.00	97.7	390.1	5.2	28.4	468.9	5.9
60.00	98.7	389	5.5	29.1	465.2	5.9
70.00	95.9	386.8	5.2	29.1	465.2	5.9
80.00	94.2	386.8	0	29.1	465.2	6.1
90.00	93.9	386.2	0	29.1	465.2	6.1
100.00	89.8	386.2	0	29.1	465.2	5.4

Scenario 4:

water price	wheat bushel	potato cwt	alfa. tons	sugar-beet tons	onion cwt	pas-ture AUM
0.00	98.8	391	5.2	28.6	469	9.1
10.00	98.8	391	5.1	28.6	469	9.1
20.00	98.8	391	5.0	28.6	469	9.1
30.00	98.8	391	4.9	28.6	469	9.1
40.00	98.8	391	4.8	28.6	469	9.1
50.00	98.8	391	4.8	28.6	469	8.6
60.00	100.2	391	4.7	28.6	469	5.5
70.00	100.7	391	4.5	28.6	469	5.5
80.00	100.7	391	4.5	28.6	469	5.5
90.00	100.7	391	3.1	28.6	469	5.5
100.00	100.7	391	3.0	28.6	469	5.5

Table 5.10 Predicted per Acre Water Input Level by Crop in Solution to Conserved Water Trade Simulations

Scenario 3:

water price	wheat ac.ft.	potato ac.ft.	alfa. ac.ft.	sugar-beet ac.ft.	onion ac.ft.	pas-ture ac.ft.
0.00	3.09	4.19	4.08	4.69	5.59	3.96
10.00	3.09	4.19	4.08	4.69	5.59	3.96
20.00	3.09	4.19	4.08	4.69	5.59	3.25
30.00	3.09	4.19	3.98	4.69	5.59	2.71
40.00	2.57	3.66	3.72	4.69	4.67	1.90
50.00	2.36	3.63	3.60	4.63	4.67	1.90
60.00	2.36	3.46	3.49	3.91	4.42	1.90
70.00	2.22	3.54	3.26	3.91	4.42	1.90
80.00	2.08	3.54	-	3.91	4.42	1.90
90.00	2.07	3.44	-	3.91	4.42	1.90
100.00	1.93	3.44	-	3.91	4.42	1.62

Scenario 4:

water price	wheat ac.ft.	potato ac.ft.	alfa. ac.ft.	sugar-beet ac.ft.	onion ac.ft.	pas-ture ac.ft.
0.00	3.09	4.19	4.08	4.69	5.59	3.96
10.00	3.09	4.19	4.08	4.69	5.59	3.96
20.00	3.09	4.19	4.08	4.69	5.59	3.96
30.00	3.09	4.19	4.08	4.69	5.59	3.96
40.00	3.09	4.19	4.08	4.69	5.59	3.96
50.00	3.09	4.19	3.97	4.69	5.59	3.52
60.00	3.07	4.19	3.83	4.69	5.59	1.90
70.00	3.05	4.19	3.70	4.69	5.59	1.90
80.00	3.05	4.19	3.59	4.69	5.59	1.90
90.00	3.05	4.19	2.51	4.69	5.59	1.90
100.00	3.03	4.19	2.40	4.79	5.59	1.90

management to improved furrow management and 4) 75% of onion acreage will utilize cut-back furrow management rather than improved furrow management. These irrigation efficiency input strategies reduce diversions by 3,542 acre feet, allowing water rights holders to supply 2,657 acre feet to the conserved water market.

The remainder of the 11,916 acre feet of water supplied to the water market in scenario 3 are provided through deficit irrigation strategies and changes in crop rotation. Reduced water applications to pasture provide most of these reductions. Specifically, relative to the base case, the average depth of water applied to pasture is reduced by 52%, with a resultant 36% reduction in yield. The corresponding 10,758 acre foot reduction in water diversions allows water rights holders to supply 8068 acre feet to the conserved water market, with the remainder going to instream use.

At water prices in excess of $60 an acre foot, incremental water supplies come almost exclusively from deficit irrigation strategies and crop rotation changes. A large portion of the marginal supply comes from gradual replacement of sugar beets and alfalfa in rotation at prices in excess of $60 an acre-foot. These crops grown at very near base case yield and water application rates are replaced with deficit irrigated pasture.

At prices from $60 to $100 per acre foot, most of the marginal water supply comes from the moderate to small reductions in water applications. These reductions, summarized in table 5.10, range from an average per acre reduction of 0.42 feet of water applied to wheat to an average per acre reduction of 0.11 feet of water applied to potatoes.

Scenario 4 is a simulation of markets for conserved water with restrictions on transfers designed to guarantee the absence of return flow externalities. Specifically, it is assumed that only water conserved through measures which lead to reductions in the level of consumptive water use is eligible for transfer. The restrictive conditions limiting water trade implicit in this scenario result in a rather circumscribed irrigator response, especially at water prices of less than $40 per acre foot. At prices in excess of $40 an acre foot, some adaption of deficit irrigation strategies is predicted. Specifically, as indicated in table 5.9, the dominant response involves reducing the level of water applied to alfalfa and pasture.

5.4 The Impact of Water Trade Rules on Key Economic and Hydrologic Outcomes

The results of the research summarized in this section illustrate the way that rules governing water transfers and the price of water would likely influence the study area. In this section, discussion focusses on the predicted impacts of water price and water trade rules on: 1) water supply, 2) producer profit, 3) the local study area economy, 4) groundwater quality, and 5) the water rights of third party water rights holders.

5.4.1 Water Supply

Figure 5.2 is a family of curves representing study area willingness to supply water. The curves represent the long run supply response to well functioning markets involving permanent transfer of water rights. The values along the Y-axis represent the annual price in dollars associated with leasing an acre foot of water on a long-term basis.

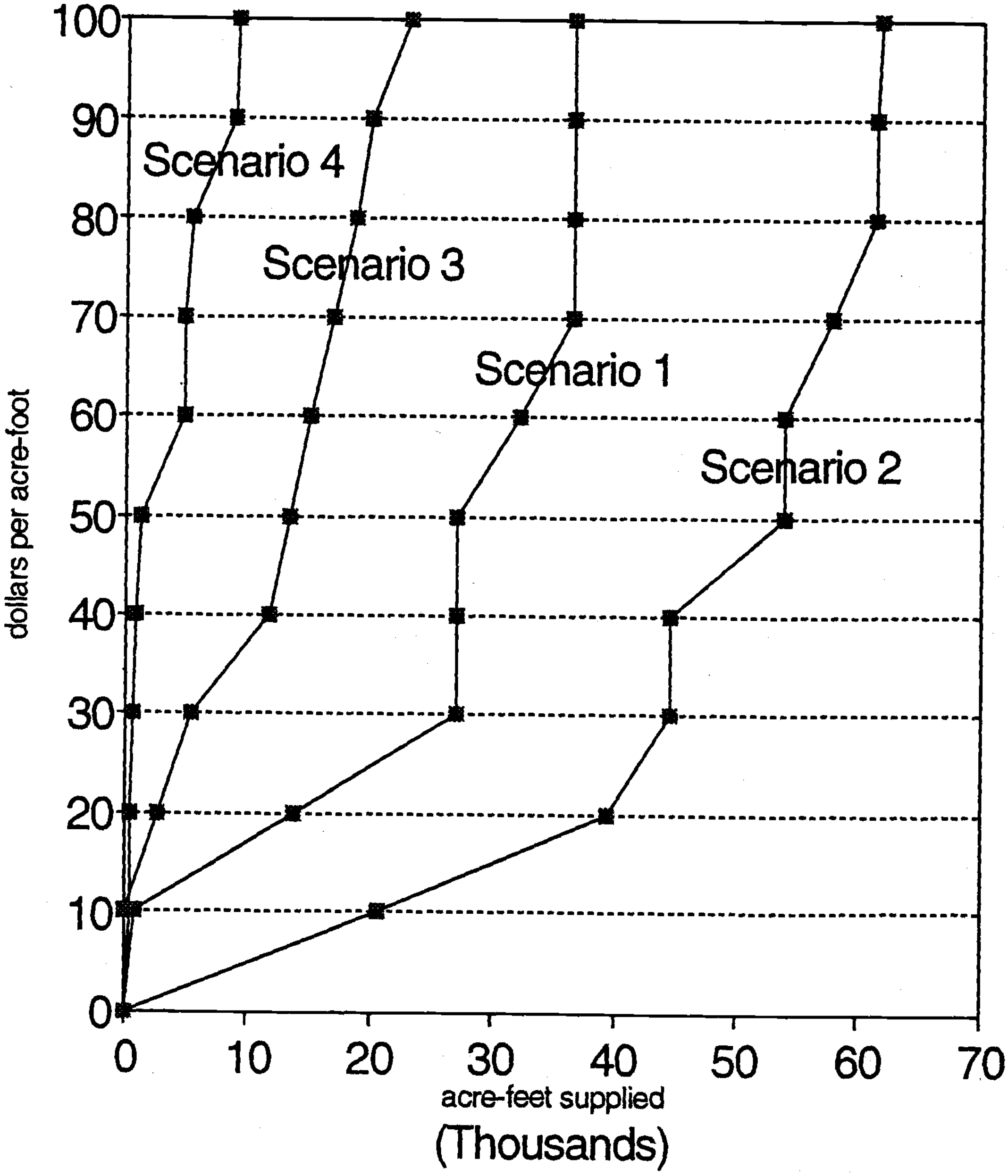
The results show that transfers in place and purpose of water diversion would likely lead to comparatively large water supply responses in the study area. This is clearly evident in figure 5.2 water supply curves for scenarios 1 and 2. Along these curves relatively small water prices induce large water supply responses, especially at the lower end of the modelled price range. For example, at a price of $30 an acre foot, 27,096 acre feet (or 39% of study area base case water endowment) and 44,689 acre feet (or 65% of study area base case water endowment) are supplied in scenarios 1 and 2 respectively. The supply response becomes somewhat more price inelastic at higher prices. For example, tripling price from $30 to $90 per acre- foot increases supply by 35% to 36,639 acre feet and by 37% to 61,371 acre feet in scenarios 1 and 2 respectively.

The results also indicate that restrictive non-impairment provisions are likely to reduce the quantity of water supplied to markets for transfer in place and purpose of water diversion. Recall that scenario 1 simulates transfers in place and purpose of water use with restrictive non-impairment provisions designed to protect water rights holders downstream from negative return flow effects. By contrast, scenario 2 simulates transfer in place and purpose of water diversion without restrictive provisions designed to protect third parties downstream. The result presented in figure 5.2 shows that the restrictive non-impairment rules modelled in scenario 1 effectively shift the water supply curve up and to the left. A smaller quantity of water is supplied in scenario 1 at any price than in scenario 2.

Another key finding of this water supply analysis is that transfers of conserved water would likely induce comparatively small water supply responses, especially at low to moderate water prices. For example, in the markets for conserved water (simulated in scenarios 3 and 4), a price of $30 an acre foot, induces supply responses of 772 acre-feet (or 1% of the study area water endowment) and 4,939 acre feet (7% of study area water endowment) respectively. Supply responses at higher prices are somewhat more price elastic. Tripling the price of conserved water to $90 per acre foot induce 1150% and 444% supply increases in scenarios 3 and 4 to 8,876 acre feet and 21,951 acre feet respectively.

Finally, results presented here suggest that restrictive non-impairment provisions are likely to reduce the quantity of conserved water offered for sale at any

Figure 5.2: Predicted Water Supply Response to Simulated Water Markets



given price. This can be seen in figure 5.2 where the water supply curve for scenario 4 (with its restrictive definition of tradeable conserved water) lies below the water supply curve for scenario 3 (with it less restrictive non-impairment conditions) at all modelled prices.

5.4.2 The Profitability of Water Market Participation

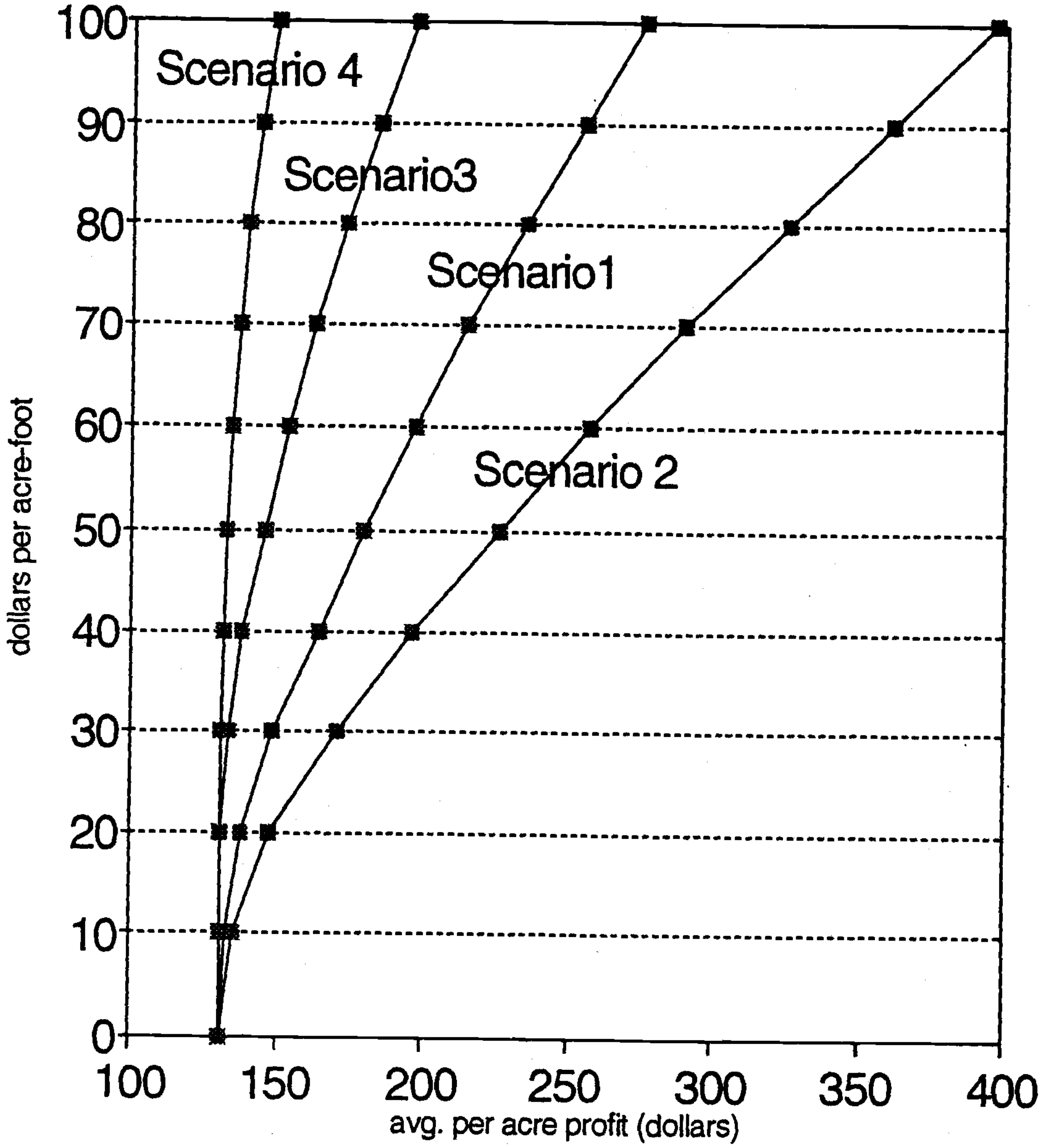
Figure 5.3 contains a family of profit curves. The values along the X-axis represent estimated annual per acre returns to land and water that would accrue to water rights holders in the study area. The estimated profits result from using water rights in irrigated crop production and (or) market water transfers.

These results suggest that water rights holders would likely profit from selling water in place and purpose of water diversion markets. Estimated profits from participation in such markets are significant, even at low to moderate water prices. Specifically, in scenarios 1 and 2 at a water price of $40 an acre-foot, water rights holders realize average per acre profits of $164.53 (125% of base case profit) and $196.62 (150% of base case profit) respectively. At the high end of the modelled price range, estimated profits become even larger. At a water price of $80 an acre-foot, water rights holders realize average per acre profits of $235.53 (180% of base profits) and $325.71 (249% of base profit) respectively.

The results also show that non-impairment provisions in markets for place and purpose of water rights transfer can effect profit. Specifically, more restrictive non-impairment conditions imposed on water trade in scenario 1 reduce profits relative to scenario 2 (with its less restrictive conditions). Again, this is evident in figure 5.3 where the profit curve for scenario 1 lies below the profit curve for scenario 2 at all modelled prices.

Finally, the profit estimates presented here suggest that returns to participation in conserved water markets in the study area are likely to be very marginal at the lower end of the range of modelled prices. This finding holds regardless of assumptions regarding non-impairment conditions. For example, at a price of $40 an acre foot, the estimated profit levels of 140.40 per acre in scenario 3

Figure 5.3: The Estimated Profitability of Water Market Participation



and 131.90 in scenario 2 exceed base case profits of 130.76 by only 7% and 1% respectively. Estimated scenario 4 profits remain low even at higher water prices. For example at a price of $80 an acre foot, average per acre profits of $139.86 accruing to water rights holders exceed the base case profits by less than 7%.

5.4.3 Local Economy

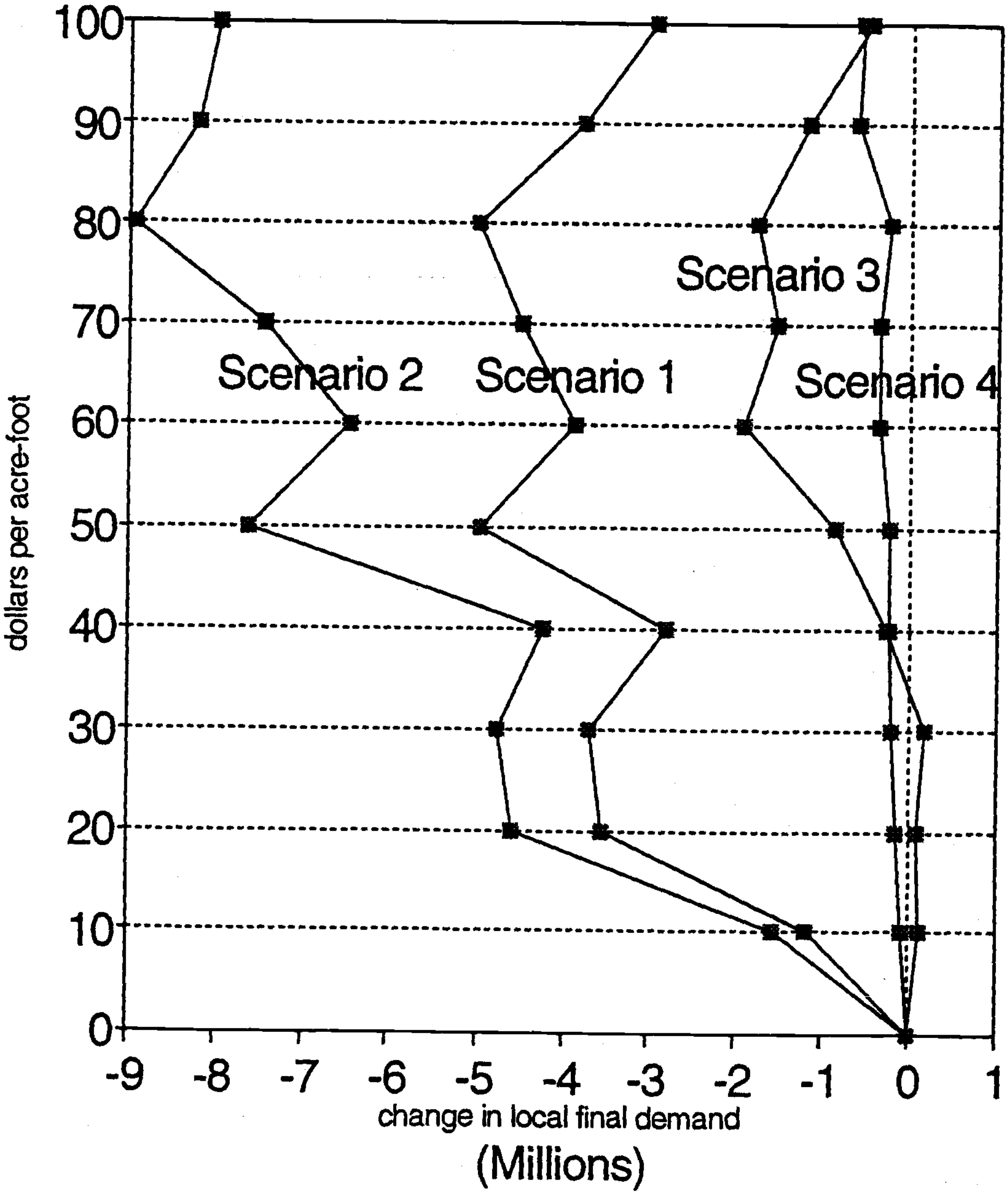
Figure 5.4 contains a summary of the estimated local economic impact of the water market scenarios modelled for this research. These estimates characterize the short-run economic impact that water markets would have on the study area economy. The estimates include first round effects of changes in the incomes of households selling water rights and changes in gross revenues in the crop production sector of the local economy. The estimates also include indirect and induced economic impacts.

The estimates are based on the assumption that labor and capital assets which become unemployed as the result of water sales do not become re-employed within the county. If area irrigators selling water are able to use their human capital to generate income in the county without displacing others from their jobs, result of this analysis will represent an overstatement of local economic impact. It should also be noted that in the long-run from a state or national perspective, increased water trade is likely to bring net economic benefits. This is because water markets are likely to reallocate water to higher value uses, increasing the sum of consumer plus producer surplus. These long-run state/national effects are not estimated here.

One significant finding of the local economic impact analysis is that transfers in place and purpose of water diversion would likely have adverse secondary economic effects on the study area economy. This can be seen in figure 5.4, where estimated direct, indirect and induced economic impacts are significant and negative in the place and purpose of water diversion scenarios (1 and 2).

These negative economic impacts are particularly large at the moderate to high end of the modelled price range. For instance, a water market price of $50 an acre foot induces short-run local economic losses of $5.0 and $8.9 million dollars in scenarios 1 and 2 respectively.

Figure 5.4: Estimated Short-run Local Economic Impact of Water Trade



These estimated effects represent a 22% and 39% reduction in the total direct and induced economic benefits of crop production in the study area compared to the base case.

The overall negative local economic impacts arise primarily because returns to land and water resources used in irrigated crop production represent a small fraction of output value (about 20% on average across the study area in the base case analysis). Consequently, estimated increases in household income resulting from water market sales tend to be small compared to estimated reductions in the value of crop output.

Another significant finding of the research is that sales of conserved water would not likely create large adverse impacts on the study area economy. For example, at a water market price of $50 an acre foot, estimated short-run direct, indirect and induced economic losses in the local economy are $0.9 and 0.2 million dollars in scenarios 3 and 4 respectively. These estimates represent 4% and 1% reductions in base case direct, indirect and induced economic benefits of crop production in the study area.

Finally, it is notable that in the scenario modelling conserved water trade with non-restrictive non-impairment provisions (scenario 3) estimated secondary economic effects are positive (though small) at some prices. For example, at a water price of $40 an acre foot the economic benefits to the study area exceed estimated base case scenario benefits by 0.4 million dollars (2%).

These relatively small negative to small positive estimates of net local economic impact arise because the rules of conserved water transfer as modelled here require water savings offered for sale be achieved without retiring land. As discussed in section 5.3, the predicted farm-level response to conserved water market incentives involves substitution of capital and labor for water, as well as deficit irrigation strategies and crop rotation changes. While crop rotation changes and deficit irrigation strategies lead to some reduction in the value of crop output, these effects are small and are substantially offset by increases in income accruing to households selling water.

5.4.4 Groundwater Quality

One of the central purposes of this dissertation is to investigate the potential of water trade as a policy to improve groundwater quality in the Treasure Valley area. The methodology used to predict groundwater quality outcomes is described in chapter 4. One feature of this methodology which distinguishes this research from most previous economic assessments of agricultural non-point source pollution is inclusion of an explicit model simulating the process of nitrate spreading and dilution in groundwater. Inclusion of this process model is useful because it allows assessment of how economic policies influence nitrate concentrations. Pollutant concentrations (rather than loading rates) are typically the focus of environmental policy.

Another advantage of predicting concentrations rather that loading rates is the opportunity for validation. State and federal environmental quality agencies often monitor and publish concentrations in a network of monitoring wells. In contrast, observations of nitrate loading rates are typically unavailable. This research includes a comparison of predicted nitrate concentrations in study area groundwater with observed conservations (see section 5.2.2). The results of this comparison summarized in Table 5.5 suggest that the combined economic optimization - nitrate loading - groundwater base case model estimated average groundwater nitrate concentration quite well. However, the model appeared to significantly under estimate the spatial variance in nitrate concentration. Results of the initial assessment of groundwater quality impacts of water trade appeared to be significantly influenced by this underestimated variance. Thus, results of two models are reported here. The first is the original or "uncalibrated" model. The second is a "calibrated" model designed to test the hypothesis that the under-estimation of spatial variance in nitrate concentration inherent in the original model leads to biased estimates of the rate of compliance with groundwater quality standards.

Figure 5.5 portrays rates of compliance with the EPA nitrate groundwater standard of 10 ppm nitrate-N estimated with the "uncalibrated" model. The numbers along the Y-axis represent the estimated percentage of the studied aquifer area with concentration of nitrate less than or equal to 10ppm. The X-axis represents the price per acre-foot of water.

The curves in figure 5.6 portray rates of compliance with the groundwater quality standards estimated with the "calibrated" model. The procedure used to compute each "calibrated" compliance rate curve involved five steps:

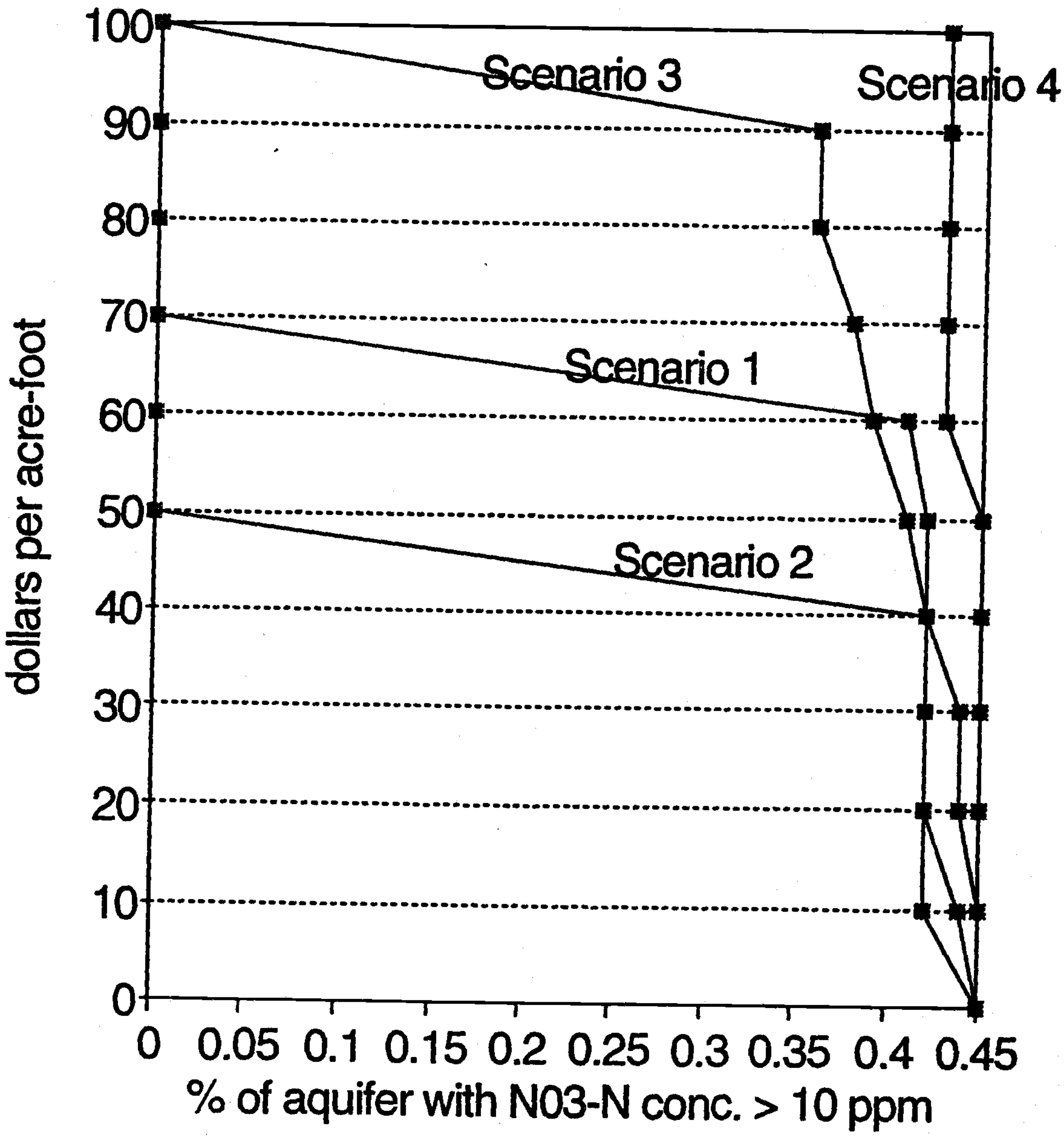
1) Generating three vectors each containing 100 normally distributed random numbers, one vector for each zone used in results reporting (see figure 5.1 for a description of zones). The mean value used to generate each vector was zero and the standard deviation used corresponds to the standard deviation of concentration of samples reported by the Oregon Department of Environmental Quality for water taken from monitoring wells in each zone (these values are reported in Table 5.5).

2) Developing calibrated zonal concentration vectors by adding the mean zonal concentration estimated with the uncalibrated model to each element of the standard normal random number vector developed for that zone.

3) Calculating the calibrated zonal compliance rate for each zone by computing the percentage of observations in the calibrated zonal concentration vector with a concentration value in excess of 10 ppm.

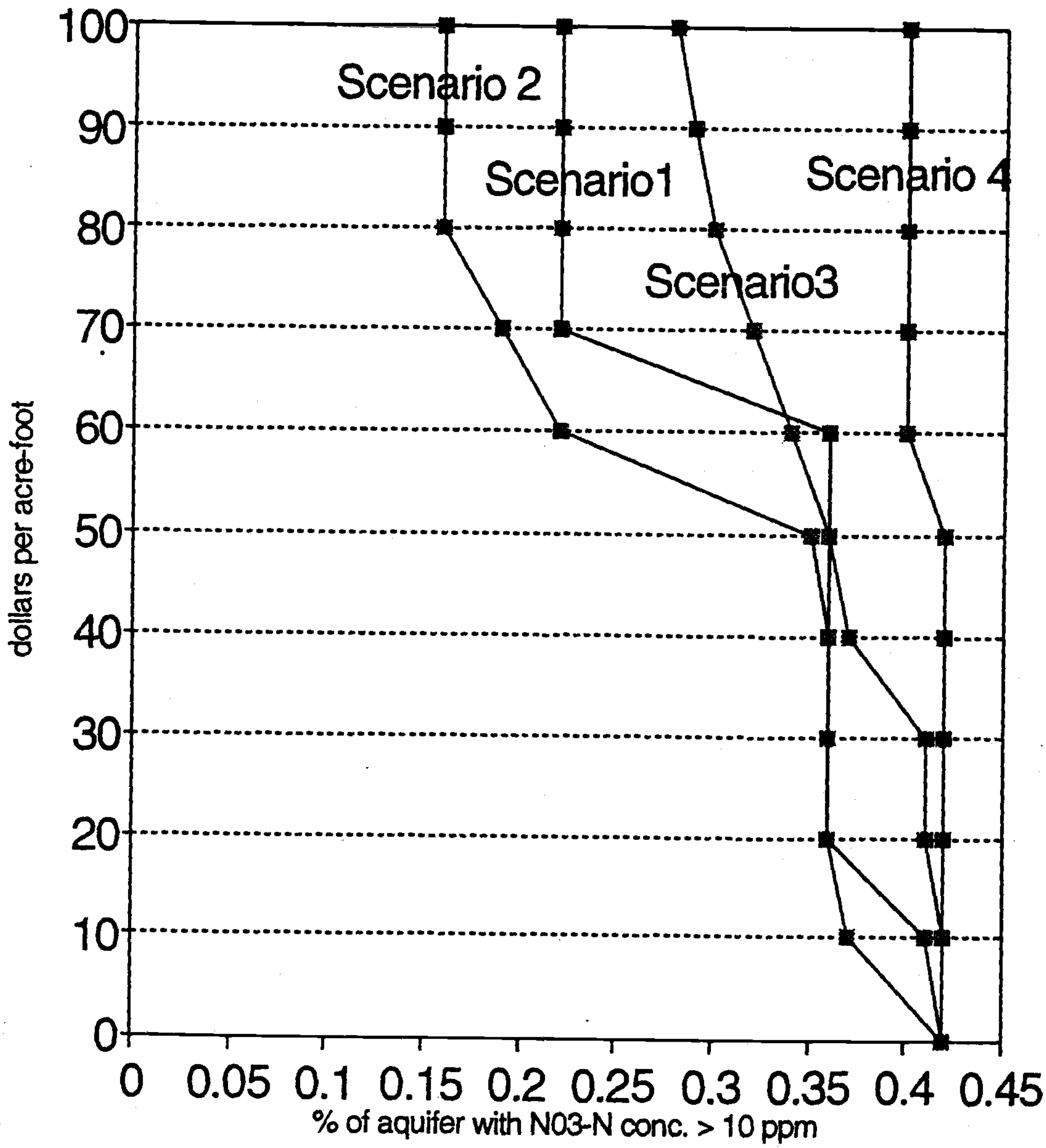
4) Calculating the calibrated aquifer compliance rate as the zonal area weighted average calibrated zonal compliance rates.

Figure 5.5: Rates of Compliance with EPA 10ppm Groundwater Nitrate Water Quality Standard Estimated with "Uncalibrated" Groundwater Model



One significant finding of the groundwater quality analysis is that there appears to be threshold prices in markets for transfer in place and purpose of water rights use. Small changes which result in a price just greater than the threshold price cause large increases in the rate

Figure 5.6: Rates of Compliance with EPA 10ppm Groundwater Nitrate Water Quality Standard Estimates with "Calibrated" Groundwater Model



of compliance with groundwater quality standards. For example, "uncalibrated" model results suggest that in scenario 2 moving from a water price of $40 to a price of $50 would increase the groundwater quality standard

compliance rate from 58% to 100%. In scenario 1, moving from a water price of $60 to a price of $70 would increase the groundwater quality standard compliance rate from 59% to 100%. Below the threshold prices, even large changes in price have little influence on the estimated rate of compliance with EPA standards.
For example, in scenario 2 an increase in water price from $0 to $40 an acre foot results in a mere 7% increase in the rate of groundwater quality standard compliance. In scenario 1 an increase in water price from $0 to $60 an acre foot results in only a 9% increase in the rate of groundwater quality standard compliance.

Threshold price effects are also evident in "calibrated" model results, though to a lesser extent. For example, in scenario 2 a water price increase from $50 to $60 an acre foot causes a 37% increase in the rate of groundwater quality standard compliance. In scenario 1 a water price increase from $60 to $70 an acre foot causes a 39% increase in the rate of groundwater quality standard compliance. In contrast, in scenario 2 a water price increase from $0 to $50 an acre foot causes a 17% increase in the rate of groundwater quality standard compliance. In scenario 1 a water price increase from $0 to $60 an acre foot causes a 14% increase in the rate of groundwater quality standard compliance.

Part of the threshold effect is the result of zonal differences in the economics of nitrogen input use and the opportunity cost of water use. The results discussed in section 5.3 suggest that, at prices below the threshold level, acreage is taken out of production to sell attached water rights primarily in zones 2 and 3, zones where the opportunity cost of water is low. Crops grown in these zones, primarily grain, hay and pasture are produced with relatively low nitrogen input levels. Reduced cropping in these areas does not effect water quality standard compliance greatly because it leads primarily to reduced nitrate concentrations in areas of the aquifer with concentration already below the 10 ppm threshold level.

Comparison of calibrated and uncalibrated place and purpose of water use transfer simulation results suggests that a residual component of the threshold effects are a result of model specification. Specifically, the 100% compliance with the water quality standard in the uncalibrated model at prices above the threshold prices appears to result from under-specification of nitrate concentration variance. In the uncalibrated model, concentrations remain above the standard in at least a small part of the aquifer, even at very high prices.

Another significant finding of the research is the prediction that markets for conserved water are less likely to increase compliance with groundwater quality standards than markets for transfers in place and purpose of water use. Markets for conserved water with restrictive non-impairment conditions of the sort modelled in scenario 4 are particularly unlikely to improve groundwater quality. Both uncalibrated and calibrated model results predict negligible changes in groundwater quality standard compliance at water prices of less than $60 an acre foot. Even the highest modelled water price of $100 an acre foot, results in an uncalibrated (calibrated) model estimated 4%(5%) increase in groundwater quality standard compliance.

Predicted improvements in groundwater quality are minimal in scenario 4 because the restrictive non-impairment provisions implicit in this scenario limit the range of practices irrigators may adapt to conserve water for marketing. This scenario allows only sale of reductions in consumptive use achieved without reducing irrigated acreage. The model developed for this research provides two strategies to irrigators wishing to supply water to such markets: 1) adapting deficit irrigation strategies and accept the associated yield reductions, and 2) substituting low water requirement crops for high water requirement crops. Both options induce little response as they are associated with high opportunity costs.

Finally, results of this analysis suggest that markets for conserved water that do not require any provision to protect third party water rights could induce small to moderate increases in the rate of compliance with groundwater quality standards. Such a market is simulated in scenario 3. Results show that a water price of $40 an acre foot causes a 12% increase in the rate of groundwater quality standard compliance estimated with the calibrated groundwater model relative to the base case. A $90 an acre foot prices causes a 31% increase in the rate of compliance estimated with the calibrated model.

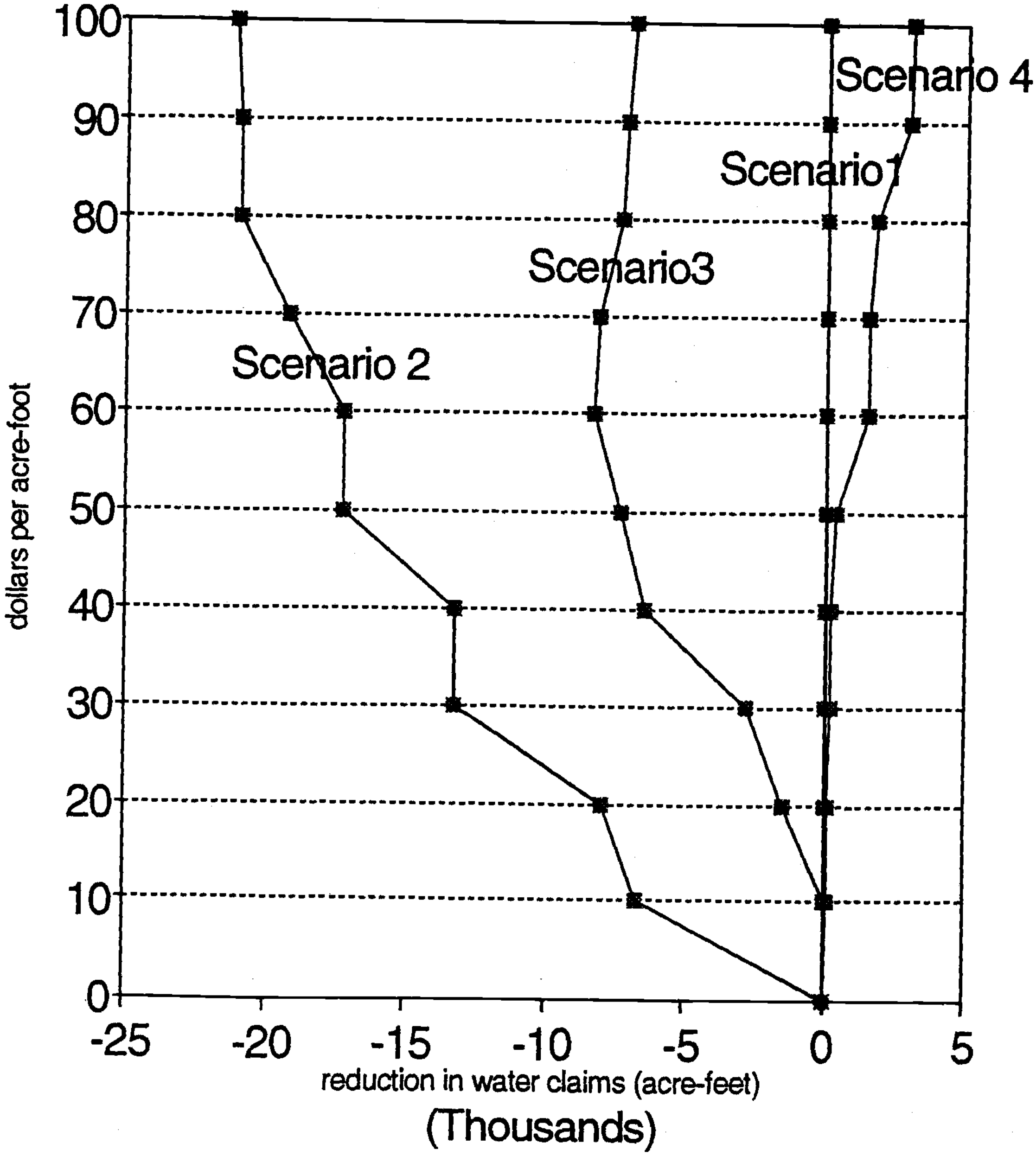
5.4.5 Third Party Water Rights

Figure 5.7 is a family of curves representing the estimated changes in the annual volume of water rights available down stream from the study area. The predictions represent upper bound estimates of the return flow externalities resulting from the water market scenarios modelled here.

The results suggest that failure to impose restrictive non-impairment provisions on water market transactions may lead to negative return flow externalities. The estimated negative return flow effects of transfers in place and purpose of water diversion without explicit non-impairment provisions (scenario 1) are particularly significant. For example, the estimated annual reductions in the volume of river flow available to down stream water rights holders exceeds 13,000 acre feet for prices in excess of $30 an acre foot in scenario 1.

Results also imply that failure to impose non-impairment provisions on sales of conserved water may induce significant negative return flow externalities.

Figure 5.7: Estimated Return Flow Externality Level Resulting from Water Trade



The estimated negative return flow effects of trade in conserved water without explicit non-impairment provisions (scenario 3) are considerable. For example, the estimated annual reductions in the volume of river flow available to down stream water rights holders exceeds 6,000 acre feet for prices in excess of $40 an acre foot in scenario 3.

CHAPTER 6: SUMMARY AND CONCLUSIONS

6.1 Chapter Overview

This chapter draws the findings of this study together with the objectives of:

1) assessing the likelihood of increased water trade in the Treasure Valley of Eastern Oregon,

2) assessing the feasibility of water trade policies as an approach to mitigation of water quality problems both in general and in the Treasure Valley specifically,

3) discussing study limitations, and

4) making suggests for further research.

6.2 The Likelihood of Increased Water Trade in the Treasure Valley

The likelihood of increased participation in water markets by Treasure Valley area irrigators depends on forces outside the area, as well as local willingness to supply water. This section begins with a discussion of water market conditions in the Snake and Columbia River Basins. The discussion serves as background for the discussion of the estimated water supply response to regional water market conditions. In addition the potential influence of third party local economic and return flow impacts on the political/legal feasibility of water trade is discussed.

6.2.1 Forces Influencing Regional Water Market Prices

The Treasure Valley is just one of many watersheds in the Snake-Columbia River Basin. Thus, potential water supply from the region represents only a small portion of all water potentially available to a regional market. If a market for water were to become well developed in the region, the Treasure Valley would face an exogenously determined water price dictated by regional forces of water supply and demand. Water market transactions in the region are still too few to warrant accurate prediction of what an eventual market equilibrium price would be. Nonetheless, the limited available data describing water trades in the area does give some feeling for where water prices in the region seem to be heading.

Two large government organizations, the Bureau of Reclamation and the Bonneville Power Administration, are potentially significant water buyers in the regional water market. The Bureau of Reclamation is presently charged with the mission of acquiring 427,000 acre feet of water to augment flows in the upper Snake River for the benefit of endangered salmon stocks (Associated Press). As of August, 1995 the Bureau had made two purchases of rights to stored water in reservoirs in the upper reaches of the Snake River from Idaho irrigation districts. Specifically, the Bureau acquired 6,500 acre feet from the Salmon River Canal Company last year and 15,800 acre feet from the Canyon View Irrigation Company this year. The price per acre foot associated with these permanent transfers were $154 and $138.50. As a point of comparison, a $150 one time payment is equal to a series of $13.22 amortized annual payment assuming an interest rate of 8% and a time horizon of 30 years[1].

The Bonneville Power Administration (BPA) is another potential buyer of large volumes of water in the region. A market for water transfers represents a potential source of hydropower generation capacity to the agency. Participation

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[1] the equivalent payment, AP of a one time payment, OTP is computed as $AP = OTP\ (i(1+i)^t/(1+i)^t-1)$, where i is the assumed discount rate and t the assumed time horizon in years.

in such a market would be attractive to the agency if the cost of acquiring marginal power generation capacity through water purchases were less than the wholesale cost of power from other sources. Presently, the BPA values wholesale "firm supply" water at between 14 and 25 mils per KWH. The Agency values water which can only generate surplus power at 6 to 11 mils per KWH (Daley). These prices and the energy potential of water above Brownlee Dam near Wiesser, ID estimated by Houston and Whittlesey can be used to estimate BPA willingness to pay for water. Specifically, using this information results in an estimate of BPA maximum willingness to pay for an acre foot of reduced consumptive use in the Treasure Valley of between $15.85 and $28.33 an acre foot if the water can be used as a "firm supply". If the water can only be used to generate surplus power the estimated maximum willingness to pay is $6.21 to $11.36 for an acre-foot of consumptive use reduction.

The BPA leased 16,000 acre feet of water on an annual basis from a large farm just north of Ontario in the 1994-95 irrigation season and plans to lease the water again in the 1995-1996 season (Daley). The Agency paid a lease fee of $112,000 which is the equivalent of approximately $7 an acre foot of diversionary water rights or $10.75 per acre-foot of consumptive use.

Other data characterizing regional water price include: 1) the average $344 an acre- foot price of water in three small water transfers (200 acre feet or less) in the Hermiston area reported by Landry, 2) the $250 an acre foot mitigation fee paid for the right to divert 5.5 cubic feet per second of water from the Columbia River by US Generation Corporation (Landry) and 3) the $33 per acre-foot per year paid by the Oregon Water Trust to an irrigator for not diverting 200 acre feet of water from a tributary to the lower Deschutes River (Landry).

These few observations are only rough indicators of the water price that Treasure Valley irrigators would be likely to face if regional water markets became well established. Still, it seems reasonable to draw a preliminary conclusions about the prices that Treasure Valley irrigators are likely to face. The available evidence seems to suggest that:

1) Water markets in the area are presently dominated by a few large buyers.

2) These buyers appear to be pursuing a monopsonistic strategy of seeking out the lowest cost sources of supply first

3) It seems unlikely that regional water prices are likely to rise much above $20 to $30 per acre foot in the near future. They may be less (closer to $10 an acre foot).

6.2.2 Study Area Water Supply

The willingness of study area irrigators to supply a regional water market depends on the opportunity cost of continuing to use water in irrigated crop production. The results of this research suggest that the opportunity cost of participating in water markets is sensitive to rules defining how water can be traded. Significant conclusions that can be drawn from the study area water supply response predictions include:

1) In large portions of the study area, the annual returns to selling water rights attached to land would exceed the returns to continued irrigated crop production, even at very moderate water prices ($20 an acre foot). The water supplied at low water prices is predicted to come primarily from land best suited to grain, hay and pasture production. The most productive row crop land in the study area is not predicted to supply much water at prices below $50 an acre-foot. A free market for transfer in place and purpose of water rights would result in considerable supply response from the study area.

2) Two forms of water transfer markets are common in the west. One involves selling the entire right to divert water. The other involves selling only a portion of the right to divert water, the portion of diversion which has historically been used consumptively. A market for consumptive use represents a realistic simulation of water markets in which non-impairment provisions protecting third party water rights holders are strictly enforced. The results of the study shows that area irrigators would supply considerably less water to a market for consumptive use water rights than to a market for the right to divert.

3) Oregon has developed a progressive new law allowing sale of conserved water. However, results of this study suggest that the Treasure Valley is unlikely to experience much trade in conserved water. This conclusion follows from simulation results showing that the opportunity cost of participation in such markets is high, especially if water trade is subject to strict non-impairment provisions. Study estimates indicate that negligible amounts of water would be supplied to such markets at water prices of less than $50 an acre foot. Although the results predict a modest supply response at water prices of $50 to $100 an acre foot, estimated profits of farmers participating in such markets barely exceed the estimated base case profit. This finding suggests that predictions of water supply in this price range are not particularly robust.

4) If no special consideration of negative return flow impacts of water trade on downstream water rights holders were required, a market for conserved water could induce a moderate supply response in the area at water prices greater than $40 an acre-foot.

6.3 Potential Impacts of Water Trade on Down Stream Water Right and the Local Economy

A central premises underlying this research is that the feasibility of a water market policy is not dictated by the interests of direct parties to water trade alone. Third parties are also likely to influence the likelihood that a given water allocation policy will be adapted or a given water transfer proposal approved. Third parties influence water allocation because water rights are usufractuary rights. Water rights holders do not possess ownership of the "corpus of the water" rather they possess rights to a certain set of services the water provides. The right to the "corpus" of the water belongs to the state and the state is required to make water allocation decisions which serve individual as well as public interests. Two potentially important third party effects of water trade were examined in this research: 1) the potential of water trade to reduce the availability of water to downstream water rights holders and 2) potential negative impacts of water trade on the local economy.

6.3.1 Return Flow Externalities

Third party water right holders have long established rights to protection against water reallocations which potentially reduce their water allotment. The results of this study show that strict rules designed to guarantee protection of third party water rights holders would reduce the profitability of water market participation and reduce the quantity of water the study area would be willing to supply at any given water price. This supply shift cannot be viewed as a pure efficiency loss. The cost of non-impairment conditions is rather the cost of protecting existing property rights.

Actual return flow externalities depend on conditions specific to individual trades including source and destination of water to be transferred and degree of allocation in the basin where trade takes place. This study includes upper-bound estimates of the magnitude of return flow effects resulting from water trades in the absence of non-impairment provisions. Both in the case of transfer of place and purpose of water diversion and in the case of conserved water trade, the upper-bound estimates of third party water rights denied represent one-third to one-half of the volume of water traded. Actual claims denied probably would be less as water in the basin is not likely to be fully allocated in high flow years.

It is possible that an alternative to the present treatment of non-impairment provisions could increase the volume of trade and still protect third party water rights holders. Specifically, an alternative involving negotiated mitigation payments between trading parties and third parties exposed to return flow externalities might warrant serious exploration if the region were intent on increasing water trade volume.

6.3.2 Local Economic Impact

Sales of water from the study area can impact the local economy in two ways. First, households selling water rights experience increased income in the form of return to water sales and resulting induced economic effects. Second, sale of water can lead to decreases in the value of agricultural output and induced economic effects. Communities such as the Treasure Valley can and do exercise influence over the probability of water transfers through local ordinances and court challenges to water trade which they believe will negatively impact the local economy.

Three central conclusions can be drawn from the results of the local economic impact analysis conducted for this study:

1) When water markets are supplied by retiring local farm land from irrigated crop production, the negative economic impact of reduced agricultural revenues and consequent secondary economic effects are likely to outweigh positive household income effects . The negative impacts occur because returns to irrigated production represent only a small portion of the value of output. The minimum water price sufficient to bid water away from irrigated production in the study area is much less than the consequent reduction in value of output.

2) The local economic impact of conserved water trade, in contrast, is estimated to be minimal. This is so for two reasons. First, markets for conserved water are predicted to induce relatively small water supply responses. Second, supplying water to such markets does not involve taking land out of irrigated crop production. It does involve deficit irrigation strategies and crops substitutions which result in reduced value of crop output. However, the reduced value of output per acre foot of water supplied in conserved water markets is relatively small.

3) At current water prices, a well established water market in the Treasure Valley would be likely to have relatively little impact on the area economy. Current low water prices are likely to induce supply response primarily from parts of the watershed used to produce low value grain, hay and pasture crops.

6.4 Water Trade as a Water Quality Policy

6.4.1 Theoretical Analysis

This research includes a conceptual, comparative static analysis of the potential impact of water trade on water quality. The analysis represents an extension of existing theoretical water market models. Specifically, it includes a more realistic treatment of pollutant dilution and spreading than has been incorporated into previous water market models. The framework is a useful tool for drawing conclusions regarding the influence of water markets on water quality.

One conclusion drawn using the framework is that water markets may generate negative water quality externalities under some circumstances. This conclusion is significant because existing water market simulation studies identify only positive water quality externalities, yet negative water quality externalities have been observed to result from actual water market transactions in some instances. The potential for both positive and negative water quality externalities can be explained using the theoretical framework developed for this research as follows. When water market incentives result in sales of water from an area with existing or potential water quality problems, area water bodies are affected in two ways. First, to the extent that reallocated water had been carrying polluted effluent into the water body, reallocation of water will lead to reduced loading and improved water quality. Second, to the extent that reallocated water had been introducing a flow of comparatively clean water into the water body, reallocation will lead to decreased dilution and degeneration of water quality. The result suggests the need for careful screening of potential hydrologic outcomes before recommending policies which encourage market water transfers.

6.4.2 Water Quality Simulation Results

One of the central objectives of this research was to explore the potential of policies encouraging increased water trade to improve Treasure Valley groundwater quality. The portion of the Treasure Valley studied in this research lies within the region designated as a critical groundwater quality area by the Oregon Department of Environmental Quality. Concentrations of Nitrate in many monitoring wells in this area exceed the EPA groundwater quality standard of 10 ppm Nitrate-N.

At the outset of this research it was hypothesized that policies encouraging increased water trade would likely have the desirable side effect of reducing area groundwater nitrate concentrations. Using water trade to achieve improved groundwater quality is a potentially attractive option. Participation in water markets leads to increased irrigator profits. In contrast, command and control policies, externality tax or input tax policies impose significant costs on irrigators. Furthermore, because irrigators have an incentive to participate in water markets voluntarily, the cost of administering water trade policies are likely to be less than the costs of administering command and control or tax policies.

The hypothesis that water trade would significantly improve area groundwater was tested using an interconnected set of computer algorithms. The algorithms model water and nitrogen input choices and crop output choices in response to water market incentives, the resultant rate of aquifer nitrate loading, as well as the spreading of nitrate in area groundwater. Several significant conclusions can be drawn from this analysis.

Specifically:

1) A well developed water market in the area would not likely lead to full compliance with EPA groundwater quality standards. The explanation for this conclusion is that at

current water prices (less than $20 an acre foot), the parts of the study area most likely to supply water to markets are areas used for extensive cultivation of hay, pasture and grain which contribute little to the loading of the underlying aquifer with nitrates.

2) Higher water prices are likely to lower average concentrations of nitrate significantly. The study area soils used to grow intensive row crops are the largest contributors to nitrate loading in the area. The results of this research suggest that significant retirement of acreage from irrigated production and water conservation is likely on these soils in response to water prices of $50 an acre foot or more. In three of the four scenarios modelled, water prices in the $50 to $100 per acre foot price range resulted in estimated average aquifer nitrate concentration of less than 10 ppm in the area directly below the intensively cropped soils.

3) Full compliance with the EPA groundwater quality standards is unlikely even at very high water prices. While increasing water prices would likely cause an asymptotic movement toward full compliance, pockets of high nitrate concentration are likely to persist. This outcome seems probable because the spatial distribution of nitrate concentrations in the aquifer has a large variance. While the causes of the large observed variance are not completely understood, it seems likely that they are the combined effect of several factors including: (a) variations in farm manager skill, attitudes and capital assets which influence nitrogen and water input decisions, (b) variation in conditions across fields such as slope and drainage conditions which influence leaching rate directly or by their influence on crop management, and (c) small scale variation in the aquifer materials influencing the pattern of nitrate spreading.

The initial model specification used in this research significantly underestimated the variance in nitrate concentrations in area groundwater. A sensitivity analysis was performed to explore the influence of high variance in nitrate loading and dispersion rates on study area groundwater. Results of the sensitivity analysis show that even at the highest modelled price of $100 an acre foot, predicted nitrate concentrations in excess of the EPA standard persist in 14% to 40% of the aquifer area depending on scenario assumptions. In the original, "small variance", model a zero non-compliance rate was reached in 3 out of 4 modelling scenarios.

6.5 Policy Recommendations

1) Although the volume of trade in a market for water is strongly influenced by willingness of water rights holders to supply water and the willingness of interested parties to buy water, there are actions which can be taken at the state and local level to influence the volume of water trade. Assuming that a region (such as the Treasure Valley) wanted to actively market water, they could take several actions aimed at decreasing the cost of searching out trading partners, negotiating price, and enhancing the value of local water in exchange. Specifically:

- Irrigation districts in the area can continue their efforts to clearly define their water rights through the adjudication process. Also, irrigation districts can work to clarify the obligations of an individual selling his/her water right to meet federal water project debt obligations. As in other real estate markets, uncertainty about property right title or uncertainty regarding future liability decreases the value of the asset in trade.
- Irrigation districts or other local institutions could develop a central bid posting system, to reduce the cost of searching out willing buyers and sellers.

In Colorado and other parts of Oregon irrigation district offices often provide bid posting as a service to irrigation district members.

At the state and federal level actions to enhance the functioning of water markets can also be taken including:
- A central data-base to record water market transactions including a record of the quantity of water transferred, the price paid, location, attributes of the water right traded and so forth. This information would provide guidance to water rights holders attempting to price their water.
- The Bureau of Reclamation and the state Water Resource Department could take actions to clarify ownership of water rights and the conditions of transfer, including non-impairment conditions and debt repayment obligations.

2) Even when water market incentives induce water quality improvements, water markets alone are not likely to be the full solution to a large number of water quality problems. In the case of the Treasure Valley, two factors limit the potential of such policies. The first is that the relatively low water prices prevailing in regional markets at the present are likely to induce supply only from the most marginal irrigated land in the area. Second, although water markets offer some incentive to reduce the use of one input which contributes to the nitrate leaching, they do not specifically target irrigators, fields, crops, fertilizer management practices or aquifer areas which contribute significantly to nitrate leaching. The incentives that water markets do create can be enhanced by efforts to focus on links between the potential to participate profitably in water markets and simultaneously reduce nitrate leaching. The Treasure Valley has a skilled pool of agricultural experts who can contribute significantly to such efforts including personal of the Extension Service, the Natural Resource Conservation Service, irrigation districts, agricultural consultants and individual farm operators.

6.6 Study Limitation

6.6.1 Limitations of the Economic Analysis

1) In this study it is assumed that the prices of crops are not related to the study area water market supply response. If the water price prevailing in the Treasure Valley also prevailed in the rest of the region, significant changes in crop supply could result from water market trade. Under these circumstances, a price endogenous agricultural sectoral model would be a more appropriate modelling methodology.

2) This study is comparative static, meaning that it compares two snap shots in time. The first is a period when water trade does not take place and the second is a time period when water markets have been successfully functioning for several years. The economic and water quality adjustments which take place in the time elapsed between these two intervals is not explored in this research.

3) In this study markets for the permanent transfer of water rights are considered. Although many water market transactions are permanent transfers, temporary leases of water (usually on an annual basis) are also popular. The results of this research do not generalize to the case of annual water rights leases because the economics of leasing for one year is different than the economics of permanent water rights transfer. In general, a profit maximizing irrigator will only be willing to lease water rights for a year if the lease payment exceeds the return to producing crops with the water less the variable costs of production and costs of maintaining overhead necessary to produce crops in future years. In the case of permanent transfer, capital assets can be fully depreciated or sold. Thus participation in such markets pays when the payment for water exceeds the marginal revenue to the water in crop production less the

variable cost of production. The estimates presented here would overstate water supply, irrigator profit, local economic impact, groundwater quality impacts and third party water right holder effects of annual water lease markets.

4) The transactions cost of completing a water transfer can be considerable. They include the costs of searching out trading partners, negotiating price, hiring necessary engineering and legal services. These water market transaction costs tend to drive a wedge between the price at which water rights holders are willing to sell water and the price which water buyers are willing to pay for water. Transactions cost were assumed to be zero in this study. Consequently, the supply estimates presented here are likely to be overstated.

5) The local economic impact analysis included in this study is based on several key assumptions which influence the appropriate interpretation of results. Specifically, the model provides a reasonable estimate of local economic impact in the short-run for relatively small volumes of water trade, when all demand for water comes from outside the study area.

6.6.2 Limitations of the Hydrologic-Agronomic Analysis

This research included a pollution process model used to quantify the spatial distribution of nitrate loading in the study area groundwater, as well as the spread of nitrates with groundwater flow. Pollution process modelling remains an inexact science. Specific limitations of the hydrologic-agronomic model used in this research include:

1) Uncertainty with respect to nitrogen transformation rates and soils property parameters reduces the predictability of nitrogen leaching estimates used in this study. While leaching predictions are treated

deterministically, under- or overestimation of the true rates is possible as a consequence of nitrogen leaching model uncertainty.

2) Several simplifying assumptions were required in this analysis as a substitute for incomplete information characterizing nitrogen input decision-making. Better information characterizing how producers are likely to adjust nitrogen fertilizer input levels in response to water conservation measures induced by water market incentives would result in more accurate estimates.

3) The groundwater model used in this analysis predicts long-run steady state groundwater nitrate concentrations. The model is an appropriate tool for assessing response to a water market policy which once in place, remain unchanged for a long time (30 to 40 years), assuming that all other conditions (i.e. prices, technology) remain constant. The model does not trace the dynamic path of nitrate concentrations likely to result from water market changes.

4) Two key assumptions underlying the groundwater model are that the transmissivity of the aquifer material is constant within zones and that nitrate is a conservative mass. Better data characterizing the micro scale difference in aquifer material transmissivity, as well as information characterizing the potential for denitrification in parts of the aquifer experiencing seasonal high water tables could improve this research.

6.7 Directions For Further Research

Although this research provides significant insight into the potential impact of increased water trade in the Treasure Valley, the analysis could be expanded. Extensions of the models used in this research which could answer locally relevant policy questions include:

1) Expansion of the water supply analysis to include the entire 250,000 irrigated acres in the Treasure Valley rather than just a 17,400 acre area around the city of Ontario.

2) Use of the models developed here to explore the potential for water trade among irrigators within irrigation districts and (or) trade among irrigation districts, as well as the groundwater quality, local economic impact, and third party water rights holder impacts of such trade.

3) Use the models developed here to explore the potential for irrigation districts in the area to sell water gained through system management changes which conserve water. Sale of water conserved through ditch lining or rationalization of delivery schedules would be examples. Again, such analysis could include exploration of the groundwater quality, local economic impact, and third party water rights holder impacts of such trade.

Additionally, during the course of this study the need for two kinds of research which would aid in future water market and water quality economics research became obvious. First, the need for empirical research characterizing willingness to supply water would improve future assessments of water market potential. Specifically, hedonic price or contingent valuation type analyses of potential water suppliers could serve to valid estimates of willingness to supply computed with programming models such as the one used in this study. Such studies could also help to answer questions regarding how personal attributes influence willingness to pay. It would seem *a priori* that attitudes likely to influence willingness to supply may include attitudes toward environmental and farming issues, expected value of farm owner-operator labor in alternative employment, and level of previous experience with water markets.

Agronomic and hydrologic research which leads to improvement in the accuracy of the process models used in this research would be useful. Another form of useful research would be analysis which leads to better understanding of individual error sources in process models and allows development of confidence intervals around process model estimates.

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APPENDIX

Appendix A: Crop Prices and Production Costs Data

Table A.1: Mean Crop Prices in Malhuer County 1982-1992

Potatoes	Onions	Sugarbeets	Alfalfa	Wheat	Pasture[a]
$4/cwt	$7.25 /cwt	$37.25 /ton	$65.83 /ton	$2.99 /bu	$10 /AUM

Table A.2: Pre-harvest, Non-Irrigation and Non-Fertilizer Cost of Production[b]

Potatoes	Onions	Sugarbeets	Alfalfa	Wheat	Pasture[c]
$618 /acre	$1178 /acre	$403.2 /acre	$103.65 /acre	$123 /acre	$44-81 /acre

[a] Because there is no explicit market for forage, pasture is valued on the basis of cost of alternative sources of livestock nutrition assuming 600 lbs forage dry weight / aum and that forage from pasture is worth half as much as alfalfa.

[b] Cost based on estimates by Jensen, Simko and Synder, Malhuer County Extension Service. No charges for land or management are included as the definition of profit used in this study is the returns to those factors.

[c] Because the Malhuer County Extension Service provides no budget for pasture, a modified Version of the OSU Enterprise Budget Sheet for pasture in the Willamette Valley was used. The lower and higher cost reflect the differences in cost associated with alternative intensities of pasture management. The high cost pertains to pasture which is reestablished every eight years. the low cost to pasture which is not re-established.

Table A.3: Costs of Harvest, Hauling and Storage That Are Proportional to Yield[d]

Potatoes	Onions	Sugarbeets	Alfalfa	Wheat	Pasture[c]
$0.7 /cwt	$2.45 /cwt	$6.5 /ton	$22.5 /ton	$0.34 /bu	$0 /ton

Table A.4: Irrigation Capital, Maintenance and Repair Costs Irrigation

Irrigation System	Crop					
	Potatoes	Onions	Sugarbeets	Alfalfa	Wheat	Pasture
Present Furrow (PF)[e]	13.64	13.64	13.64	7.64	7.64	7.64
Improved Furrow (IF)[e]	13.64	13.64	13.64	7.64	7.64	7.64
Cutback Furrow (CF)[e]	13.64	13.64	13.64	7.64	7.64	7.64
Present Sprinkler (SP1)[f]	302.42	302.42	302.42	69.82	69.82	69.82
Hi eff. Sprinkler (SP2)[g]	396.48	396.48	396.48	-	-	-

[d] Cost based on estimates by Jensen, Smiko and Synder, Malhuer County Extension Service.
[e] Based on farmer interviews. Includes the costs of siphon tube depreciation and interest (15 years @ 10%,, seasonal clearing of tail-water ditches and concrete delivery ditch maintenance assuming 1000 ft square 24 acre field dimension.
[f] It is assumed that row crops are irrigated with solid set and close grown crops with side roll irrigation technology. Capital cost based on farmer interviews, irrigation equipment dealer price quotes (B2M Irrigation, Wiesser, ID) assuming 15 year system life and 10% interest rate. Repair and Maintenance cost are assumed to equal 4% of initial system cost (David and Gohring).
[g] Capital cost of a high efficiency solid set system is are based on the cost of present systems. However, costs are

Both the cost of irrigation labor and the cost of irrigation pumping power are assumed proportional to the frequency of irrigation. The per acre, per irrigation labor requirements associated with alternative irrigation systems in this study are summarized in table A.5. To obtain an estimate of irrigation labor cost at full irrigation, summarized in table A.6, per irrigation labor requirements are multiplied by the number of irrigations required to in a season if the soil profile is refilled each time it reaches the critical soil moisture. Critical soil moisture is defined as the level available water soil capacity beyond which reduced yield do to plant water stress would result (Doorenboos and Kasam). In the case of the improved furrow and cut-back furrow strategies the additional cost associated with irrigation scheduling and furrow stream management are included (Taberina; CH2M-Hill). For deficit irrigation, the labor cost of irrigation is assumed to be reduced proportionally to water depth.

Table A.5: Irrigation Labor Requirements[h]

Present Furrow	Improved Furrow	Cut-back Furrow	Present Sprinkler	High Eff. Sprinkler
.42/acre /irrig.	.42/acre /irrig.	.63/acre /irrig.	.062-.124[i] /acre /irrig.	.081/acre /irrig.

adjusted upward to reflect the costs of additional laterals and sprinkler heads necessary to increase system efficiency from 65% to 80%. Adjustment cost are based on the irrigation efficiency cost curve for row crop production using solid set irrigation derived by Chen and Wallender (p.742).

[h] estimates based on farmer interviews and Roberts et. al.

[i] the smaller estimate is for solid set irrigation, the larger for side-roll systems.

The cost of irrigation energy assumed in this study are at $6.42/acre foot and $4.59/acre for side-roll and solid set irrigation systems respectively. Estimates assume that lifting water 5 feet from the irrigation ditch to the sprinkler system and to pressurizing to 45 and 35 psi is required for side-roll and solid-set systems respectively. Estimates of irrigation system energy requirements are taken from Roberts et. al. and irrigation electricity costs quotes were obtained from Idaho Power.

Table A.6: Irrigation Labor Costs at Full Irrigation

Irrigation System	Crop					
	Potatoes	Onions	Sugarbeets	Alfalfa	Wheat	Pasture
Present Furrow (PF)	63.72	67.26	60.18	21.24	28.32	21.24
Improved Furrow (IF)	77.72	81.26	74.18	28.24	35.32	28.24
Cutback Furrow (CF)	109.58	114.89	104.27	38.86	49.48	38.86
Present Sprinkler (SP1)	9.54	10.07	9.01	6.36	8.48	6.36
High eff. Sprinkler (SP2)	12.51	13.21	11.81	-	-	-