SOME ECONOMIC IMPACTS OF A RURAL-TO-URBAN WATER TRANSFER: A CASE STUDY OF CROWLEY COUNTY, COLORADO

by

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EXTENDED SUMMARY

Introduction and Objectives

Urban water supply agencies seeking to meet growing municipal water demands in the arid southwest are finding that the purchase of water from existing agricultural uses is, from their perspective, often more cost-effective than construction of additional storage. Colorado municipalities have been among the most active purchasers of irrigation water rights. Agriculture-to-urban water transfers have economic impacts at the local, regional and state levels. Although the transfers represent "willing buyer-willing seller" exchanges, and represent a gain for both parties to the transactions, concerns have been voiced over whether the economic values to the transacting entities fully take into account the values to the region and the state.

Starting in the 1970s, water for urban use has been purchased in Crowley County, a small rural county in southeastern Colorado. Crowley County lands are irrigated from the Lower Arkansas River via the Colorado Canal. Some 85% of the water rights formerly serving 47,000 irrigated acres in Crowley County have been purchased by municipalities. This study had two main purposes. The first was to employ a nonmarket valuation technique to estimate the foregone *direct* economic benefits (opportunity costs) of irrigation water used in Crowley County. The second purpose was to estimate regional (direct plus secondary) employment impacts of the reduced irrigated agriculture.

Part I: Direct Economic Impact Analysis

To study direct foregone economic benefits, the authors originally formulated a conventional deterministic, single-stage linear programming model of farmer decision-making. However, this modeling approach failed to replicate observed historical cropping practices in the County. In particular, the deterministic model predicted that field corn combined with idle nonirrigated land would be the most profitable crop alternative, and be assigned the most land, while in fact, alfalfa hay is the most common crop. To improve the forecasting ability, the direct impact study was redirected into a methodological investigation, seeking to find a more appropriate model of water user actions, one which would provide a more accurate measure of foregone benefits.

A Reformulated Approach

It was noted that conventional approaches to irrigation water demand and impact studies often disregard uncertainty in water supplies. Crowley County farmers own low-priority water rights from the Arkansas River and experience significant delivery losses as water is transported over thirty miles in their unlined delivery canal and further along the lateral or secondary canals.

An estimated 31% of diversions from the Arkansas River are lost before reaching farmers' fields. Therefore, they face highly variable irrigation water supplies in an already limited and variable rainfall regime. These irrigators, who must choose management practices appropriate for these unusual production risks, are likely to formulate different cropping practices than would occur with a risk-free water supply. Specifically, Crowley County farmers must plant a portfolio of crops and determine irrigation amounts under conditions of limited and uncertain (stochastic) irrigation deliveries and precipitation. As the growing season progresses, during which they learn the magnitude of the season's water deliveries, farmers must decide which of the previously planted crops to irrigate and harvest as they face uncertain growing season precipitation. Therefore, a newer modeling approach, "Discrete Stochastic Sequential Programming" (DSSP), was adapted to model the stochastic water supply and rainfall and the sequential production process for water and land use decisions by farm producers in the region. As was the deterministic model, the DSSP incorporated alternative levels of irrigation water application for the various crops. The model is designed to solve for the most profitable crop mix and water application schedule under a range of water supply conditions.

Another adaptation to reflect the specific production conditions in Crowley County was consideration of varying soil productivity. The 47,000 irrigated acres in Crowley County are divided almost equally between soils with relatively good productivity and soils which are saline or alkaline exhibiting impaired productivity. In the DSSP, soils in the irrigated portion of the County were aggregated into four primary soil associations. Each soil association exhibits different yields for given levels of irrigation. The most productive soils are the 17,000 acres of loam. Sandy soils are the second category, comprising 9,600 acres. For a given amount of applied water, yields on these sandy soils relative to the best soils are reduced for the shallow-rooted corn and sorghum crops 25% and 10%, respectively (Larsen et al., 1968). The third soil category includes alkaline and saline soils accounting for 16,400 acres, which yield 80% of that expected on the first soil category for alfalfa; 70% for sorghum; and because of corn's alkalinity intolerance, 60% for corn. The final category of soils includes the least productive alkaline and saline soils, comprising about 4,500 acres, suited only for pasture and alfalfa (each crop yielding but 60% of that achieved on the best soil).

Despite the water transfers that have already taken place, water-intensive alfalfa continues to dominate the cropping pattern in the county. Thus, historical county data on crop mixture provides an observed behavior to which DSSP predictions can be compared. Solutions of the DSSP model produced a more correct projection of the actual changes in crop acreage resulting from water withdrawals than did the deterministic formulation.

Results of Direct Foregone Benefit Analysis

Following validation of the DSSP, water demand schedules were derived corresponding to increasing levels of diversions. There are two demand schedules for irrigation corresponding to the "adequate" or "inadequate" states of nature modeled in the DSSP. The first characteristic of the regional stochastic irrigation demand is that the value of expected deliveries in one state of nature is positively related to expected irrigation deliveries in the opposite state. Expected deliveries in one state of nature complement actual water use in the opposite state in the stochastic sequential production process. Planting and irrigation decisions are undertaken with the expectations of future irrigation deliveries and irrigation in one state of nature cannot substitute for water in the opposite state.

The second water demand characteristic is that demand for diversions in the inadequate state of nature is more price-elastic than in the adequate state of nature diversions. When adequate diversions are expected at 50% of normal, they are valued at approximately $3 per acre foot; given that expectations of inadequate diversions are also at 50% of normal. When inadequate diversions are 50% of normal, diversions are valued at approximately $76 per acre foot; given that inadequate diversions are also at 50% of average. Irrigation in the inadequate state of nature is usually the binding constraint on crop production, along with the greater probability that the inadequate state of nature combines to have the effect that a given percentage in irrigation in this state will cause a greater change in the value of crops of grown in the county. When adequate diversions occur, the amount of amount of water delivered exceeds the capacity of agricultural production utilization.

The model confirms casual observation: irrigation water provided with certainty is more valued than are uncertain water supplies. At mean deliveries in each delivery state of nature, uncertain water is valued at $25 per acre foot. By comparison, at mean diversions irrigation water delivered with certainty is valued at $36 per acre foot. Thus, economic efficiency of resource use on irrigated farms is reduced when irrigation water supply is stochastic. The vertical distance between the demand functions is the effect of risk to the marginal value of water to the firm. Or stated differently, the vertical distance is the payment needed to make a farmer indifferent between uncertain and uncertain irrigation deliveries. Thus, we found an $11 per acre foot "penalty" associated with risky irrigation water supplies. Cities that have purchased water and are now contemplating lease-back agreements for unneeded water face differing values for that irrigation water depending not only on the state of nature in which the water is to be leased, but also the expected amount to be leased in the alternative state of nature.

The model's objective function measured the expected regional return to the residual claimants of water, land, management and overhead (depreciation and taxes). The expected regional return to the residual claimants was predicted to have dropped from $5.5 million, before water was withdrawn, to $1.6 million after 75% of the water in the inadequate years is transferred from the region.

To derive the value of foregone water withdrawals, the nonwater components of the residual claimant in the objective function must be accounted for. Annual management and overhead costs of $46 per acre are therefore subtracted. The estimated average foregone value was about $21 per acre foot, although this varied considerably among soil types. The derived value of raw water for residential use is, according to Gibbons (1985) worth about nine times the value of the transferable value of water in crop production in Crowley County. Our findings strongly suggest that the transfer of water from Crowley County results in an increased value of the resource to the Colorado economy.

Part II: Direct and Indirect Employment Impacts

Because of the economic interdependence among producers in the Lower Arkansas River Valley Region, the activities in one sector create indirect repercussions throughout the remaining sectors of the economy. The indirect impacts of irrigation transfers are the ripple effects as farmers cease to produce crops. These indirect ripple effects are of two origins: 1) the backward linkages "induced by" farmers as they cease to purchase inputs (labor, fertilizer, equipment etc.) to produce crops, and 2) the forward linkages "stemming from" the loss of supply of crops for industries using these crops in their production (feedlots, cattle ranches, etc.). Considerable concern has been expressed in the state that even if the direct values of water use increase by transferring to higher valued uses, the indirect economic impacts may make it worthwhile to adopt policies to protect agricultural-based economies. The limited resources available to this study preclude a full analysis of the secondary impacts question, but we did attempt to estimate one aspect of the secondary impacts: that relating to employment losses of the water transfer. Regional output and employment impacts of various levels of water transfers were estimated.

An Input/Output model was developed for a seven county area in the Lower Arkansas River Valley from which multipliers were derived. The IMPLAN system of synthesizing a regional I/O model, developed for use in situations where resource limitations prevent developing a more accurate survey-based method, was adopted. However, the direct employment estimates in the IMPLAN agricultural sectors, largely derived from national averages, were found to be inadequate reflections of the local situation as shown from U.S. Census data and other sources. Hence, the IMPLAN data were replaced with more accurate estimates of direct employment in the final model.

Several scenarios were tested with the regional model. In general, we found that estimated cumulative impacts of water diversions from Crowley County on regional employment and income due to backward-linked effects were very small. Because the hay and feed grains produced under irrigation in the valley are largely used for livestock (mainly cattle) feeding, the impacts will be mainly on that sector. If a shortfall of feed was not replaced by reducing exports or increasing imports, then the forward links to the cattle sector, and the resulting decrease of local spending by the cattle sector, would result in significant losses of employment and income. However, since 2/3 of the hay and 85% of the grains produced in the region were exported prior to the diversion, there is little reason to expect the local livestock production would be reduced. The likely scenario would be for a reduction in feed exports to follow from the Crowley County water sales.

Total predicted hay and grain output in the seven county region fell by less than 2% due to the Crowley County water diversion. Thus, abundant supplies of cattle feed are likely to continue to exist in the seven county region. Under the most likely scenario of impacts, a 75% transfer of water from Crowley County, the total employment loss (including the multiplier effect) in the seven county region was estimated at 125 full-time job equivalents. This would be a fraction of the 80,000-plus employment reported in the seven-county region. Further, it appears that the water transfer would occur over a period of two or more decades, as the new owners gradually apply their water rights to urban uses. Thus, the impact during any one year, from the regional perspective, would be relatively minor.

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INTRODUCTION

In the arid western United States, agriculture accounts for the great majority of water diversions. With capital and environmental costs of capturing and storing water rising, purchases from agriculture are often the least costly method of providing water to growing cities. As urban demands for water increase, additional water supplies are sought. The purchase of water from agriculture is often more cost effective than construction of additional storage to fulfill urban water requirements. Agriculture to urban water purchases are increasingly of the nature that an entire regional agricultural water supply is purchased. A region's agricultural water will be purchased in entirety because the high fixed costs of transfer (both legal and physical) dwarf the actual cost of the water. The urban user, in the meantime, can lease the water back to agriculture until it is needed.

Water transfers from agriculture are economically feasible when benefits in urban uses exceed the sum of foregone agricultural benefits plus transaction, conveyance and environmental mitigation costs (Young, 1986). Measurement of the foregone economic benefits as water is transferred to urban use is important in assessing the economic feasibility of agriculture to urban water transfers. Impact studies and conventional approaches to irrigation water demand often ignore uncertainty in water supplies. Farmers faced with uncertain water supplies, either from precipitation or irrigation delivery, are likely to develop different cropping practices over riskless situations. The fundamental problem is that farmers in Crowley County must plant a mixture of crops (alfalfa, corn or sorghum) without the certainty that they will receive adequate irrigation water or precipitation. As the growing season progresses, during which they learn the magnitude of the season's irrigation water deliveries, farmers must decide which of the previously planted crops to irrigate and harvest given the uncertainty of precipitation.

Area farmers, even as urban water transfers depleted the region's water supply, continued to plant a crop portfolio dominated by water-intensive, low-valued alfalfa as opposed to the comparatively high-valued but less water-intensive corn crop (Colorado Department of Agriculture). Modeling this situation using a deterministic, single-stage linear program (assuming mean water supply and rainfall) failed to account for observed behavior. Specifically, rather than emphasizing alfalfa, the deterministic model predicted that in the expectation of limited water supplies, the optimal cropping pattern idled some land and emphasized corn production on the remainder. We hypothesized that the problem of inaccurate prediction arose from a combination of factors: uncertain irrigation supply and rainfall, the sequential nature of irrigated agricultural production decisions, and the varying drought tolerance of regional crops.

As part of the economic feasibility analysis of one such transfer) water purchased from farms by growing Colorado cities) we undertook to estimate foregone regional agricultural net benefits. The objective of the research was to develop a model that could better explain and predict farmers' production and irrigation decisions, which in turn improves the accuracy of estimated foregone benefits and impacts of the agriculture-to-urban water transfers. The demand for uncertain water supplies, foregone benefits, and regional economic impacts of the water transfers were then estimated.

Case Study Description

The region from which some of the water was purchased was Crowley County, a small county in southeastern Colorado. Virtually all of Crowley County's irrigated lands were supplied by the Arkansas River through the earthen Colorado Canal built in 1892. Beginning in the 1970s, water rights serving much of the 47,000 irrigated acres in Crowley County were purchased by municipalities, leaving only about 15% in the hands of farmers. Water supplies available to the region via the Colorado Canal are limited and highly variable. Water rights owned by Crowley County farmers have low priority on river diversions. Thus, Colorado's "first in time)first in right" water allocation law exacerbates irrigation uncertainty. Further, rainfall in this semi-arid region averages only 11 inches per year. With limited storage capability, water is frequently inadequate in late season after snow melt briefly swells the supply. Compared to other counties in Colorado, Crowley County has a low percentage of prime farmland and few acres of adequately irrigated farmland. However, nearly half the acreage in Crowley County would be considered prime farmland if adequate irrigation were available; which is high compared to other Colorado counties (Heil and Anderson). Three principal crops, corn, sorghum and alfalfa, comprise a major portion of the irrigated acreage in Crowley County. Other crops such as wheat, beans, and hay exist in Crowley County but make up an insignificant portion of the irrigated acres. These crops may function as rotation and cover crops for the three major crops since they amount to a small percentage of the agricultural acres in the county.

The distinguishing characteristic of the crop production process within this region is farmers' adaptation to uncertain regional irrigation deliveries via a sequential crop decision production process. Farmers in the region plant crops (principally alfalfa, corn or grain sorghum) without certain knowledge that they will receive adequate irrigation water or precipitation during the production season. As the growing season progresses, the status of irrigation water deliveries becomes known and the schedule and level of growing season irrigation can then be determined. At season's end, farmers decide which of the previously planted and irrigated crops to harvest given the outcome of uncertain growing season water supply. Sequential cropping activities are coordinated by climatic conditions (e.g., farmers plant at similar times as permitted by weather) and irrigation deliveries are then scheduled by the farmer-controlled irrigation authority consistent with regional water demands based upon the stages of crop maturity.

METHODS

This section will be discussed in two parts. First, an overview of the development of the discrete stochastic sequential programming (DSSP) model is presented. This is followed by a description of the data that constitutes the various component matrices of the model. Components of the DSSP model describe regional crop production, irrigation practices, climate, and economic choices. Next, the DSSP is developed as a model of farmer behavior, with emphasis on integration of data and model formulation to aid interpretation of the results. Finally, the results validate the model in a comparison of observed and predicted farmers' decisions and are followed by a discussion of irrigators' decisions on planting and irrigation.

Background

Economic evaluation of changes in agricultural production policy implicitly or explicitly requires a model of producer choice. The model should be able to *explain* observed behavior in specific or similar situations. Then it can be relied on to *predict* impacts of hypothetical or actual policy initiatives (Johnson, 1986). Following the usual practice (Hazell and Norton, 1986), we assume that the producer makes choices with the goal of profit maximization, constrained by natural resource endowments (climate, quality and productivity of soils and water), crop production technology, the firm's productive resources (land, labor, capital, water), input and product prices, and lastly, political-legal constraints and/or incentives. The next section of the paper provides an overview of the decision making process in irrigated agriculture. We then develop, display and evaluate a model which more accurately incorporates the specific choice environment faced by Crowley County farmers.

Irrigated crop production is a dynamic biological process in which input decisions are made sequentially as crops are planted, grown and harvested. Each farmer decision in this sequential dynamic process is contingent upon results of past decisions, past events and information regarding future events. Since outcomes of future events are rarely known with certainty, a farmer's objective (e.g., maximum profit) is risk-dependent. Accurate predictive models of farmer behavior need to incorporate risk if the objective that the farmer seeks to achieve is a function of the probability distributions of random variables, and the farmer incorporates these distributions into decision making (Angle, 1983b). Risk then influences farmer decisions even if the farmer is risk neutral (Angle, 1983b), and the sequential crop production is the mechanism through which production risk affects irrigation decisions. In contrast, conventional models are often couched in a static production process where risk can only influence the decisions if the farmer is risk averse. In the conventional framework, it is the disutility of risk that matters, as opposed to the influence of risk in the production process. The static deterministic models predict water allocation such that high value crops remain in production, but land will be idled in the face of increasing water costs or declining water supplies. In many cases, irrigation water supply is quite predictable, (in the presence, for example of adequate surface or ground water storage), and deterministic models may be quite suitable for policy analysis.

Previous Research

Models of agricultural production decisions can take several forms, ranging from simple farm budgets to complex mathematical optimization models. The simplest planning exercise is the farm budget (Brown, 1979). In this approach, whole-farm budgets are calculated to determine net farm income *with* versus *without* the project or policy initiative being studied. The estimated difference between the *with* and the *without* calculations of net income is imputed as the economic benefit to the policy initiative. The U.S. Water Resources Council (1979) instructions for economic appraisal of irrigation projects adopted this process, which it referred to as the "Change in Net Income" procedure.

The "Change in Net Income" approach requires the analyst to make a number of *a priori* judgments in making the calculations. The most important of these judgments include assumptions about 1) crop species and acreage of each to be grown, 2) the crops' response to alternative amounts and timing of water applied, and 3) what irrigation water distribution technologies might be employed. Each of these can significantly affect estimated water use and net income. Anderson (1968), while retaining the fixed crop acreage assumption of the whole-farm budget approach, utilized computer simulation to facilitate representation of multi-stage crop response to alternative amounts and timing of water application in a model of an irrigation delivery system. Mapp and Eidman (1976) developed a complex model of yield response to water supply and timing as part of a study of groundwater mining.

Analysts who wished to make choices regarding which crop to produce, water application rates and production technologies endogenous to their models were quick to take advantage of mathematical optimization techniques, such as linear or quadratic programming (Hazell and Norton, 1985). Hartman and Whittlesey (1960), who studied the effect of hypothesized water price changes on crop choice and net farm income in western Colorado, were among the first of many to apply linear programming to irrigation planning. Early models provided only for omission of marginal crops in response to increased price or scarcity. Extensions of the mathematical programming approach to irrigation proceeded along several different paths. Sequential or multi-stage decision processes and crop response to varying water application rates were one avenue. Young and Bredehoeft (1972) took this direction and also showed that the water application portion of the Anderson simulation model (1968) could be more easily and accurately represented by a linear program. Other extensions included representation of the impacts of water supplies of adverse quality (Moore, Sun, and Snyder, 1972); seasonal crop response to water (based on highly detailed agronomic simulations) and irrigation application technology (Bernardo, et al., 1987); and irrigation decision modeling by quadratic programming to allow crop price to vary with regional output of irrigated crops (Howitt, Watson and Adams, 1980). Yet another path was to utilize dynamic programming to represent the sequential choice problem faced by irrigators in the presence of limited water supplies. Representative of this approach is Dudley's (1988) sophisticated analysis of optimal land and water use on irrigated cotton in Australia. The dynamic programming approach provides a rigorous representation of the problem of sequential water-use decisions in the face of uncertain water supplies. However, it sacrifices some realism because its heavy computational demands have limited the analysis to considering but one crop at a time. In the following sections, we attempt to extend this general mathematical optimization approach by developing a DSSP model of sequential uncertain multi-crop production process characteristic of irrigated agriculture throughout the world.

We formulated a programming model of farmer decision making which recognizes that: 1) planting, irrigating and harvesting decisions are sequentially dependent; 2) information on irrigation and precipitation availability is feedback to be utilized in subsequent decisions; and 3) decisions are revised as new information becomes available [i.e., a closed loop solution, (Angle, 1983a)]. It is through this dynamic production process that production risk determines farmers' optimal decisions for, among other inputs, irrigation water.

Discrete Stochastic Sequential Programming Model

Discrete stochastic sequential programming (DSSP) was developed to solve sequential decision problems under uncertainty. DSSP is a mathematical programming technique that optimizes decisions over the paths of expected occurrences of multiple stages where coefficients in the objective function, input-output relationships, or resource constraints are uncertain. Each decision stage is conditional upon past decisions and expected future events. This general description is the essence of the problem when irrigating with uncertain and limited water supplies. An early formulation of DSSP was presented by Cocks (1968). Rae (1971a,b) later applied it to model agricultural decisions. DSSP has since been adapted to marketing decisions (Lambert and McCarl), farm program participation (Kaiser and Apland), range improvements (Garoian et al.), and calf retention (Lambert). To our knowledge, DSSP has not been previously employed to model the sequential and stochastic process of on-farm irrigation water allocation.

DSSP was chosen over other techniques because: (1) it can manage the dimensionality problem inherent in this study resulting from regional soil variations, irrigation supplies, precipitation states of nature, multiple crop opportunities and irrigation intensities; and (2) it has the ability to account for risk in the objective function, as well as in the coefficients and constraints (McCarl, 1986).

The three basic types of activities in the DSSP model represent the sequential stages of crop production in the region: (1) preplant and planting period activities, including irrigation (2) growing season irrigation, and (3) harvest and sales activities. The sequential decision process, as influenced by the states of nature in this production process, is illustrated in Figure 1. The planting activities are the first stage in the sequential decision process. Crop selection and planting and the preplant irrigation must be undertaken before information is obtained concerning the states of nature on either irrigation diversions or precipitation. The second stage commences with specification of the level of canal diversions for the growing season. The third stage begins as the growing season ends. Producers must decide which crops to harvest and sell after both irrigation and precipitation have determined yield.

Figure 1. Decision tree of sequential crop production.

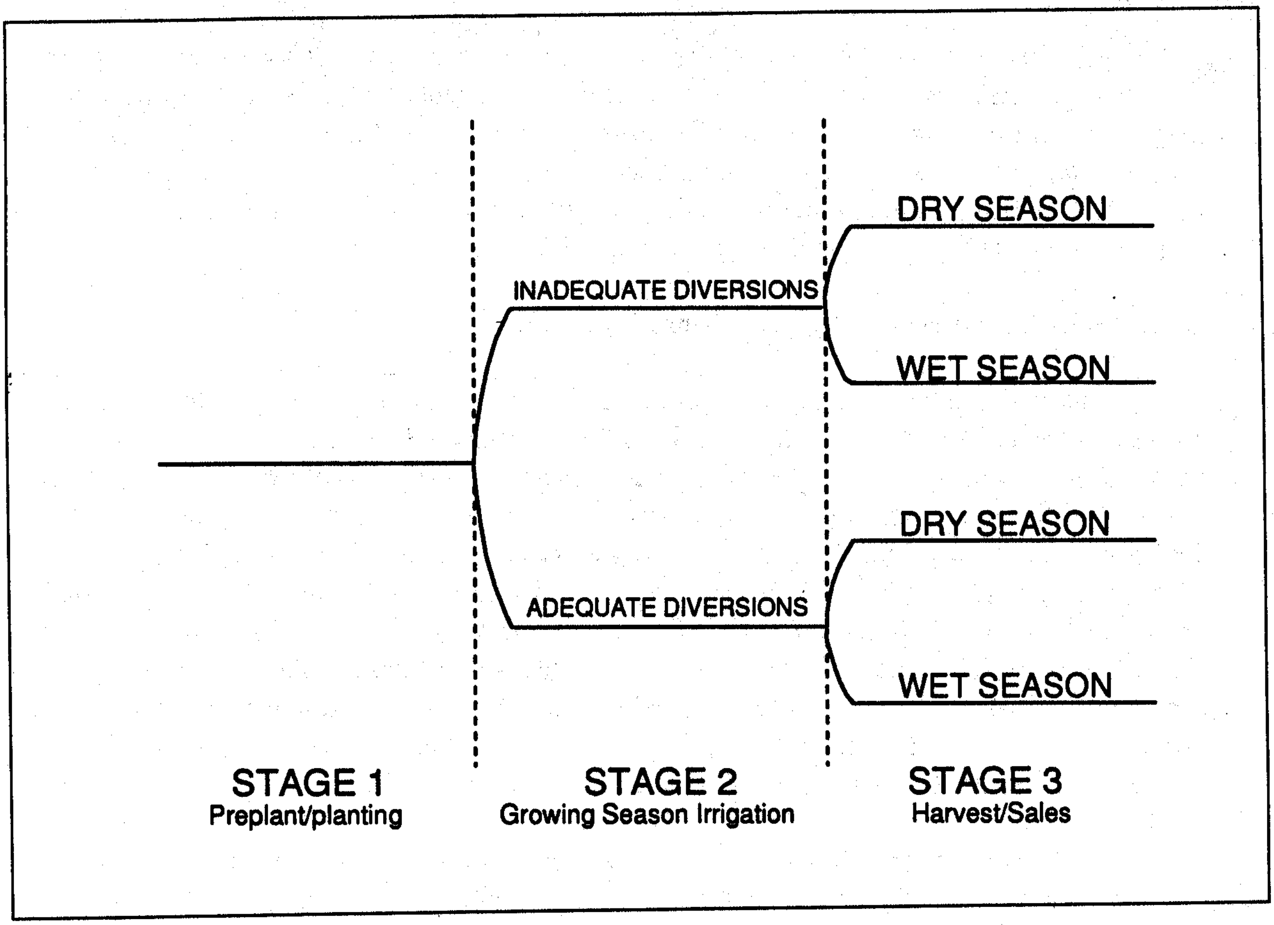

Figure 2 illustrates the general structure of the DSSP model. The DSSP is constructed to maximize the objective function, defined as the net income from the choice variables representing the three stages, weighted by the probabilities of occurrence of the stochastic events that influence net income from the choice variables representing the three stages, weighted by the probabilities of occurrence of the stochastic events that influence net income. The second block of rows are the acreage constraints for the four major soil types in the county. The third block of rows represents the crop rotation limits. The fourth block of rows reflects the constraint on total irrigation diversions for preplant and growing season. Rows five and six are the intertemporal transfer equations between stage 1 and stages 2 and 3, respectively.

Turning to the columns, Xt are activities in the sequential stages (t=1,2,3), X1 are the planting and preplant irrigation (stage 1) activities, X2 are the growing season irrigation (stage 2) activities, and X3 are the harvest and selling (stage 3) activities. Ai are the water use coefficients for preplant ($A1_k$) and growing season ($A2_{k4m}$) irrigation requirements. Ri are resource constraints, $R1_j$ are acreage constraints on soil acreages, and $R2_m$ are the constraints on irrigation water diversions for the adequate and inadequate canal deliveries.

	STAGE 1	STAGE 2		STAGE 3						
	X1	X21	X22	X311	X312	X321	X322			
MAX	C1	P21C 21	P22C22	P21P31C 311	P21P32C 312	P22P31C 321	P22P32C 322			
	1	0	0	0	0	0	0	<=	R1j	Resource constraint vector for stage 1 (soil acreage j=1...4)
	B1	0	0	0	0	0	0	<=	R1	Resource constraint vector for stage 1 (crop rotation requirement)
	A1	A21	0	0	0	0	0	<=	R2w 1	Resource constraint for stage 2 with water supply state of nature 1 (inadequate diversions)
	A1	0	A22	0	0	0	0	<=	R2w 2	Resource constraint for stage 2 with water supply state of nature 2 (adequate diversions)
	-I	I	0	0	0	0	0	=	0	Transfer rows stage 1 to stage 2
	-I	0	I	0	0	0	0	=	0	Transfer rows stage 1 to stage 2
	0	-I	0	I	0	0	0	=	0	Transfer rows stage 2 to stage 3
	0	-I	0	0	I	0	0	=	0	Transfer rows stage 2 to stage 3
	0	0	-I	0	0	I	0	=	0	Transfer rows stage 2 to stage 3
	0	0	-I	0	0	0	I	=	0	Transfer rows stage 2 to stage 3

Xt Planting, irrigation and harvest activities in stage t (t = 1, 2, 3)
X1 Preplant irrigation and planting activities in stage 1 (three crops on four soil types)
X21, X22 Growing season irrigation activities in stage 2 with inadequate and adequate canal diversions
X311, X312, X321, X322 Harvest and selling activities in stage 3 with inadequate diversions and low rainfall, with inadequate diversions and high rainfall, with adequate diversions and low rainfall, with adequate diversions and high rainfall
P: Probabilities of states of nature (P2: water supply states in Stage 2; P3: rainfall states in Stage 3) C: Cost or revenue coefficients (state and stage dependent) B: Crop rotation requirement coefficients A:Irrigation requirement coefficients for stages and water availability states

Figure 2. Schematic of DSSP Tableau.

B represents the minimum crop rotation schedules. Pi are the probabilities of each state of nature: $P2_m$ is irrigation supply state and $P3_n$ is rainfall state. Ci are the costs or revenues associated with activity Xt, $C1_k$ is planting costs, $C2_{jk}$ is labor costs of growing season irrigation, and $C3_{jk}$ is revenues net of harvest costs. Using the same notation, the model in Figure 2 is expressed algebraically as follows:

$$MAX \sum_{j=1}^{4}\sum_{k=1}^{3} C1_k X1_{jk} + \sum_{j=1}^{4}\sum_{k=1}^{3}\sum_{t=1}^{3} C2_{jkt}\left[\sum_{m=1}^{2} P1_m X2_{jktm}\right] + \sum_{j=1}^{4}\sum_{k=1}^{3}\sum_{t=1}^{3} C3_{jkt}\left[\sum_{m=1}^{2}\sum_{n=1}^{2} P1_m P2_n X3_{jktmn}\right]$$

subject to:

$$\sum_{k=1}^{3} X1_{jk} \leq R1_j \quad (j=1 \ldots 4)$$

$$\sum_{k=1}^{3} B_k X1_{jk} \leq 0$$

$$\sum_{k=1}^{3} A1_k X1_{jk} + \sum_{k=1}^{3}\sum_{t=1}^{3}\sum_{m=1}^{2} A2_{ktm} X2_{jktm} \leq R2_m \quad (m=1 \ldots 2)$$

$$X1_{jk} - X2_{jktm} = 0$$

$$X2_{jktm} - X3_{jktm} = 0$$

$$Xi \geq 0 :$$

The indexes of activities for the three stages are defined as:

soil type j where j=1,2,3,4
1 = highly productive
2 = less fertile and higher water use sandy soils
3 = poor soils (alkaline and/or saline soils);
4 = poorest soils (very saline and infertile)
crop type k where k=1,2,3
1 = alfalfa hay
2 = corn for grain
3 = sorghum grain;
water application options, □ = 1,2,3
1 = low: first two cuttings of alfalfa or low water use for corn and sorghum,
2 = medium: third cutting for alfalfa or mid water use for corn and sorghum,
3 = high: fourth cutting for alfalfa or high water use for corn and sorghum.
water delivery state of nature m=1,2
1 = inadequate canal water delivery
2 = adequate canal water delivery;
growing season precipitation state of nature n=1,2
1 = dry
2 = wet

The actual data for each of the three stages in the DSSP are compiled in the respective three tables in Appendix I. Data sources, assumptions and interpretation of these data for each component of the DSSP model are the focus of the remainder of the methods section.

Soil Characteristics and Crop Rotation Constraints (R1 and B)

The 47,000 irrigated acres in Crowley County are divided almost equally between soils with relatively good productivity and saline or alkaline soils of impaired productivity (Larsen et al., 1968). To achieve parsimony in the DSSP model soil activities, the acreage estimates of irrigated soil types were aggregated into the four soil associations. These soil associations categories closely resemble each other in input and output coefficients (i.e. potential yield of the major crops and water use efficiency soils). In the DSSP, soils in the irrigated portion of the county were aggregated into four primary soil associations. Each soil association exhibits different yields for given levels of irrigation. Within the association, soil responses are homogeneous such that little is lost in accuracy by aggregation. The most productive soils are the 17,000 acres of loam. Sandy soils are the second category, comprising 9,600 acres. For a given amount of applied water, yields on these sandy soils relative to the best soils are reduced for the shallow-rooted corn and sorghum crops 25 percent and 10 percent, respectively (Larsen et al., 1968). The third soil category includes alkaline and saline soils, accounting for 16,400 acres which yield 80% of that expected on the first soil category for alfalfa, 70% for sorghum, and because of corn's alkalinity intolerance, 60% for corn. The final category of soils are the least productive alkaline and saline soils, comprising about 4,500 acres, suited only for pasture and alfalfa (each crop yielding but 60% of that achieved on the best soil).

The method of obtaining the acreage of the four soil associations for the irrigated acreage in Crowley County was accomplished in two steps. First a map of lands irrigated by the canal and reservoir system in the county (Wheeler and Assoc.) was transcribed to the Soil Conservation Service aerial soil maps (Larsen et al., 1968)[1]. Second, acreage of each irrigated soil was tallied using a dot grid.

Crop rotation constraints followed the recommendations by Larsen, et al. (1968) for each soil association. Alfalfa on soils 1 and 2 should be rotated at least every six years with either corn or sorghum while corn should be rotated with either sorghum or alfalfa every 4 years. Alfalfa on soil 3 should be rotated every 4 years to maintain permeability on these poor soils. Crop rotation requirements in the model are minimums, not strict equalities, to reduce interference with profitable crop choice (i.e., a crop could be rotated more often if profitable).

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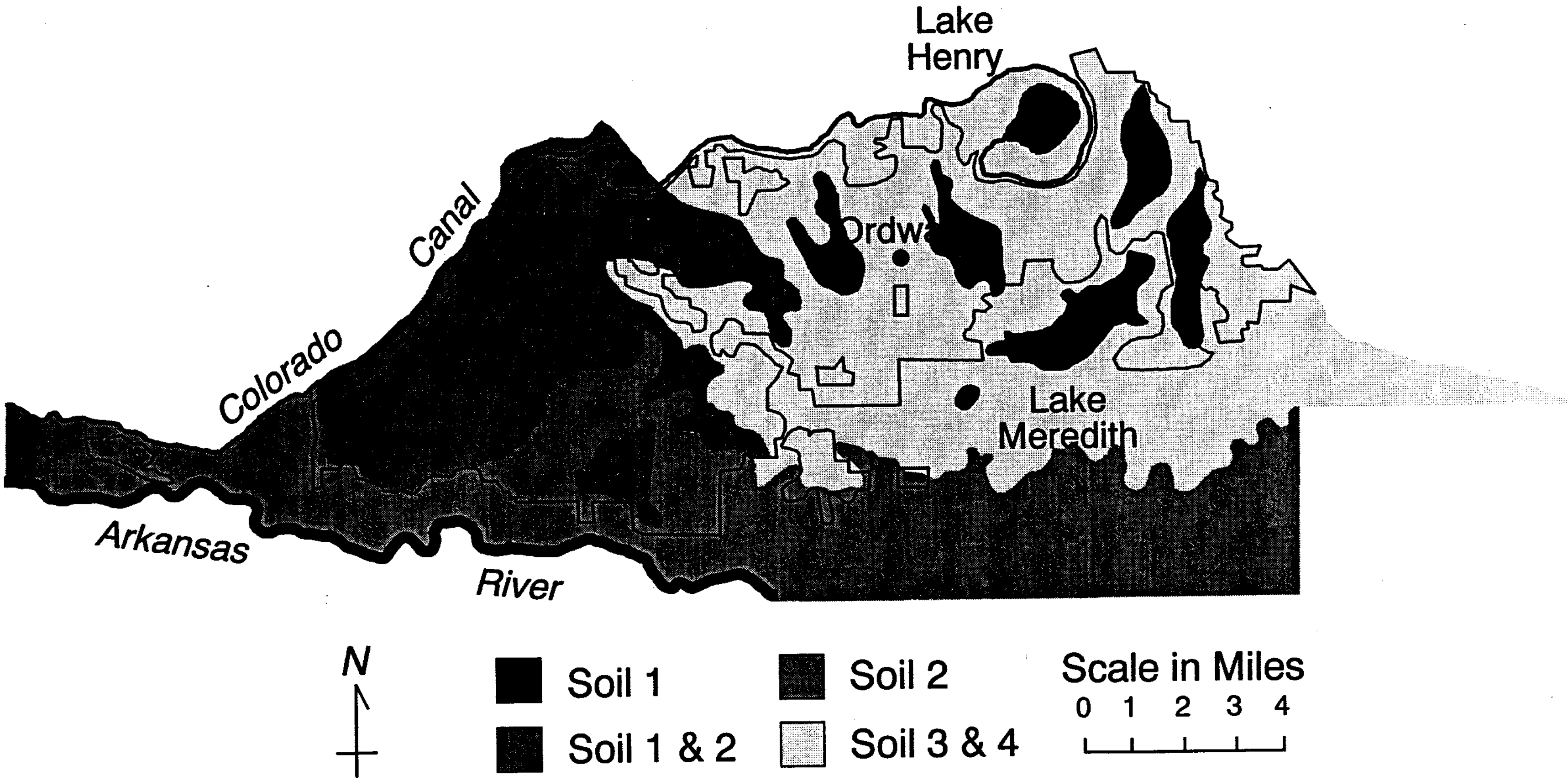
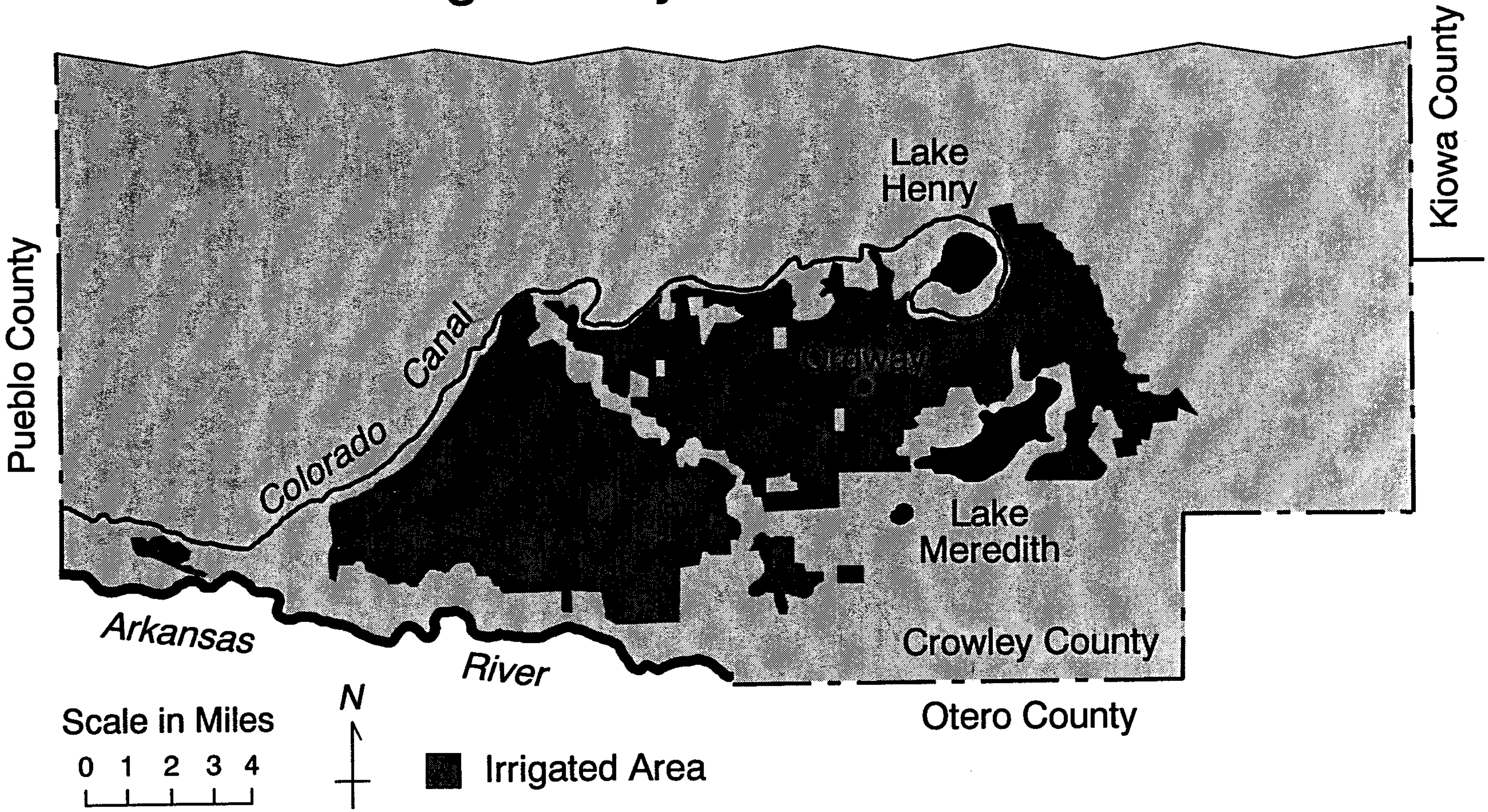
[1] Since the study focus was canal and reservoir irrigation, the minor amount of acreage irrigated by groundwater in the county was excluded.

Crowley County, Colorado
Area Irrigated by the Colorado Canal By Soil Type



Crowley County, Colorado
Area Irrigated by the Colorado Canal



Costs of Production and Crop Prices (Ci)

Costs of production are quoted in 1987 prices, adapted from published crop enterprise budgets for the region. Alfalfa and corn budgets were from Dalsted et al. (1988), and the grain sorghum budget was derived from one reflecting nearby Oklahoma Panhandle conditions (Oklahoma State University Extension Service, 1987). Variable costs (exclusive of irrigation water costs) in the enterprise budgets were disaggregated into the following: (1) planting and preplant irrigation (stage 1) activities, or C1; (2) growing season irrigation (stage 2) activities, or C2; and (3) harvest and selling (stage 3) activities, or C3. Labor at $5.00 per hour was the only growing season irrigation activity cost. (Irrigation water costs are a fixed annual per acre assessment paid to the canal company prior to the irrigation season.) Alfalfa establishment costs were amortized over the average stand life in southeast Colorado. The objective function is thus expected (probability-weighted) annual regional return to the residual claimants of water, fixed capital (machinery), management and land.

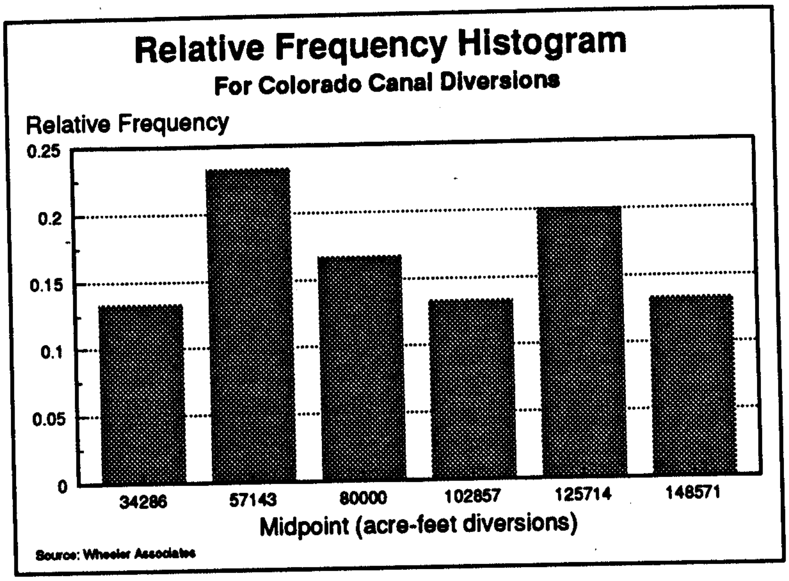
The long-term time frame of the proposed water rights sale (all water rights sales are permanent to the City of Aurora) requires that crop prices used in the water value analysis reflect long run prices rather than annual fluctuations. These prices must also be in real or constant dollars to net out the effects of inflation. Several indices are commonly used to convert the nominal prices (prices not adjusted for inflation) to real dollar prices. The Gross National Product (GNP) implicit price deflator was selected as the best index to convert the nominal crop prices to real prices because this index has the broadest scope and encompasses all the goods and services in the United States, including agricultural commodities. Crop prices used in this analysis were taken directly from the Colorado Agricultural Statistics and then adjusted to real dollars using the GNP index. From these real prices, a seven year crop average using values from 1981 through 1987 was calculated for alfalfa at $73.38/ton, sorghum at $2.46/bu and corn at $2.75/bu. In summary, price risk is excluded, and only production risk is modeled. Production risk, however, determines the unique portfolio of crops planted in Crowley County as compared to neighboring regions with identical crop prices but differing risk levels in irrigation water deliveries.

Probabilities of the States of Nature and Irrigation Water Delivery Constraints (Pi and R2)

Probabilities for the second and third stages reflect regional perceptions of adequate or inadequate irrigation deliveries and rainfall. The low priority water rights held by Crowley County farmers often result in inadequate diversions. The conventional understanding in the region is that inadequate water supplies will be received in about 75% of the years (Ringle, 1989; Miles, 1989; personal communications). Shortages, when they occur, are in the mid to late summer. The consequences of inadequate irrigation water supplies are that farmers in Crowley County cannot irrigate to obtain a fourth cutting of alfalfa nor irrigate corn after the blister stage.

Probabilities of the first stage are the states of nature for the delivery of irrigation water. The probability density function for total irrigation diversions (Wheeler) for 30 years (1954-1983) is shown in Figure 3. Mean diversions for the 30-year period were 89,687 acre feet annually.

Figure 3. Relative Frequency Histogram for Colorado Canal Diversions.



State of Nature	Probability	Amount
Canal Delivery		
Inadequate	.75	73,199 ac ft
Adequate	.25	135,252 ac ft
Precipitation		
Dry Season	.6	4 inches
Wet Season	.4	8 inches

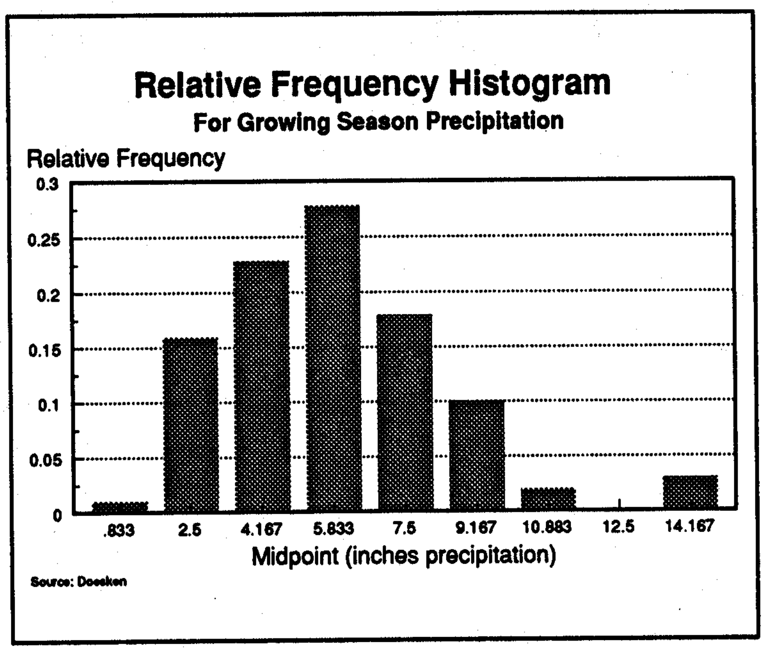
Table 1. Probabilities and Conditions for Each State of Nature.

Because of the junior rights held by Crowley County farmers, for 75% of the years, diversions have not been adequate to meet farmers' demands for irrigation water (Ringle communication). For the 75% of the years where diversions have not been adequate, mean diversions were 73,119 acre feet and mean diversions for adequate years totaled 135,252 acre feet (Table 1). The constraint on total irrigation water (R2) for the adequate and inadequate years is the total water diverted through the canal to the region.

Water supplies actually available to farms are diversions less transit losses. Water is lost in three ways from the total water diversions before the water is applied to fields: (1) canal seepage, (2) lateral ditch seepage, and (3) evaporation from storage. The sum of these losses has historically averaged 31 percent of total diversions (Wheeler, 1985).

The second stage states of nature compound delivery of irrigation and growing season precipitation. The Probability Density Function (PDF) for growing season precipitation (June through September) for 104 years of measurement at the nearby Rocky Ford station is presented in Figure 4. Mean growing season precipitation is 5.87 inches. Two precipitation states of nature were constructed: "dry years" is defined as average or below precipitation, and "wet years" is defined as average or above precipitation. Approximately 60% of the years had less than average rainfall, and rainfall in those years averaged 4 inches. The remaining 40% of the years were wet years with an average 8 inches of rainfall.

Figure 4. Relative Frequency Histogram for
Growing Season Precipitation.



Irrigation Water Input Coefficients and Crop Yields (A1 and A2)

A production function relating crop response to applied water was approximated for each of the three major crops (corn, sorghum, and alfalfa) on each of the four soil categories. Three levels of applied irrigation water, corresponding to the level and timings of irrigation within the region, were incorporated into the DSSP model as discrete points on corn, sorghum and alfalfa production functions, allowing choice across crops and irrigation intensities. The typical response to limited irrigation supplies in the region is not to reduce water per irrigation turn, but rather to decrease the number of irrigation turns received by each crop. For alfalfa, this results in fewer cuttings and, consequently, lower yields. The level and timing of irrigation water applications were assumed to be constant across wet and dry years because farmers do not have prior knowledge of the forthcoming precipitation within the growing season. For all crop activities, the contribution of effective precipitation under the two precipitation states of nature was subtracted from the total applied water quantities on the production function to obtain the irrigation water coefficients.

Crop response is the mechanism whereby risk affects farmers' decisions. The apparent anomaly that water-intensive alfalfa dominates the crop portfolio can thus be explained in terms of crop response and soil characteristics. When water shortages occur within a season, a complete crop failure can result for corn, while yields are merely diminished for alfalfa. Alfalfa needs early season watering but can become dormant in the absence of late-season irrigation. The model predicts that an alfalfa crop will be produced if an initial early season irrigation is applied, and yields are in proportion to amount of irrigation water applied. One cutting can be reliably expected from spring runoff, and subsequent harvests can be obtained if water supplies continue to be available throughout the summer. This makes alfalfa a good choice when irrigation water supply is uncertain. In contrast, corn exhibits a serious decrease in production when water is limited and, if deprived of water for even several weeks in key growth stages (e.g., tasseling), corn will exhibit little or no yield. The third major crop in the county, grain sorghum, exhibits response to water shortage between the extremes of alfalfa and corn.

Crop water production functions were estimated for the three major crops grown in the county for the four soil associations. This was accomplished in two steps. First, a crop water production function for the best soil type was obtained for alfalfa, corn and sorghum. These production functions were then prorated by the percentage differences in expected yields estimated for the three soil categories (Larsen et al.). From the total water requirements on the production function the contribution of effective precipitation under the three precipitation states of nature was subtracted to obtain the irrigation water requirement.

Alfalfa yields are linearly related to water application over the range common harvest yields (Bauder et al., 1978.; Ayer and Hoyt, 1981), whereas corn and sorghum exhibit diminishing returns to water applications. The alfalfa production responses were estimated by regional extension specialists (Miles; Tranel, personal communications) to yield a maximum of four tons per acre for the best soils, with yield declining over the four cuttings by the ratio 4:3:2:1. Alfalfa was assumed to be irrigated after each of the four cuttings at 6 inches per acre.

As opposed to alfalfa, corn and sorghum production functions have been empirically derived using applied water. The production function for corn is:

$$Y_c = -4042 + 779W - 10.5W^2 ;$$

where Y_c is corn yield in pounds per acre, and W is season total field water supply (growing season precipitation and irrigation) (Stewart and Hagan). The amount of the preplant irrigation (4 inches) was add to W to standardize water input units as compared to alfalfa.

The sorghum production function is;

$$Y_s = 2169 + 523.7W_1 - 14.9W_1^2 ;$$

where Y_s is sorghum yield in pounds per acre, and W_1 is seasonal irrigation water applied (Shipley). Several modifications were then made to this function. The first was the addition of the preplant irrigation and seasonal precipitation to make the units comparable to the alfalfa and corn production functions. The experimental production functions for sorghum and corn were then prorated downward (25%) to match actual reported farm yields for the best soils in the region. Corn is assumed to be irrigated 4 to 6 times at the rate of 5 inches per acre per irrigation. Sorghum is irrigated 2 to 3 times at 4 inches per acre per irrigation. For both corn and sorghum, a 4 inch preplant irrigation is necessary (Miles, personal communication). A comparison of the derived production functions for corn, sorghum and alfalfa on the best soil shows that alfalfa begins producing even at the lowest levels of water application and continues throughout the growing season commensurate with water applications. At moderate levels of water, sorghum exceeds corn yields, while at high irrigation, sorghum production levels off and corn exceeds both alfalfa and sorghum yields. These simple production functions can only capture the quantity dimension of water application. With corn in particular, timing of water application is critical. Corn is most sensitive to water stress during pollination, and because of this sensitivity it is recommended that in the high evaporative demand of the southwest limited irrigation on corn should not be practiced (Musick). The timing problem can be somewhat ameliorated in Crowley County by releasing stored water during corn's critical pollination period. However, during drought years under high evaporative demand, corn yields can be reduced due to stress even when soil moisture is adequate (Musick). Timing of sorghum irrigation is not as critical as that of corn, provided that adequate moisture is available during the time of rapid seed head enlargement (Musick). Alfalfa can be dormant and, following precipitation or irrigation, can yield additional forage.

Since a continuous production function cannot be implemented into an DSSP, discrete points on corn, sorghum and alfalfa production functions are the production function activities with the corresponding input (water use) and output (yield) coefficients. The level of applied water at which the corresponding yields occur will be at the levels of the common irrigation timings and levels as shown in Table 4 (Don Miles, communication). The level of irrigation is assumed to be held constant across wet and dry years, since farmers do not know if the coming period is going to be wet or dry. Thus, the variation in yield in each production activity is assumed to be caused by stochastic variation of rainfall.

Alfalfa is commonly irrigated after each of the three cuttings at an average rate of 5 acre inches of water per acre. Water is usually not available for a fourth irrigation that would yield a fourth cutting or grazing. For alfalfa, two irrigation/harvest activities are constructed in the DSSP corresponding to the second and third cuttings. Revenues for the first cutting are included in the planting activities, as first cutting occurs as a result of pregrowing season water application along with preplant irrigation for sorghum and corn.

ALFALFA at 5 acre inches per irrigation.

1st	April 20 - May 10 runoff irrigation.
2nd	Early June after first cutting
3rd	Early July after second cutting
4th	Late July - early Aug after third cutting
5th	Late August - mid Sept. after fourth cutting in excess water years but occurs too infrequently to be included.

CORN at 4 acre inches per irrigation.

1st	Early May runoff irrigation for preplant.
2nd	Late June or early July
3rd	July 20 -25 critical tasseling irrigation
4th	Mid August at the blister to milk stage
5th	Late August - Early September at soft dough stage in excess water years but occurs too infrequently to be included.

SORGHUM at 4 acre inches per irrigation.

1st	Early May runoff irrigation for preplant.
2nd	Early July
3rd	July 25- August 15
4th	August to Sept. to increase grain yield in excess water years but occurs too infrequently to be included.

*Sorghum irrigation follows corn and is significantly less critical in timing.

Table 2. Irrigation Schedule and Amounts for Alfalfa, Corn and Sorghum

Two levels of irrigation for sorghum and corn are implemented as activities. Sorghum is irrigated an average of two to three times at a rate of 4 acre inches per acre, including a preplant, a June-July irrigation, and an August irrigation (Don Miles, communication). An optional fourth irrigation can occur in excess water years but is not usually practiced. For sorghum, two production function levels are constructed in the irrigation/harvest activities corresponding to the levels of the two growing season irrigation turns. The highest level is at a yield of 93 bushels per acre, and the lower level is at a yield of 77 bushels per acre on the best soils in wet years.

Corn is irrigated an average 4 to 5 times at the rate of 4 acre inches per acre, including a preplant irrigation that is usually assumed to be necessary, a late June or early July irrigation, the critical tasseling irrigation in late July, and a mid August irrigation to add an increment to grain yield. The activities are evaluated at the levels of the last two irrigations. Corn yields are at 131 and 154 bushels per acre for the two activity levels on the best soils in wet years.

Transit Water Loss

There are three principal causes of water loss from the total water diversions of the Arkansas River before the water is applied as irrigation. These losses consist of the seepage loss from the lengthy Colorado Canal, the loss after leaving the canal on the lateral ditches, and the evaporation loss in transportation and storage in Lake Meredith and Lake Henry.

Wheeler and Associates gathered data which consisted of Colorado Canal inflow-outflow measurements plus measurements of daily flow. They graphed Colorado Canal seepage as a percent of the Arkansas River headgate diversions and found that, on average, the seepage loss from the Colorado Canal was 15 percent at an exchange rate of 300 cfs. Lateral canal seepage loss was projected by Wheeler and Associates based on the U.S. Bureau of Reclamation canal design standards and the average lateral canal capacity. While lateral capacity varies within a season, Wheeler and Associates estimated lateral capacity at 60 percent for most of the irrigation season. At 60 percent capacity, the seepage loss from the lateral canals is about 10 percent.

Canal seepage loss of 25 percent from the Colorado Canal and the lateral canals agrees with the estimates of Don Miles, Colorado State University Extension Irrigation Engineer, who estimated that total canal seepage averaged 23 to 25 percent (Personal communication, Don Miles). Twenty-five percent canal seepage loss also matches the figures used by the Twin Lakes Irrigation Company in determining canal diversions (Personal communication, Allen Ringle).

Evaporation losses from Lake Henry and Lake Meredith, plus the evaporative losses from water in transit, were obtained from the Twin Lakes Irrigation Company records. The Twin Lakes Irrigation Company estimates that between 12 and 15 percent of the water stored in Lake Meredith and Lake Henry is lost due to evaporation from the lakes as well as evaporation of water in transit (Personal communication, Allen Ringle).

Total Loss due to canal seepage, evaporation from Lake Henry and Lake Meredith, and evaporation from water in transit was calculated at roughly 31 percent of the total Arkansas River diversions. The following general procedure was used to calculate Total Loss:

1. Fifteen percent of the total irrigation diversions was calculated, to arrive at the Colorado Canal seepage loss. This amount was then subtracted from the total diversions to adjust for the seepage loss.
2. Ten percent of the adjusted total diversions was calculated, to account for lateral canal seepage loss. This lateral seepage loss was added to the Colorado Canal seepage loss to arrive at the total canal loss.
3. Percentages of the total diversions were determined for Lake Meredith and Lake Henry, using data provided by Wheeler and Associates. Fifteen percent of these lake diversions was calculated to account for evaporation loss from storage and the evaporative loss in transit.

4. Total canal loss was added to the evaporation loss to arrive at a total loss figure. The total loss was then divided by the total Arkansas River diversions to come up with a 31 percent Total Loss due to canal seepage and evaporation.

Deterministic Static LP Formulation

To contrast conventional static analysis to the DSSP a deterministic static linear program (DSLP) was formulated. In the notation used for the DSSP the DSLP format was:

$$\text{MAX} \sum_{j=1}^{4}\sum_{k=1}^{3}\sum_{l=1}^{3} C_k \ X_{jkl}$$

$$\textit{subject to:}$$

$$\sum_{k=1}^{3} X_{jkl} \ \leq \ R1_j \ \ (j = 1 \ldots 4)$$

$$\sum_{k=1}^{3} B_k \ X_{jkl} \ \geq 0$$

$$\sum_{k=1}^{3} \sum_{l=1}^{3} E[A_{kl}] \ X_{jkl} \ \leq \ E[R2]$$

$$X \geq 0.$$

where: E is the expectations operator. Thus E[R2] is the mean irrigation diversion and E[A] is applied irrigation under mean precipitation. The data used in the DSLP were the expected value of irrigation deliveries and the expected crop production for each of the three crops on each respective soil for the three levels of irrigation application with mean precipitation.

RESULTS

Results of the study can be classified as the direct and the indirect consequence of irrigated agriculture. Indirect impacts follow from the direct changes in crop production resulting from changing amounts or prices of irrigation water in Crowley County. The value that irrigation has for the Crowley County and the Lower Arkansas River Valley region economy is two-fold: (1) the direct or primary benefit to the farms that use the irrigation water, and (2) the indirect or secondary benefits from economic activity that irrigated farms generate. We will first discuss the direct and indirect impacts of irrigated farming on the Lower Arkansas River Valley region economy.

Before examining and interpreting the results, the reliability of the model should be assessed. An economic model should be able to explain observed behavior in a specific or similar situation. Then, the model can be relied on to predict impacts of hypothetical or actual policy initiatives (Johnson). To validate the DSSP as a forecast of irrigation demand, we can show how the DSSP primal results explained regional farmer behavior as water has been transferred from the county. When primal results are accurate, reliability of dual results follow. Primal DSSP results are then contrasted to primal DSLP results. Following the assessment of the DSSP, the dual results of demand for agricultural irrigation water and the expected foregone agricultural benefits are discussed with reference to the agriculture to urban water transfers.

PART I: DSSP VALIDATION

Soils upon which crops are planted cannot be observed. However, historic crop acreage is available for Crowley County over time as water has been withdrawn from the county (Colorado Department of Agriculture). Regional crop mixture thus provides an observed behavior to which predicted behavior can be compared to validate DSSP primal results. In 1972, before water transfers began and in a year when Colorado Canal diversions were virtually equal to the mean, there were 46,200 irrigated and harvested acres of the major crops in the county: 15,500 in corn (34%); 23,700 in alfalfa (51%); and 7,000 (15%) in sorghum (the remaining acres in minor crops) (Colorado Department of Agriculture). The reported total acres harvested and crop mixture in 1972 was approximately that predicted by the DSSP (Table 1). The DSSP showed 32% corn, 58% alfalfa, and 11% sorghum as the optimal crop mix prior to irrigation withdrawals or at the mean of irrigation diversions as shown in Table 1. The actual acres of 47,000 is close to the DSSP prediction of 43,000 acres. In 1972, about 1,000 acres of potentially irrigated land were idle compared to the DSSP which showed that 4,500 acres of the poorest soils would not be cropped. Only with above average irrigation deliveries did the DSSP predict the poorest quality soil (soil 4) to be cultivated.

Despite the water transfers, water-intensive alfalfa continued to dominate the actual cropping pattern in the county. By 1989, an estimated 60 to 70% of the water had been transferred from the county (Flack, personal communication), causing irrigated acres of the major crops to drop by 60% to 18,300 acres, including 6,500 acres (36%) of corn; 2,500 acres (14%) of sorghum; and 9,300 acres (51%) of alfalfa (Colorado Department of Agriculture). At 35% of mean diversions (Table 3), the DSSP showed 18,073 acres irrigated, including 2,395 acres of corn (13%); 15,486 acres of alfalfa (86%); and 192 acres of sorghum (1%). As was the case prior to irrigation withdrawals, predicted versus actual total irrigated acres was again close. However, the correspondence of predicted to actual crop mix was not as close as it was prior to water withdrawals.

Following withdrawals, the disparity between predicted crop mix and actual crop mix is, we conjecture, in large part a result of a court ordered revegetation project in progress on dried-up lands in the county. Under the ruling, alfalfa is prohibited, and corn or sorghum are used as cover crops to establish native grasses. Approximately 10,000 acres were to be revegetated incrementally beginning in 1988 and to be completed by 1993 (City of Aurora). A second reason for the discrepancy may be the existence of integrated crop-livestock farms. This integration, in the case of Crowley County, would result in corn and sorghum being used as on-farm livestock feed (e.g. silage). An on-farm shadow price higher than the market price might be associated with those crops as on-farm livestock feed in lieu of purchasing such feeds. This markup would be particularly true for corn and sorghum for silage, which have a higher transportation cost per nutrient content. As irrigation water is transferred from the county, a localized shortage of silage might be created, prices could rise and corn could become more profitable to raise. Thus, corn acreage might increase in the crop portfolio. There is one moderately-sized commercial feedlot and a number of farms that include livestock in the county.

PART II: DIRECT IMPACT MEASURES

The direct impacts of the water transfers are reflected in the declining demand for irrigation as water prices are raised or water is transferred outside the county. To estimate the scenarios of declining water use allocations or increasing irrigation price, results of the DSSP will be called into use. DSSP results will be used to predict changes in farm decisions (soil use, crops planted and irrigation usage) and the resulting demand for irrigation. Each of these issues will be discussed in the following section.

Soil Quality, Crop Portfolio and the Planting Decision

At the first stage in the sequential production process, before irrigation deliveries and precipitation are known, a farmer must decide on crop planting amount and mixture on each soil. Optimal crop and soil mix changes as water is withdrawn from the county. In a scenario where irrigation is non-binding relative to the better quality soils (e.g., 125% of the mean deliveries), the three crops are predicted to be grown on the soils with the greatest comparative advantage (Table 3). Corn would be planted exclusively on all 17,000 acres of soil 1, with alfalfa as a rotation crop. Alfalfa would be the sole crop planted on soils 2 and 3, in rotation with sorghum. Because no other crop can be grown on soil 4, alfalfa is planted there without a rotation crop. Besides the crop and soil portfolio, the DSSP solution gives the shadow price of the land for the various soil types. These shadow prices can be thought of as a short-run rent, or the price that farmers with an adequate supply of machinery, labor, and managerial capacity would be willing to pay to farm an additional acre of land with its associated water right in the respective soil type. At 125% of mean water deliveries, an acre of soil 1 land would be worth $130 per acre to a farmer. Because other soils exhibit reduced productivity, their value declines correspondingly, down to $3 per acre for soil 4.

Crop Planted	SOIL 1	SOIL 2	SOIL 3	SOIL 4
SCENARIO 1: MEAN IRRIGATION DIVERSIONS[b]				
alfalfa	3,394	8,212	13,094	0
corn	13,577	0	0	0
sorghum	0	1,371	3,273	0
land price[c]	80	49	8	0
SCENARIO 2: 125% OF MEAN IRRIGATION DIVERSIONS				
alfalfa	3,394	8,212	13,094	4,453
corn	13,577	0	0	0
sorghum	0	1,371	3,273	0
land price	130	83	36	3
SCENARIO 3: 75% OF MEAN IRRIGATION DIVERSIONS				
alfalfa	3,394	8,212	1,397	0
corn	13,577	0	0	0
sorghum	0	1,371	349	0
land price	64	40	0	0
SCENARIO 4: 50% OF MEAN IRRIGATION DIVERSIONS				
alfalfa	14,193	8,212	0	0
corn	2,778	0	0	0
sorghum	0	1,371	0	0
land price	7	4	0	0
SCENARIO 5: 35% OF MEAN IRRIGATION DIVERSIONS				
alfalfa	14,542	944	0	0
corn	2,395	0	0	0
sorghum	34	158	0	0
land price	2	0	0	0
SCENARIO 6: 25% OF MEAN IRRIGATION DIVERSIONS				
alfalfa	12,461	0	0	0
corn	2,081	0	0	0
sorghum	0	0	0	0
land price	0	0	0	0

[a] Optimal planting is the crop acreage decision made at the first of the three sequential stages of production, which corresponds to decisions made at stage one in the decision tree of Figure 1.

[b] Irrigation diversion scenarios were made by changing the diversion constraint ($R2_m$ m=1,2) by the respective percentage of the mean diversions in both adequate and inadequate states of nature.

[c] Land price ($/acre) is the shadow price of an acre of the respective soil type.

Table 3. Predicted Optimal Acres Planted, by Crop and Soil Type, for Various Levels of Irrigation Diversions in Crowley County.

As the first increment of water was withdrawn from the county, the DSSP predicted that farmers would discontinue planting a portion of alfalfa, in favor of corn, to accommodate the declining water supply. After 25% of the irrigation had been withdrawn, the amount of corn planted on soil 1 remained the same (Table 3). Under the same level of withdrawals, planting of alfalfa fell by 50% on soil 4, (the worst soils) and on a portion of soil 3 acreage. With 50% or more irrigation withdrawal, the DSSP predicted that alfalfa alone (with corn or sorghum in rotation) will be the optimal planting decision for Crowley County farmers. Alfalfa acreage will rise over the first phases of water withdrawal as alfalfa increases in farmers' crop portfolio, including on the best soils (soils 1 and 2). Table 1 shows that at 50% of mean diversions, alfalfa will be grown on all 17,000 acres of soil 1 and on all 9,600 acres of soil 2, in rotation with corn and sorghum, respectively. In the final stages of water withdrawal (e.g., 25%), corn was discontinued even as the rotation crop.

In summary, before water is withdrawn, the model predicts corn to be planted on the best soil and alfalfa on the remaining soils. As water is withdrawn, farmers steadily decrease alfalfa planting, continuing to plant corn on the best soil. As water withdrawals pass 50%, corn planted on the best soil is replaced by alfalfa, except as a rotation crop. As the water shortage becomes more acute, alfalfa will dominate the crop plantings.

Irrigation Intensity Decisions

In the second stage of the sequential crop process, farmers are informed of the level of canal diversions available for the coming growing season. They then decide on the irrigation intensity in the coming growing season for those previously planted crops. Recall that this decision is contingent upon diversions being inadequate or adequate, after which the farmer has for each crop a choice of one of three levels of irrigation intensity: low, medium, and high.

When farmers find that irrigation deliveries will be adequate, the optimal decision by farmers is to irrigate all of the previously planted crops to the highest level. The reason for this decision is that acreage and planted crop mix are made in anticipation of inadequate diversion, as is the case 75 percent of the time. Inadequate diversions are the binding constraint on the amount and mixture of crop land planted and, when adequate water does occur, it cannot be used effectively. Indeed, historically, when diversions have been abundant, some water has not been used for growing season irrigation, but rather has been reservoir-stored or soil-stored as fall irrigation. The exceptions to this are when diversions are at the 50% and 25% levels. At these levels, a fraction of the alfalfa is irrigated to mid levels (Table 4). For example, at 50% of water withdrawals, 18% of the 8,211 total acres planted to alfalfa on soil 2 will be irrigated at the mid level, and 82% will be irrigated at the highest level (Table 4). However, the optimum irrigation for all other crops is at the highest level. Thus, at the severest levels of water withdrawal, it is sometimes more profitable to irrigate only a fraction of alfalfa at the mid level in order to apply water to the previously planted rotation crop of corn or sorghum.

In general, when farmers are informed that irrigation deliveries are inadequate, the strategy is to irrigate corn to the highest level at the expense of alfalfa, which is then irrigated at the lowest levels in rotation with sorghum irrigated at mid to high levels. This optimal decision

CROP IRRIGATED	SOIL 1	SOIL 2	SOIL 3	SOIL 4
SCENARIO 1: MEAN IRRIGATION DIVERSIONS				
INADEQUATE IRRIGATION STATE				
alfalfa	3,394.low	8,212.low	13,094.low	0.
corn	13,577.high	0.	0.	0.
sorghum	0.	1,371.med	2,651 low; 622.med	0.
ADEQUATE IRRIGATION STATE				
alfalfa	3,394.high	8,212.high	13,094.high	0.
corn	13,577.high	0.	0.	0.
sorghum	0.	1,371.high	3,273.high	0.
SCENARIO 2: 125% OF MEAN IRRIGATION DIVERSIONS				
INADEQUATE IRRIGATION STATE				
alfalfa	3,394.med	8,212.med	12,353 low; 740. med	4453.low
corn	13,577.high	0.	0.	0.
sorghum	0.	1,371.high	3,273.high	0.
ADEQUATE IRRIGATION STATE				
alfalfa	3,394.high	8,212.high	13,094.high	4453.med
corn	13,577.high	0.	0.	0.
sorghum	0.	1,371.high	3,273.high	0.
SCENARIO 3: 75% OF MEAN IRRIGATION DIVERSIONS				
INADEQUATE IRRIGATION STATE				
alfalfa	3,394.med	8,212.med	1,397.low	0.
corn	13,577.high	0.	0.	0.
sorghum	0.	1,371.high	349.high	0.
ADEQUATE IRRIGATION STATE				
alfalfa	3,394.med	8,212.med	1,397.low	0.
corn	13,577.high	0.	0.	0.
sorghum	0.	1,371.high	349.high	0.
SCENARIO 4: 50% OF MEAN IRRIGATION DIVERSIONS				
INADEQUATE IRRIGATION STATE				
alfalfa	14,193.low	8,212.low	0.	0.
corn	2,778.med	0.	0.	0.
sorghum	0.	1,371.med	0.	0.
ADEQUATE IRRIGATION STATE				
alfalfa	14,193.	1,479 med; 6,732.high	0.	0.
corn	2,778.	0.	0.	0.
sorghum	0.	1,371.high	0.	0.
SCENARIO 5: 35% OF MEAN IRRIGATION DIVERSIONS				
INADEQUATE IRRIGATION STATE				
alfalfa	14,542.low	944.low	0.	0.
corn	2,395.med	0.	0.	0.
sorghum	33.low	158.low	0.	0.
ADEQUATE IRRIGATION STATE				
alfalfa	14,542.high	944.high	0.	0.
corn	2,395.high	0.	0.	0.
sorghum	33.high	158.high	0.	0.
SCENARIO 6: 25% OF MEAN IRRIGATION DIVERSIONS				
INADEQUATE IRRIGATION STATE				
alfalfa	12,461.low	0.	0.	0.
corn	2,081.high	0.	0.	0.
sorghum	0.	0.	0.	0.
ADEQUATE IRRIGATION STATE				
alfalfa	3,941 mod; 8,520. high	0.	0.	0.
corn	2,081.	0.	0.	0.
sorghum	0.	0.	0.	0.

Low, med, and high refer to the optimal irrigation intensities in the model solution as applied to the corresponding crop acreage. Optimal irrigation intensity is determined for previously planted crops. This decision is made at the second of the three sequential stages of production, (Stage two of the decision tree of Figure 1) upon coming to expect that growing season irrigation diversions will be either adequate or inadequate.

Table 4. Predicted optimal irrigation intensity, by crop and soil type, for various scenarios of irrigation deliveries.

to heavily irrigate corn with minimal alfalfa irrigation continues until approximately 50% of the irrigation water has been transferred from the county. At this point corn is no longer a profitable choice to be planted on soil 1, as determined in the planting stage. Alfalfa then becomes the principal crop to be irrigated at the lowest level when water is inadequate. Corn is the rotation crop to be irrigated at the mid level. In summary, when farmers expect that water will be inadequate, alfalfa will be irrigated at the lowest level and corn will continue to be irrigated at the higher levels, similar to the practices followed in the presence of adequate irrigation water.

Demand Schedules for Irrigation Water -- Dual Results

Dynamic decisions must account for previous decisions, uncertainty, and the effect of present decisions on future decisions. Thus, factor demands in a sequential production process are a function of previous input quantities, expected output prices, and expected future input quantities (Antle 1988). Likewise, demand for preplant through growing season irrigation, as modeled by the DSSP, is determined by expectations of crop prices, precipitation and irrigation deliveries. From this list of demand determinates, crop price, precipitation and probabilities of deliveries[2], are determined outside Crowley County. In contrast, irrigation diversions and water sales policies are determined by decision makers within Crowley County and, thus, become the focus of demand results.

There are two demand schedules for irrigation corresponding to the two states of nature for diversions ($R2_m$ m=1,2) in the DSSP. The demand schedules in Tables 5 and 6 (shown as graphs in Appendix III) are derived from the DSSP by plotting the shadow price for diversions in the adequate state of nature (Table 6) and diversions in the inadequate state of nature (Table 5) obtained from parameterizing the constraint on diversions across intervals of 10% of mean diversions in each state of nature. Held constant in these demand schedules are attributes of the production process (crop rotation, production function technology and acreage constraints) and above mentioned factors exogenous to Crowley County decision makers (precipitation, crop prices and probabilities). Apparent from these demand schedules are the principal characteristics of stochastic irrigation demand in Crowley County.

The first characteristic of the regional stochastic irrigation demand is that the value of expected deliveries in one state of nature is conditional, based upon expected irrigation deliveries in the opposite state. Expected deliveries in one state of nature complement actual water use in the opposite state in the uncertain sequential production process. The planting and irrigation decisions are undertaken with the expectations of future irrigation deliveries, and irrigation in one state of nature cannot substitute for water in the opposite state. Reflecting the complementary of diversions in the adequate and inadequate states of nature, the horizontal quantity axis rotates in opposite directions around the vertical price axis (Figures 1 and 2, Appendix III). When diversions in the adequate state of nature are expected to be 50% of

[2] Changing probability of diversions is in effect changing the seniority of water right which cannot be altered by local policy nor has it been exchanged in the market.

Inadequate Diversions		Adequate Diversion									
Amount		0	13525	27050	40576	54101	67626	81151	94676	108201	121727
(ac-ft)	Percent	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%
0	0%	88	89	88	88	88	88	88	88	88	88
7312	10%	0	81	88	88	88	88	88	88	88	88
14624	20%	0	57	81	88	88	88	88	88	88	88
21936	30%	0	39	71	80	86	86	86	86	86	86
29248	40%	0	0	57	72	79	86	86	86	86	86
36559	50%	0	0	51	71	76	76	76	76	76	76
43871	60%	0	0	39	54	72	76	76	76	76	76
51183	70%	0	0	0	46	64	72	72	72	72	72
58495	80%	0	0	0	39	39	40	55	55	55	55
65807	90%	0	0	0	22	27	39	48	55	55	55
73119	100%	0	0	0	10	26	37	39	48	48	48
80431	110%	0	0	0	0	22	27	38	39	39	39
87743	120%	0	0	0	0	10	26	27	27	27	27
95055	130%	0	0	0	0	4	10	15	18	26	26
102367	140%	0	0	0	0	0	7	10	10	10	10
109679	150%	0	0	0	0	0	4	9	9	9	9
116990	160%	0	0	0	0	0	2	4	4	4	4
124302	170%	0	0	0	0	0	0	0	0	0	0
131614	180%	0	0	0	0	0	0	0	0	0	0
138926	190%	0	0	0	0	0	0	0	0	0	0
146238	200%	0	0	0	0	0	0	0	0	0	0

Table 5. Shadow Prices ($/acre-foot) for Inadequate Diversions Given a Level of Adequate Diversions.

average, those diversions are valued at approximately $3 per acre foot; given that expectations of diversions in the inadequate state of nature are also at 50% of average (Table 6). However, if expected inadequate diversions were at the mean, the value of adequate diversions would rise to $13 per acre foot (Table 6). Further, the complementary relation is evident when inadequate state of nature diversions are 50% of normal. Irrigation in that state of nature has a value of approximately $76 per acre foot, given that expectations of inadequate state of nature diversions are also at 50% of average (Table 5). However, if expected adequate diversions were at the

Inadequate Diversions		Adequate Diversions									
Amount		0	13,525	27,050	40,576	54,101	67,626	81,151	94,676	108,202	121,727
(ac-ft)	Percent	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%
0	0%	122	0	0	0	0	0	0	0	0	0
7,312	10%	122	3	0	0	0	0	0	0	0	0
14,624	20%	122	24	3	0	0	0	0	0	0	0
21,936	30%	122	51	11	3	0	0	0	0	0	0
29,248	40%	122	122	24	8	3	0	0	0	0	0
36,559	50%	122	122	32	9	3	3	0	0	0	0
43,871	60%	122	122	39	24	8	3	0	0	0	0
51,183	70%	122	122	104	32	13	3	0	0	0	0
58,495	80%	122	122	104	32	13	9	0	0	0	0
65,807	90%	122	122	104	32	24	11	4	0	0	0
73,119	100%	122	122	104	50	24	13	11	3	1	0
80,431	110%	122	122	104	67	32	23	11	3	1	0
87,743	120%	122	122	104	67	50	24	13	3	1	0
95,055	130%	122	122	104	67	59	24	13	9	1	0
102,367	140%	122	122	104	67	67	24	16	9	3	0
109,679	150%	122	122	104	67	67	28	16	9	3	0
116,990	160%	122	122	104	67	67	32	16	9	3	0

Table 6. Shadow Prices ($/acre-foot) for Adequate Diversions Given a Level of Inadequate Diversions.

mean, inadequate diversions value would remain at $76 per acre foot (Table 5). This brings us to the second aspect of stochastic demand for the region.

The second demand characteristic, illustrated in a comparison of Figures 1 and 2, Appendix III, is that demand for diversions in the inadequate state of nature is more elastic than adequate state of nature diversions. The demand for diversion in the adequate state of nature exceeds $120 per acre foot when adequate diversions are at low levels and with inadequate diversions present to complement the adequate diversions (Table 6). Demand for diversions in the adequate state of nature then drops quickly. Conversely, the demand for inadequate diversion is more elastic and reaches a high value of just under $90 per acre foot when adequate diversions are present to complement the inadequate diversions (Table 5). When adequate diversions are expected at 50%

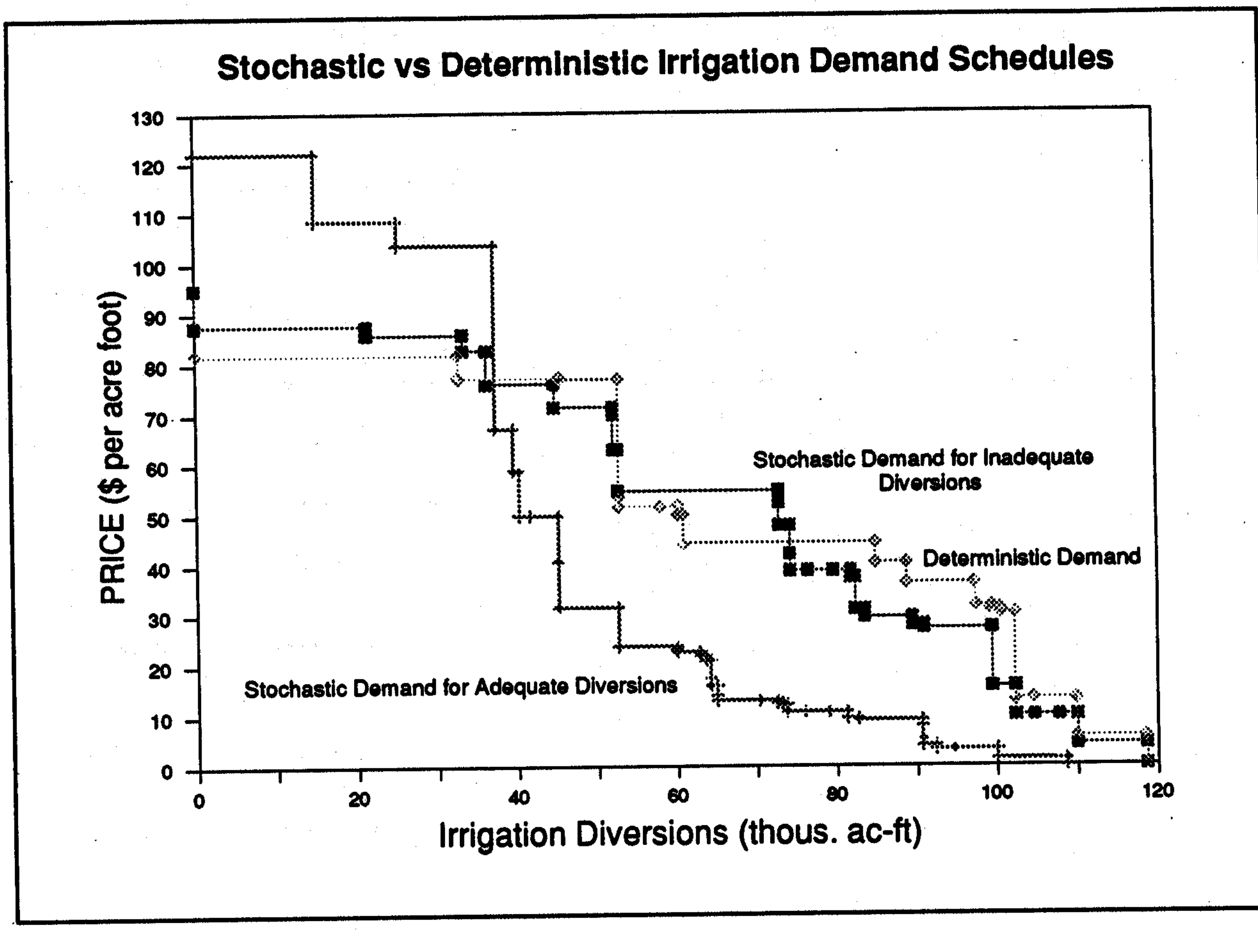
of normal, adequate diversions are valued at approximately $3 per acre foot; given that expectations of inadequate diversions are also at 50% of average (Table 6). The differences in elasticity are evident as compared to when inadequate diversions are 50% of normal, diversions are valued at approximately $76 per acre foot, given that inadequate diversions are also at 50% of average (Table 5). Irrigation in the inadequate state of nature is usually the binding constraint on crop production, along with the greater probability that the inadequate state of nature combines to have the effect that a given percentage in irrigation in this state will cause a greater change in the value of crops of grown in the region. When adequate diversions occur, the amount of water delivered exceeds the capacity of agricultural production utilization. Thus, when the demand functions are portrayed as percent of the mean deliveries, as was done in Tables 5 and 6, it is obvious that irrigation in excess of the mean in the adequate state of nature will have no value.

Taking a cross section of Figures 1 and 2, Appendix III, again allows comparison of elasticities but further allows comparison of stochastic demand with the certain demand derived from the DSLP. Price and own quantity demand schedules were obtained by parameterizing the constraint on irrigation deliveries (R2) from zero to unbounded and obtaining the shadow price at each basis change. In the DSSP derived demands, deliveries in the opposite state of nature held fixed at the mean. At the mean level of diversions for the two states of nature, an acre foot of irrigation in the inadequate state of nature is valued at $48 (Figure 5). In an adequate irrigation water year, 26,600 acre feet go unused, making its shadow price zero. At approximately 40,000 acre feet of diversion, the value of irrigation in the two states of nature is equal at approximately $80 per acre foot. At the historic median diversion level of 87,000 acre feet, the shadow price of irrigation in the inadequate state of nature is $27 per acre foot, while in the adequate state of nature the same level of diversion is $9 per acre foot (Figure 5).

When risk is accounted for in a sequential crop production process, input use efficiency declines (Antle), which decreases the expected value for the stochastic input. Water provided with certainty is equivalent in value to water in shortage years, as shown in Figure 5, by coincidence of derived demand from the DSLP model and demand for water in the inadequate years (Figure 5). The expected value of uncertain irrigation is derived by prorating the value of deliveries by probabilities of occurrence. At mean deliveries in each delivery state of nature, uncertain water supplies are valued at $25 per acre foot (.75 * $30 + .25 * $9). In comparison, at mean diversions irrigation delivered with certainty is valued at $36 per acre foot. Thus, economic efficiency of irrigation is reduced when irrigation is stochastic. The vertical distance between the demand functions is the effect of risk on the marginal value of water to the firm or, stated differently, the vertical distance is the payment needed to make a farmer indifferent between uncertain and uncertain irrigation deliveries. Thus, there is an $11 penalty for risky irrigation. Again, this example is based on conditional demands and would vary if the adequate and inadequate demands were taken at different cross sections of the demands in Figures 3 and 4.

Demand elasticity and interdependence of deliveries play an important role in water policy for the region. Cities that have purchased water and are now contemplating lease-back agreements for unneeded water face differing values for that irrigation water, depending not only on the state of nature in which the water is to be leased, but also the expected amount to be leased in the opposite state of nature. If cities plan to transfer water for their needs only in shortage years this policy may make the value of water leased back to farmers in adequate years worthless. The loss in value of water can be illustrated through the penalty for assuming the risk in deliveries of irrigation.

Figure 5. Stochastic Versus Deterministic Demand for Irrigation Diversions



Regional Foregone Income

The expected regional return to the residual claimants (in 1987 prices) will have dropped from $5.5 million before water was withdrawn to $1.6 million after 75% of the water in the inadequate years is transferred from the region (Table 8). Instead of a straight percentage withdrawal, water was withdrawn from areas of poorer soils first, thus creating the necessity of modeling separate soil associations in the DSSP[3]. The objective function measured the expected regional return to the residual claimants of water, land, management and overhead (depreciation and taxes). Thus, to derive the value of foregone water withdrawals, the annual management and

[3] The exception was of several areas served by lengthy leaky lateral ditches.

overhead costs of $46 per acre are subtracted. The estimated average foregone value was about $21 per acre foot, and value of soil 1 alone was one third greater (Table 7). These values represent the areas under the demand functions (net of a payment to land, management and overhead) where the constraint on soil use corresponds to a level of water use (Figures 3 and 4). The $21 per acre foot is equal to $0.065 per 1,000 gallons, or $0.10 per 1,000 gallons, after converting water withdrawn to the consumptive use basis that can actually be transferred. In comparison, Gibbon (1987) and Young (1984) provide derived estimates for residential water value in the western U.S. of about $0.90 per 1,000 gallons ($300 per acre foot). Thus, residential water is about nine times the value of the transferable value of water in crop production in Crowley County.

Of course, a number of additional costs must be accounted for to demonstrate that a net economic gain will be achieved from the transfer. These are the conveyance and transactions cost of accomplishing the transfer from agriculture to urban use. With this overwhelming value in favor of urban use, it is doubtful that the lower value that risk brings to agricultural water would be the deciding factor in the social benefit of transfer from agriculture to urban use of water from Crowley County.

Scenario	Soil Associations	Water Value
1	All (1,2,3,4)	$21
2	1,2,3	$23
3	1,2	$27
4	1	$28

Table 7. Annual Value of Irrigation Water Withdrawn From Crowley County by Soil Associations (1988 dollars per acre-foot).

Irrigation Deliveries (% of mean)*	Planted Acreage (acres)			Expected Regional Income (millions)
	CORN	ALFALFA	SORGHUM	
		DSSP Results		
150%	14,948	29,153	3,273	6.4
125%	14,948	29,153	3,273	6.1
100%	13,577	24,700	4,644	5.5
75%	13,577	13,003	1,721	4.5
50%	2,778	22,404	1,371	3.2
35%	2,395	15,486	191	2.2
25%	0	12,461	2,081	1.6
		DSLP Results		
150%	14,948	29,152	3,273	6.7
125%	14,948	29,152	3,273	6.6
100%	13,577	24,700	4,644	6.0
75%	13,577	15,510	2,347	5.0
50%	13,577	6,509	520	3.7
35%	10,641	2,660	0	2.6
25%	7,601	1,900	0	1.8

***Irrigation deliveries for the DSSP scenarios are percentages of the mean deliveries in the inadequate and adequate states of nature.**

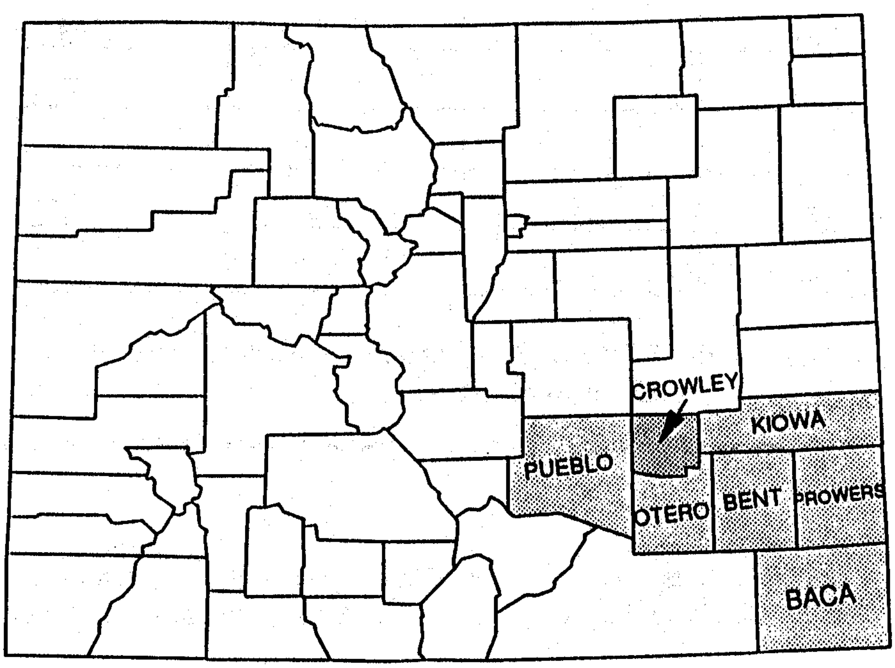
Table 8. Primal Results: Optimal Crop Mix and Expected Regional Income Under Scenarios of Water Transfers for Both the Adequate and Inadequate States of Nature, as Forecast by the DSSP and DSLP.

PART III: INDIRECT EMPLOYMENT IMPACTS

Preliminaries

The first step in regional impact analysis is the definition of the region over which the impacts are to be assessed. A region may be delineated on political, hydrologic or geographic boundaries. However, for reliable impact analysis several economic criteria must be evoked. The first criteria is that the region must incorporate the direct impacts of the project in question. If portions of the project development lie outside the defined region, impacts will be understated. The second criteria aids in assessment. The region should encompass the major trade centers for the project direct impacts. In the case of Crowley County, the major trade center for agriculture input purchases, and most other purchases, is outside the county. Thus, the major impacts of irrigation withdrawals would be felt in a larger region that provides these inputs to Crowley County. The last criteria is that the estimated impacts of Crowley County irrigation withdrawals must be comparable to other proposed irrigation withdrawals within an identical region definition. For these reasons, the impact analysis region will be defined as the entire lower Arkansas River Valley, which includes the seven counties of Baca, Bent, Crowley, Kiowa, Otero, Prowers and Pueblo as shown in the shaded area of Figure 6.

Figure 6. The Seven-County Lower Arkansas River Valley Region of Colorado.



Any economy, be it national, regional, or local, is characterized by interdependence among producing sectors of the economy. Industries who produce goods and services for final use or export are similarly dependent upon other industries for production inputs. Producers must also rely on those industries providing factors of production which are produced outside the region and must be imported. Because of the economic ties that exist among producers in a developed economy, such as the Lower Arkansas River Valley region, the activities in one sector create indirect repercussions throughout the remaining sectors of the economy. The tool we use to examine these regional interrelationships is an input-output (I/O) model for the Lower Arkansas River Valley region economy, with data partly derived from the MicroIMPLAN system (Taylor et al., 1990).

The I/O model is both an accounting and analytic tool. The I/O model provides a systematic method of regional accounting in a double entry format. Appendix II shows a legend for the sector definitions. The total gross sales/purchases, employment and business multipliers for each sector of the Lower Arkansas River Valley Region are shown in Table 9.

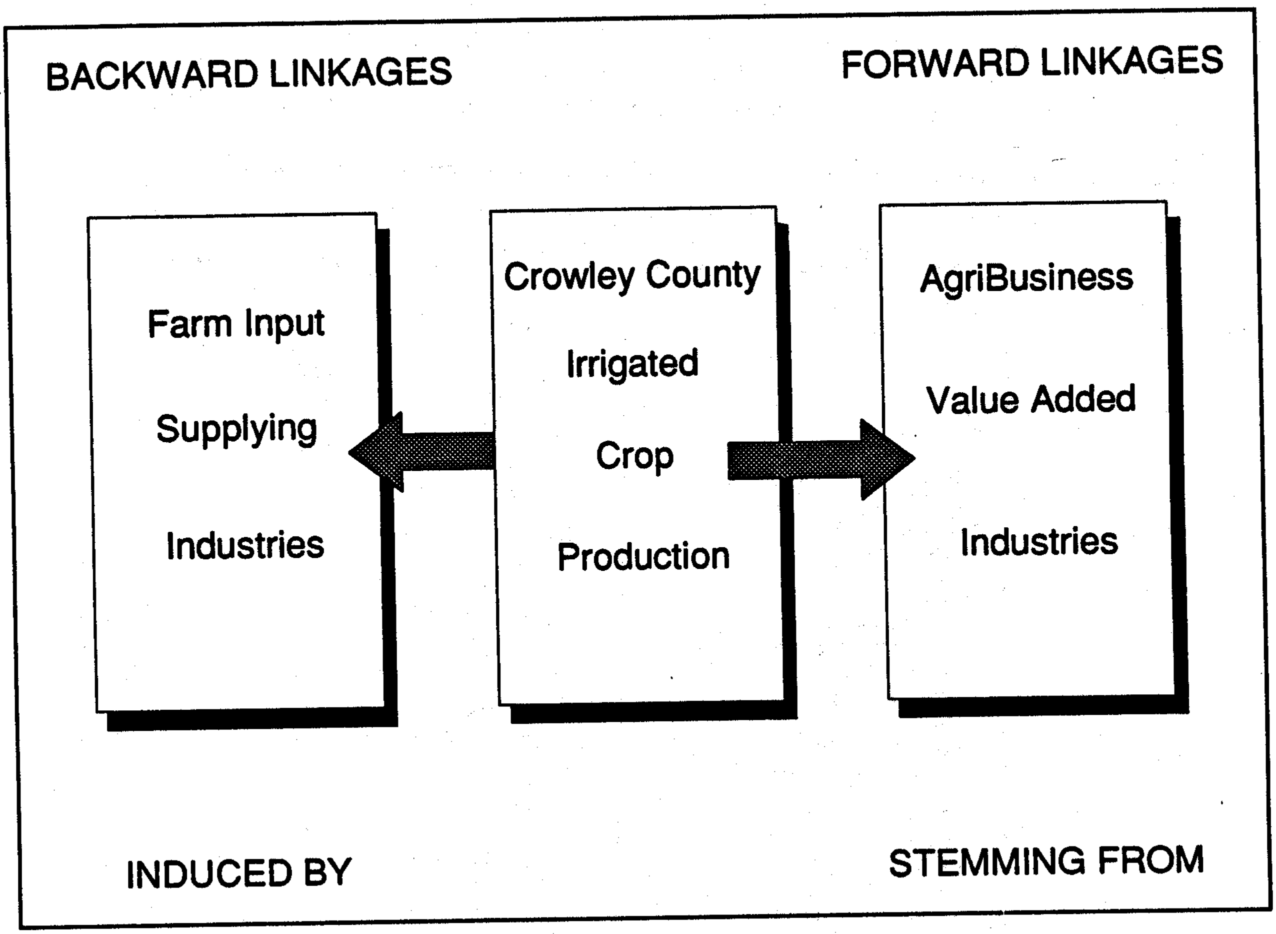
INDUSTRY	GROSS SALES	MULTIPLIER	JOBS
1 Other Livestock	18,843,450	3.01	379.85
2 Beef Cattle	503,520,960	2.80	5473.27
3 Grains	99,501,992	1.67	790.04
4 Hay	38,364,000	2.30	39.13
5 Other Ag	58,423,824	2.43	1543.99
6 Mining	41,256,840	1.23	201.62
7 Construction	323,527,680	1.76	4578.99
8 Farm Inputs	49,874,888	1.73	387.99
9 Beef Process	6,314,940	3.18	17.99
10 Poultry Process	2,063,390	1.44	6.99
11 Food Process	170,721,632	1.57	1067.00
12 Grain Process	776,980	1.77	3.99
13 Apparel	16,816,210	1.78	288.99
14 Wood/Paper/Publishing	50,316,008	1.87	728.00
15 Chemicals/Petroleum	39,300,568	1.49	209.00
16 Stone/Glass	23,244,200	1.70	272.99
17 Metal Industry	399,996,864	1.77	2133.00
18 Machines	191,496,416	1.56	868.99
19 Technical/Electric	82,157,760	1.83	930.99
20 Transportation/Communication	218,787,632	2.00	2663.0
21 Utilities	197,845,760	1.42	669.99
22 Trade	393,548,928	2.14	16617.24
23 F-I-R-E	448,881,920	1.51	3836.00
24 Services	314,895,008	1.88	9654.99
25 Health	393,054,880	2.09	8541.00
26 Government/Non profit	570,165,760	2.61	18169.0
27 Other	38,546,496	1.14	2558.94
28 Households	2,511,000,064	1.85	

Table 9. Total Gross Sales (1990 dollars), Employment, and the Output or Business Multipliers (direct, indirect, and induced spending per dollar of added sales to final demand) in the Lower Arkansas Valley Region.

Methods of Indirect Impact Assessment

The indirect impacts of irrigation transfers are the ripple effects of the primary impact as farmers cease to produce crops (Figure 7). These indirect ripple effects can have two origins: 1) the backward linkages, "induced by" farmers as they cease to purchase inputs (fertilizer, equipment etc.) to produce crops, and 2) the forward linkages, stemming from the loss of supply of crops for industries using these crops in their production (feedlots, cattle ranches etc.).

Figure 7. Classification of Industries Indirectly Affected by Crowley County Irrigated Crop Production.



Some irrigated crops from Crowley County are sold to industries inside and outside the county (corn grain, hay and sorghum grain are transported to nearby counties) and these sales constitute the backward links. Crops that are sold to feedlots and cattle ranches in the seven county region are the forward links. Conventional I/O applications involve backward linked effects. The problem with the forward linked impacts is that feedlots, ranches and other industries that use crops from Crowley County may import feed to continue operation, thereby mitigating any possible impacts. Also, other farmers in the Valley may stop exporting hay and sell to the local cattle industry as the irrigation water from Crowley County is transferred to urban areas.

The physical amounts of crops--measured by tons of alfalfa and bushels of corn and sorghum--with each level of irrigation water transferred, is the basis from which to measure the multiplier effect upon the regional economy. Changes in physical amount are then translated into gross value of crop output from Crowley County. Gross value of output, in turn, determines the ripple or multiplier effect on the Lower Arkansas River Valley economy.

The physical amount of crop production was determined from predictions of the DSSP. However, as shown previously, crop production is not deterministic, but rather stochastic.

The estimated crop acreage for each soil was prorated by the predicted yield. This was determined by predicted irrigation intensity and the probability of that yield occurring as determined by the probability of the diversions and growing season precipitation from the DSSP model. Expected crop production used in the I/O model is taken as the physical amount of irrigated crop which underlies the DSSP estimates of expected regional income (Table 8). Thus, the total physical production of crops is the expected (average) amount, and the corresponding impacts of the water transfers are also measured as expected impacts.

Irrigation Diversions	Alfalfa	Corn	Sorghum
	tons	bushels	
100% of Average	58,184	1,631,955	263,563
125% of Average	71,216	1,631,955	298,920
75% of Average	39,446	1,631,955	125,351
50% of Average	58,911	292,246	94,455
35% of Average	40,806	251,954	10,373
25% of Average	32,500	250,136	0

Table 10. Expected crop Production From Crowley County Under Various Levels of Irrigation Diversions.

The direct impacts of the respective scenarios of decreases in crop production (Table 10) can also be interpreted as direct employment changes. Direct employment and Gross Sales (Table 9) are based upon the IMPLAN data, which in turn are based upon national spending patterns and estimates for the entire Lower Arkansas River Valley. For any given region, production technology, especially that of employment, may be far different than that predicted by

IMPLAN. The crop production technology represented for the corn sector in IMPLAN most likely represents corn production in the corn belt, in the nonirrigated Midwest.

To obtain better estimates of the direct employment impact of water transfers, we can return to the crop enterprise budget data (Dalsted). Agricultural labor can be related to the acreage of the respective crop -- alfalfa, corn, and sorghum. For the Lower Arkansas River Valley, the estimated acres of corn per *full time equivalent* (FTE) worker, (conventionally assumed to be fifty forty-hour work weeks or 2000 hours per year) ranged from 400 to 500 acres and for alfalfa, 280 acres per FTE.[4] Sorghum labor requirements were assumed to equal corn. The acreage predictions on which employment estimates are based are those acreages of the respective crop as forecasted by the DSSP model (Table 11). Labor usage is based on an average level of irrigation, and DSSP results show that optimal irrigation levels vary. However, the employment data are not sufficiently precise to judge these differences. Using enterprise budget data, the total irrigated acreage in Crowley County was estimated to employ approximately 125 FTE. In contrast, the 1974 Census of Agriculture enumerated 156 irrigated farms in Crowley County. However, 11 percent of those irrigated farms had sales of less than $2,500; thus, only 139 irrigated farms in Crowley County were more than very small "hobby" farms. A portion of the 139 farms are part-time farmers, and a portion of the larger farms hire labor. The weighted average of the two groups shows that enterprise budget estimates of county agricultural labor are very close to the Census enumeration of labor on irrigated farms.

We can also cross-check IMPLAN employment data (Table 9) with enterprise budget estimates of employment for the entire seven county Lower Arkansas River Valley region. Fairly large discrepancies are noted; enterprise budget employment estimates 451 and 489 FTE grain and hay, respectively. In contrast, IMPLAN notes employment at 790 and 39 for grains and hay, respectively. Despite the discrepancies in total regional employment estimated by IMPLAN, when adjusted, IMPLAN remains an acceptable tool to estimate the indirect impacts of water transfers. The following section shows how IMPLAN will be used to estimate indirect impacts and how enterprise budget data and other data will be used to estimate the direct impacts of water transfers.

Forward links are assessed by ascertaining purchase patterns and estimating the degree and feasibility of substitutability from imports. The industries that purchase Crowley County crops may decline by the proportion that Crowley County supplies their irrigated crop needs if imports are not feasible. The principal sectors that purchase Crowley County crops are the cattle sector and exports outside the region. If all crops were sold to export, impacts would be entirely backward linked. However, a portion of the crop is used by the local cattle industry, making impacts in this sector forward linked from the crop sectors of the economy. We can, however, calculate the maximum amount that these sectors decline and, assuming that the cattle sector

[4] Estimates for labor requirements for corn were (at $5.00 per hour) a total labor bill of $19.63 per acre and total labor bill for alfalfa of $34.72 per acre in 1989 (Dalsted). Assuming a 50 forty hour work weeks per work year per full time worker equivalent, the labor coefficient was 500 acres per worker for corn and 280 acres per worker for alfalfa.

Irrigation Deliveries (% of mean)	Planted Acreage (acres)			Crowley County Employment (FTE)
	CORN	ALFALFA	SORGHUM	
125%	14,948	29,153	3,273	140
100%	13,577	24,700	4,644	125
75%	13,577	13,003	1,721	80
50%	2,778	22,404	1,371	90
35%	2,395	15,486	191	60
25%	0	12,461	2,081	50

Table 11. Direct Employment Impacts for the Optimal Crop Mix Under Scenarios of Water Transfers for Both the Adequate and Inadequate States of Nature, as Forecast by the DSSP.

sells entirely to export, calculate the backward linked impacts of the cattle sector on the regional economy. With that overview we can proceed to develop the multipliers and impact estimates.

Backward-Linked I/O Multipliers

An I/O model is also a model of production in a regional economy. To model the indirect effects, which is the main analytical purpose of I/O, we can derive multipliers that show both direct and indirect effects of changes in the regional economy. Formulation of the backward-linked I/O model begins with a definition of an accounting identity for each sector, where the sum of sales to intermediate processing industry demands plus the sum of sales to final demands equals that sector's total gross spending and saving. For the i^{th} industry, the input-output equality can be expressed as:

$$X_i = (z_{i1} + \ldots + z_{ij} + \ldots + z_{in}) + F_i.$$

where the X_i are industry outputs which equal industry spending and saving, and the z_{ij}'s are simultaneously endogenous intermediate processing flows from sector I to sector j. The variable F_i is exogenous final demands. A condensed transactions table is shown in Figure 8, and includes P, which represents endogenous (recursive) final payments.

Figure 8. A Schematic of a Three-Industry I/O Transactions-Among-Sectors Table.

	PURCHASING INDUSTRIES					
SELLING INDUSTRIES	z_{11}	z_{12}	z_{13}	F_1	X_1	row sums
	z_{21}	z_{22}	z_{23}	F_2	X_2	
	z_{31}	z_{32}	z_{33}	F_3	X_3	
	P_1	P_2	P_3	F_m		
	X_1	X_2	X_3			
	column sums					

For an n sector model, the accounting balance equation can be expressed as;

$$X = (Z)(U) + (F)(U);$$

where **Z** is an n by n intermediate processing sector matrix, **F** is a matrix of final demands and **U** is a column vector of ones. The $(n)^2$ simultaneously determined unknowns (the z_{ij}'s) can be reduced to equal the n number of accounting balance equations by substituting the definition of the direct input requirement coefficients in place of the z_{ij}'s. The economic implication of the direct input coefficients is for fixed spending shares on factor inputs.

Define a sector's direct input requirement coefficient as $a_{ij} = z_{ij}/X_j$, thus the n by n matrix of direct input requirement coefficients is;

$$A = (Z)(X^D)^{-1};$$

where **Z** are the intermediate processing flows and $\mathbf{X^D}$ is a matrix with the total output vector on the main diagonal and zero's elsewhere. Post multiplying through by $\mathbf{X^D}$ and rearranging terms gives an expression for the intermediate processing quadrant **Z**;

$$Z = (A)(X^D).$$

The term, $(\mathbf{A})(\mathbf{X}^D)$, is substituted into the accounting equation in place of **Z**. Output equilibrium can be stated as;

$$X = (A)(X^D)(U) + (F)(U);$$

which reduces to;

$$X = (A)(X) + (F)(U) \text{ or } (I - A)(X) = (F)(U);$$

where **I** is the identity matrix. Final demands can exist at any non-negative level and regional production is <u>assumed</u> to be able to fulfill those demands. Solving this equilibrium statement results in:

$$X = (I - A)^{-1}(F)(U).$$

The solution shows the "total requirements coefficients" in matrix $(\mathbf{I}\text{-}\mathbf{A})^{-1}$ which are composed of the direct, indirect, and induced requirements per dollar of sales to final demand. Elements in a given column of the inverse matrix show total impacts on each sector of a change in sales to final demand by the sectors at the column head.

Modeling Exogenous Change in Spending

Exogenous change in farm spending, such as required by shortfall of irrigation water, is not the same as a change in sales to final demand. An exogenous change in farm output, as opposed to a change in farm exports, can be modeled by inserting new final demand columns for affected farm producers which have fixed spending coefficients similar to direct input coefficients. Each non-zero element of the new final demand columns will change in proportion to change in total output (spending) in these new "sectors." Since the coefficients define an input requirement equation for the new "sectors," it can be said that individual elements in the sector column are endogenous on total sector output (spending). Thus, these new "sectors" differ from the usual final demand column where every element is independent. This formulation is the exogenous sales multiplier defined by Stone (1961).

If industry j is made exogenous (or partly exogenous), sector j now appears in the final demand and final payments quadrants. If it is further stipulated that some of the <u>output</u> (X_j) of sector j is exogenous, the relevant calculations are a <u>concurrent</u> change of $z_{1j} = (a_{1j})(X_j)$ introduced in final demand sales by industry 1 and a change of $z_{2j} = (a_{2j})(X_j)$ introduced in final demand sales by industry 2. Likewise, changes in z_{3j} through z_{mj} and P_j are proportional to changes in X_j. Thus, each element of the j^{th} column of the transactions table is fixed by the exogenous value of X_j. The elements of the j^{th} row, z_{j1} through z_{jn} are recursively endogenous on X1 through X_n. The remaining elements of the j^{th} row, sales to final demand, F_j, are assumed to adjust to use up excess output by sector j.[5] The solution of the model becomes;

$$X = (I - A)^{-1}(F^{*})(U)$$

where the final demands matrix, F^{*}, includes columns containing $a_{1j}X_j$ ... $a_{mj}X_j$. For the constrained farm producers, part of output X_j, is now exogenous and included in the final demand matrix F^{*}.

The Stone methodology can be used to create new "sectors" not contained in the standard industrial classifications, such as exogenous spending change created by water or other resource constraints, the conservation reserve program, timber harvest restrictions by federal land management agencies, or environmental regulations. The Stone method is appropriate for modeling the cumulative economic impacts of changing irrigation water supply conditions.

Sales and Employment Impacts

Sales and employment impacts are calculated for three scenarios using the Industry Modeling System (IMS) program (Johnston and McKean, 1992) The scenarios studied are: (1) irrigation water supply declines from 100% of normal to 50% of normal in Crowley County; (2) irrigation water supply contracts from 100% of normal to 25% of normal in Crowley County; and (3) irrigation water supply contracts from 100% of normal to 25% of normal in Crowley County plus output of the livestock sector falls by 18% in the seven county region. In the first scenario, gross sales of hay rose by $58,160 and grain sales fell by $3,493,299. In, the second scenario, gross sales of hay fell by $2,054,720 and grain sales fell by $3,784,943. The third scenario is the same as the second, except that cattle output fell by $90,650,193 because of a shortfall of hay.

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[5] The implicit assumption is D_i is recursively endogenous. Excess demand is assumed.

It is clear, from comparison of the projected sales and employment impacts (Tables 12 and 13), that the critical unknown is how much the reduction of feed production in Crowley County affects cattle output in the seven county region. If feed exports from the region are cut to allow the region's cattle sector to maintain output rates, then sales and employment impacts are very small. Conversely, if local hay or imports are not used to replace the shortfall when the supply of irrigation water is reduced, then the sales and employment impacts are much larger. Employment falls by 1,486, which is about 1.8% of total employment in the seven county region. The latter scenario seems unlikely, however, since abundant hay supplies exist in the region. About 2/3 of the hay crop was exported prior to the diversions. If corn imports were restricted, the impacts are likely to be larger than shown in scenario three, where it is assumed that feed corn supplies will still be abundant. A shortage of grain feeds also seems unlikely since about 85% of grain production was exported prior to the diversions. Howe, Lazo, and Weber also found that feed lots had expanded even as water was transferred from other ditches in the Lower Arkansas River Valley. Hay and grain output in the seven county region fell by less than 2 percent due to the diversion. Thus, abundant supplies of cattle feed are likely to exist in the seven county region.

A summary of employment impacts, exogenous, direct, and indirect, are provided in Table 12. The third scenario, where cattle exports are significantly impacted, seems unlikely given the large amount of hay and corn exported from the seven county region. A 75% withdrawal (25% of average) seems to be a likely long-term scenario. Some irrigation water will continue to be supplied to the county. Some of the farmers choose not to sell their water. Also, cities have leased back unneeded water. The total impact of this scenario is a loss of 125 jobs in the Lower Arkansas River Valley economy. This comprises 75 (125-50) jobs which are the on-farm direct employment loss (Table 11), plus 14 direct jobs lost, and 36 indirect jobs lost. The direct and indirect job losses are ascertained from the I/O model, as discussed above. Thus, the largest portion of the total job loss is the exogenous (on-farm direct employment) category and is estimated without the error introduced by the use of the IMPLAN-based I/O model.

Scenario	Diversion Scenario	Exogenous	Direct	Indirect	TOTAL
1	Reduced to 50% of Average	-35	-6.5	-15.6	-57
2	Reduced to 25% of Average	-75	-14.4	-36.1	-125
3	Diversion 25% of Average and reduced Cattle	-1,854.5	-335.2	-1,151.0	-3,340.0

Table 12. Employment loss (direct, indirect and total) in the Lower Arkansas River Valley Region under various scenarios of irrigation loss.

In comparison, Howe, Lazo, and Weber estimated an employment loss of 157 jobs in the entire state of Colorado as a result of a more complete inventory of water transfers from 48,000 acres on five ditches in the Arkansas River Valley. Their finding can be expressed as one job total loss in Colorado per 308 acres. A similar calculation from only our seven county region shows a total impact of one job in the region for each 227 acres (125 jobs/ (42921 acres - 14542 acres)), in the most likely scenario of a 75% water transfer. The disparity between the two calculations can be explained by recognizing that we estimated employment loss from enterprise budget data in lieu of less accurate IMPLAN data, even though we estimated impacts on only the seven county region instead of the entire state of Colorado, and we estimated impacts resulting from only the water transfers in Crowley County. We chose not to accept the IMPLAN estimate of only 39 workers in the Hay sector (Table 9) for the entire Lower Arkansas Valley. Enterprise data-based estimates show a greater number for Crowley County alone. Thus, for the Arkansas Valley, enterprise budget- based direct job impact estimates will be greater than estimates using unadjusted IMPLAN data. We believe that the adjustment provides a more accurate estimate of job losses, although neither estimate is very large from the regional employment perspective.

INDUSTRY	50% Average		25% Average	
	Change (1990 dollars)	% Change	Change (1990 dollars)	% Change
1 Other Livestock	-8446.	-.0448	-19,082.	-.1013
2 Beef Cattle	-37,184.	-.0074	-79,904.	-.0159
3 Grains	-9,064.	-.0091	-15,728.	-.0158
4 Hay	-1884.	-.0049	-4,396.	-.0115
5 Other Ag	-73,312.	-.1255	-165,352.	-.2830
6 Mining	-2,480.	-.0060	-5,288.	-.0128
7 Construction	-23,520.	-.0073	-53,312.	-.0165
8 Farm Inputs	-61,524.	-.1234	-145,900.	-.2925
9 Beef Process	-2,611.	-.0413	-6,067.	-.0961
10 Poultry Process	-720.	-.0349	-1,671.	-.0810
11 Food Process	-8,128.	-.0048	-18,880.	-.0111
12 Grain Process	-14.	-.0018	-83.	-.0107
13 Apparel	-3,446.	-.0205	-7,972.	-.0474
14 Wood/Paper/Publishing	-6,440.	-.0128	-14,880.	-.0296
15 Chemicals/Petroleum	-336.	-.0009	-760.	-.0019
16 Stone/Glass	-144.	-.0006	-340.	-.0015
17 Metal Industry	-1,984.	-.0005	-4,672.	-.0012
18 Machines	-8,416.	-.0044	-19,504.	-.0102
19 Technical/Electric	-4,704.	-.0057	-10,904.	-.0133
20 Transportation/Communication	-64,560.	-.0295	-147,728.	-.0675
21 Utilities	-42,400.	-.0214	-96,640.	-.0488
22 Trade	-154,848.	-.0393	-360,512.	-.0916
23 F-I-R-E	-256,928.	-.0572	-576,896.	-.1285
24 Services	-108,992.	-.0346	-248,032.	-.0788
25 Health	-109,408.	-.0278	-254,016.	-.0646
26 Government/Non profit	-61,312.	-.0108	-140,224.	-.0246
27 Other	-15,564.	-.0404	-34,796.	-.0903
28 Households	-1,186,048.	-.0472	-2,753,536.	-.1097
29 Business Taxes	-204,656.	-.0838	-467,248.	-.1913
30 Property Income	-63,744.	-.0298	-146,704.	-.0686
31 Other Income	-1,747,488.	-.3948	-1,966,880.	-.4443
32 Imports	-1,419,264.	-.0527	-3,258,880.	-.1209

Table 13. Gross Sales Loss (1990 dollars) in the Lower Arkansas River Valley Region When Crowley County Diversions are 50% and 25% of Average.

INDUSTRY	25% of Average	
	Change (1990 dollars)	% Change
1 Other Livestock	-2,679,786.	-14.22
2 Beef Cattle	-19,473,632.	-3.87
3 Grains	-2,610,984.	-2.62
4 Hay	-2,497,716.	-6.51
5 Other Ag	-1,068,592.	-1.83
6 Mining	-58,416.	-.14
7 Construction	-1,024,992.	-.32
8 Farm Inputs	-666,804.	-1.34
9 Beef Process	-193,262.	-3.06
10 Poultry Process	-52,979.	-2.57
11 Food Process	-628,608.	-.37
12 Grain Process	-15,987.	-2.06
13 Apparel	-233,426.	-1.39
14 Wood/Paper/Publishing	-404,924.	-.80
15 Chem/Petrol	-16,456.	-.04
16 Stone/Glass	-9,272.	-.04
17 Metal Industry	-36,544.	-.01
18 Machines	-566,016.	-.30
19 Tech/Electric	-301,808.	-.37
20 Trans/Communication	-3,104,944.	-1.42
21 Utilities	-2,316,752.	-1.17
22 Trade	-10,140,768.	-2.58
23 F-I-R-E	-13,857,760.	-3.09
24 Services	-6,547,488.	-2.08
25 Health	-8,153,344.	-2.07
26 Govt/Non profit	-3,807,040.	-.67
27 Other	-550,144.	-1.43
28 Households	-87,434,240.	-3.48
29 Business Taxes	-17,473,376.	-7.15
30 Property Income	-3,532,672.	1.65
31 Other Income	-1,795,328.	-.41
32 Imports	-73,688,832.	-2.73

Table 14. Gross sales loss in the Lower Arkansas River Valley Region when Crowley County diversions are 25% of normal and the Crowley County hay shortage creates an 18% percent reduction of cattle output.

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APPENDIX I

Appendix I. Budgets for corn, alfalfa and sorghum for the planting/1st irrigation, growing season, and harvest activities.

Table 1. Objective function and irrigation water use for the stage 1 planting/preplant irrigation activities.

Crop Type	Irrigation	Irrigation	Planting
	Applied water	Delivered Water	costs
Alfalfa	0.50	0.66	42.35
Corn	0.33	0.44	93.71
Sorghum	0.33	0.44	67.69

Table 2. Objective function and irrigation input coefficients for irrigation activities.

Crop Type	DIVERSION STATE	DIVERSION PROB	GROW SEASON IRRIGATION	IRRIGATION DIVERSION	IRRIGATION LABOR COST	OBJECTIVE VALUE
			Acre Feet	Acre Feet	$/Acre Ft.	$/Acre
Production function level 1 (low water use)						
alfalfa	no	0.75	0.50	0.66	$11.25	$4.22
corn	no	0.75	0.83	1.09	$8.44	$5.28
sorghum	no	0.75	0.33	0.44	$8.44	$2.11
alfalfa	yes	0.25	0.50	0.66	$11.25	$1.41
corn	yes	0.25	0.83	1.09	$8.44	$1.76
sorghum	yes	0.25	0.33	0.44	$8.44	$0.70
Production function level 2 (medium water use)						
alfalfa	no	0.75	1.00	1.31	$11.25	$8.44
corn	no	0.75	1.25	1.64	$8.44	$7.91
sorghum	no	0.75	0.67	0.87	$8.44	$4.22
alfalfa	yes	0.25	1.00	1.31	$11.25	$2.81
corn	yes	0.25	1.25	1.64	$8.44	$2.64
sorghum	yes	0.25	0.67	0.87	$8.44	$1.41
Production function level 3 (high water use)						
alfalfa	no	0.75	1.50	1.97	$11.25	$12.66
corn	no	0.75	1.67	2.18	$8.44	$10.55
sorghum	no	0.75	1.00	1.31	$8.44	$6.33
alfalfa	yes	0.25	1.50	1.97	$11.25	$4.22
corn	yes	0.25	1.67	2.18	$8.44	$3.52
sorghum	yes	0.25	1.00	1.31	$8.44	$2.11

Table 3. Objective function values for harvesting and selling activities.

Crop Type	DIV	DIV PRB	PRECIP STATE	PRECIP PROB	HARVEST COSTS	YIELD SOIL 1	YIELD SOIL 2	YIELD SOIL 3	YIELD SOIL 4	CROP PRICE	OBJ Value s1	OBJ Value s2	OBJ Value s3	OBJ Value s4
Production function level 1 (low water use)														
alfalfa	no	0.75	dry	0.6	21.20	2.1	2.1	1.68	1.26	73.38	59.80	59.80	45.94	32.07
corn	no	0.75	dry	0.6	10.28	64	48	38.4	0	2.75	74.57	54.77	42.89	0.00
sorghum	no	0.75	dry	0.6	8.88	48	43.2	33.6	0	2.46	49.14	43.83	33.20	0.00
alfalfa	no	0.75	wet	0.4	21.20	2.8	2.8	2.24	1.68	73.38	55.28	55.28	42.95	30.62
corn	no	0.75	wet	0.4	10.28	88	66	52.8	0	2.75	69.52	51.37	40.48	0.00
sorghum	no	0.75	wet	0.4	8.88	68	61.2	47.6	0	2.46	47.52	42.50	32.46	0.00
alfalfa	yes	0.25	dry	0.6	21.20	2.1	2.1	1.68	1.26	73.38	19.93	19.93	15.31	10.69
corn	yes	0.25	dry	0.6	10.28	64	48	38.4	0	2.75	24.86	18.26	14.30	0.00
sorghum	yes	0.25	dry	0.6	8.88	48	43.2	33.6	0	2.46	16.38	14.61	11.07	0.00
alfalfa	yes	0.25	wet	0.4	21.20	2.8	2.8	2.24	1.68	73.38	18.43	18.43	14.32	10.21
corn	yes	0.25	wet	0.4	10.28	88	66	52.8	0	2.75	23.17	17.12	13.49	0.00
sorghum	yes	0.25	wet	0.4	8.88	68	61.2	47.6	0	2.46	15.84	14.17	10.82	0.00
Production function level 2 (medium water use)														
alfalfa	no	0.75	dry	0.6	31.80	2.7	2.7	2.16	1.62	73.38	74.85	74.85	57.02	39.18
corn	no	0.75	dry	0.6	10.28	93	69.75	55.8	0	2.75	110.46	81.69	64.43	0.00
sorghum	no	0.75	dry	0.6	8.88	68	61.2	47.6	0	2.46	71.28	63.75	48.70	0.00
alfalfa	no	0.75	wet	0.4	31.80	3.6	3.6	2.88	2.16	73.38	69.71	69.71	53.86	38.01
corn	no	0.75	wet	0.4	10.28	111	83.25	66.6	0	2.75	88.49	65.60	51.86	0.00
sorghum	no	0.75	wet	0.4	8.88	82	73.8	57.4	0	2.46	57.85	51.80	39.70	0.00
alfalfa	yes	0.25	dry	0.6	31.80	2.7	2.7	2.16	1.62	73.38	24.95	24.95	19.01	13.06

corn	yes	0.25	dry	0.6	10.28	93	69.75	55.8	0	2.75	36.82	27.23	21.48	0.00
sorghum	yes	0.25	dry	0.6	8.88	68	61.2	47.6	0	2.46	23.76	21.25	16.23	0.00
alfalfa	yes	0.25	wet	0.4	31.80	3.6	3.6	2.88	2.16	73.38	23.24	23.24	17.95	12.67
corn	yes	0.25	wet	0.4	10.28	111	83.25	66.6	0	2.75	29.50	21.87	17.29	0.00
sorghum	yes	0.25	wet	0.4	8.88	82	73.8	57.4	0	2.46	19.28	17.27	13.23	0.00
Production function level 3 (high water use)														
alfalfa	no	0.75	dry	0.6	42.40	3	3	2.4	1.8	73.38	79.98	79.98	60.17	40.36
corn	no	0.75	dry	0.6	10.28	115	86.25	69	0	2.75	137.69	102.11	80.76	0.00
sorghum	no	0.75	dry	0.6	8.88	82	73.8	57.4	0	2.46	86.78	77.70	59.55	0.00
alfalfa	no	0.75	wet	0.4	42.40	4	4	3.2	2.4	73.38	75.34	75.34	57.72	40.11
corn	no	0.75	wet	0.4	10.28	128	96	76.8	0	2.75	102.52	76.12	60.28	0.00
sorghum	no	0.75	wet	0.4	8.88	89	80.1	62.3	0	2.46	63.02	56.45	43.31	0.00
alfalfa	yes	0.25	dry	0.6	42.40	3	3	2.4	1.8	73.38	26.66	26.66	20.06	13.45
corn	yes	0.25	dry	0.6	10.28	115	86.25	69	0	2.75	45.90	34.04	26.92	0.00
sorghum	yes	0.25	dry	0.6	8.88	82	73.8	57.4	0	2.46	28.93	25.90	19.85	0.00
alfalfa	yes	0.25	wet	0.4	42.40	4	4	3.2	2.4	73.38	25.11	25.11	19.24	13.37
corn	yes	0.25	wet	0.4	10.28	128	96	76.8	0	2.75	34.17	25.37	20.09	0.00
sorghum	yes	0.25	wet	0.4	8.88	89	80.1	62.3	0	2.46	21.01	18.82	14.44	0.00

APPENDIX II

SIC Codes and IMPLAN Industrial Sector Codes for 1990 IMPLAN Model of the seven county Lower Arkansas River Valley I/O model.

SECTOR NAME and NUMBER	STANDARD INDUSTRIAL CODES (SIC)	IMPLAN NUMBER
1 Farm Inputs	2873 2874 2875 2879 3523 3556 (15, 16, 17)	52 202-204 309 330
2 Dairy-Poultry-Other Livestock	0241 0251-0253 0214 0271 0272 (0191 0219 0259 0291) 0212 0273 0213 (0191 0219 0259 0291)	1 2 6-9
3 Cattle	0211 (0191 0212 0219 0259 0291)	3-5
4 Feed and Food Grains	0111 0112 0115 (0139 0191 0219 0259 0291)	11 12
5 Hay and Pasture	(0139 0191 0219 0259 0291)	13
6 Other Crops/Forestry	0131 0132 0182 0171 0172 (0173) 0174 0133 0134 0161 (0179 0119 0139) 0810 0970 (0181 0191 0219 0259 0279 0291) 0910 0830 0710 0720 0750 0760 0780 0116 (0119 0139 0173 0219)	10 14-27
7 Meat Processing	2011 2013	58-59
8 Dairy Egg and Poultry Process	2021-2024 2026 2015	60-65
9 Food and Beverage Process	2091 2032 2033 2034 2035 2037 2038 2047 2048 2051 2067 2087 2095 2097 2098 2099 2110 2120 2130 2140 2082-2086 2052 2053 2061 2062 2063 2064 2066 2068 2092 2096	66-71 77-85 91-107
10 Grain and Oil Process	2041 2043-2046 2074-2077 2079	72-76 86-90

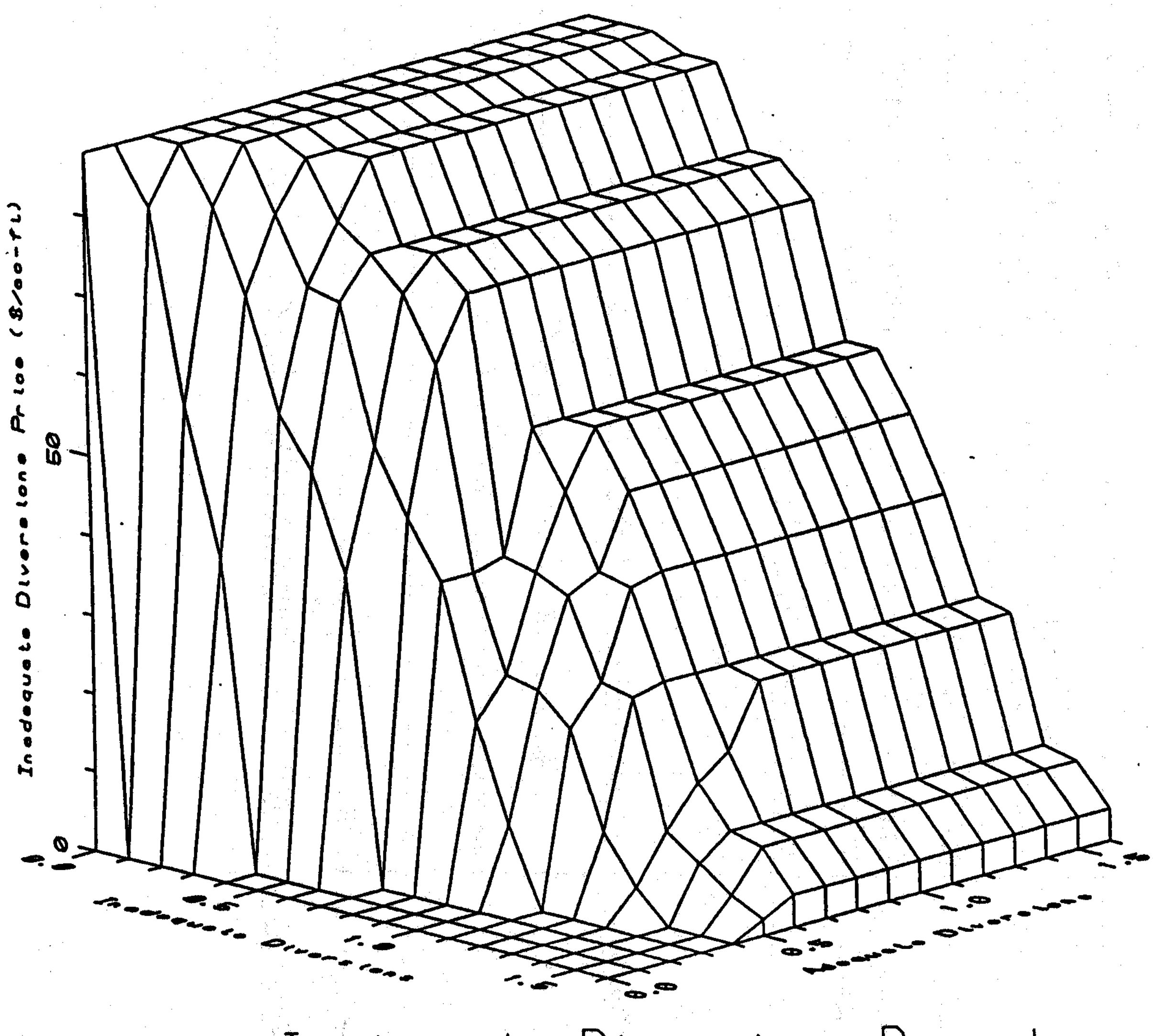
11 Mining	1010 1020 1030 1041 1044 1060 1080 1200 1094 1099 1320 1410 1420 1440 1310 1450 1474 1475 1479 1480 1490	28-47
12 Construction	1380 (15, 16, 17)	48-51 53-57
13 Metal Industries	3312 3313 3315 3316 3317 3320 3331 3334 3339 3340 3351 3353-3357 3369 3398 3399 3462 3463 3482 3483 3484 3489 3411 3412 3431 3432 3433 3441 3442 3443 3444 3446 3448 3449 3450 3465 3466 3469 3471 3479 3495 3496 3493 3494 3498 3497 3499 3363 3365 3364 3366 3421 3423 3425 3429 3491 3492 (2819)	254-306
14 Apparel/Yarn/Leather	2210 2220 2230 2240 2251-2254 2257-2259 2261 2262 2269 2270 2281 2282 2284 2295-2299 2310 2320 2330 2340 2350 2360 2370 2380 2391-2397 2399 3110 3130 3142 3143 3144 3149 3150 3160 3171 3172 3190	108-132 221-229
15 Wood/Paper/Publish	2410 2421 2426 2429 2431 2434 2435 2436 2439 2441 2448 2449 2452 2491 2499 2511 2512 2514 2515 2517 2519 2521 2522 2541 2591 2599 2610 2620 2630 2650 2710 2720 2731 2732 2740 2750 2760 2770 2782 2789 2791 2451 2493 2530 2671 2672 2673 2674 2675 2676 2677 2678 2679 2796	133-185
16 Chem/Petro	2821-2824 2830 2841-2844 2850 2861 2891 2892 2893 2895 2899 2910 2951 2952 2992 2999 3010 3020 3060 2812 2813 2816 2819 2865 2869 3080 3052 3053	186-201 205-220
17 Stone/Clay/Glass	3210 3221 3229 3230 3240 3253 3255 3259 3261-3264 3269 3271-3275 3280 3291 3292 3295 3296 3297 3299 3251	230-253
18 Machinery and Equipment	3511 3519 3524 3531-3537 3541-3547 3548 3552 3553 3554 3555 3556 3549 3559 3561-3569 3711 3713-3716 3721 3724 3728 3731 3732 3740 3750 3764 3769 3792 3799 3761 3795	307 308 310-329 331-338 384-399
19 Technology/ Electric	3572 3574 3576 3579 3651 3652 3661 3671-3679 3691 3692 3694 3699 3575 3577 3578 3571 3581 3582 3585 3586 3589 3592 3593 3594 3596 3599 3612 3613 3621 3624 3625 3629 3631 3632 3633 3634 3635 3639 3641 3643 3644 3645 3646 3647 3648 3663 3669 3695	339-383 400-432

20 Service and Professional	7000 7210 7220 7230 7240 7250 7260 7290 7310 7320 7331 7340 7350 7360 7370 7620 7630 7640 7690 7800 7910 7920 7930 7941 7948 7992 7993 7996 7997 7999 7991 7338 7383 7389 7334 7335 7336 7384 7381 7382 7510 7520 7542 7530 7549 8110 8350 8320 8390 8710 8720 8990 8740 8730	463-489 494 499 500 506-509
21 Trans/Commun	4010 4740 4810 4820 4830 4890 4100 4200 4400 4500 4600 4720 4730 4783 4785 4840 (4789)	433-442 510
22 Utilities	4910 4920 4940 4952 4953 4959 4960 4970 (4930)	443-446 514 511
23 Trade Wholesale/Retail	5000 5100 5200 5300 5400 5600 5700 5500 5800 5900	447-455
24 Financial/Real Estate	6000 6100 6710 6720 6733 6790 6200 6300 6400 6500	456-462
25 Health Services	0740 8010 8020 8030 8050 8060 8070 8080 8090 8040 8360	490-493 501
26 Education Government and Nonprofit	8210 8220 8230 8240 8290 8330 4311 8400 8650 8690 6732 8922 8610 8620 8630 8640 8660	513 512 515 519-523 495-498 502-505
27 Misc. and Balance	8800	516-518 524-528

* Those SIC codes listed in parenthesis are partially included in the IMPLAN sector.

APPENDIX III
Three Dimensional Demand Schedules for Irrigation Diversions

Figure 1. Demand for diversion in the inadequate delivery state of nature. The Y-axis is the price ($/acre foot) of inadequate diversions and the X-axis is the corresponding quantity of inadequate diversions (as percent of average). The Z-axis is the quantity of diversions in the alternative state of nature; adequate.



Inadequate Diversions Demand

Figure 2. Demand for diversion in the adequate delivery state of nature. The Y-axis is the price ($/acre foot) of adequate diversions and the X-axis is the corresponding quantity of adequate diversions (as percent of average). The Z-axis is the quantity of diversions in the alternative state of nature; inadequate. Note that the Z-axis in Figure 2 is reversed as compared to Figure 1.