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**Price-Responsiveness of Demand
for Irrigation Water Withdrawals vs. Consumptive Use:
Estimates and Policy Implications**

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***Selected Paper prepared for presentation at the Western Agricultural Economics Association
Annual Meeting, Denver, Colorado, July 11-15, 2003***

Abstract:

Of water withdrawn for agricultural crop irrigation, a portion is consumed and the remainder comes back to the hydrologic system as return flows. Previous models of irrigation water demand have mostly focused on the change in withdrawals in response to price changes, even though knowledge of the response of consumptive use is often more significant for river basin planning. This study develops a simulation/mathematical programming model of water demand representing an irrigation company in northeastern Colorado to analyze the effect of hypothetical price increases on both the demand for withdrawals and a derived demand for consumptive use. The results demonstrate that consumptive use demand tends to be significantly less price-responsive than withdrawal demand. Elasticity estimates are shown to be highly dependent on the particular model assumptions.

Key words: crop simulation, irrigation, linear programming, water conservation, water-demand elasticities, water policy

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Introduction

Irrigation of agricultural crops accounts for 80 to 90% of water withdrawals in the semi-arid and arid western United States. Most of the water used for irrigation yields relatively low net returns, so proposals for meeting growing urban and environmental uses by using price incentives are increasingly heard. However, although price incentives involving higher costs of irrigation water may change the amount of water withdrawn, the amount of water consumed is hypothesized to be relatively less affected. Consumptive use is the amount of water that is actually depleted—lost to the atmosphere from evaporation and transpiration from plant and soil surfaces, and embodied in plant products. Withdrawal measures the amount of water diverted from the water source and delivered to the crop. In field irrigation situations, withdrawal exceeds consumptive use for several reasons, mainly because of the imprecision of the water application practices. For example, in the case of irrigation with open ditch with siphons, in order to assure that enough water reaches plants at the end of the field, an excess is applied at the beginning. Farmers also may not know the precise amount of irrigation water needed and apply more water than strictly necessary. Furthermore, in some areas water in excess of consumptive use may be applied to carry salts below the crop root zone. The difference between consumptive use and withdrawal is called return flow. With consumptive use of irrigation water typically amounting to 30 to 80% of withdrawals, return flows are a relatively large portion of withdrawals and in many river basins constitute an important part of the downstream water supply. Thus water policy initiatives such

as volumetric charges for irrigation water need to be examined not only with regard to their effect on withdrawals, but also on consumptive use and return flows. This analysis develops and implements an approach to measuring the relative effects of hypothesized price incentives on withdrawals and consumption of irrigation water.

Water economists have long recognized the importance of considering both water withdrawals and consumptive use when analyzing competing demands in a river basin context. According to Hirschleifer, De Haven, and Milliman, “a withdrawal that is returned, of course, is non-consumptive in that it makes possible reuse of the water; only withdrawals that are not returned represent water demands competitive with other possible uses” (p. 69). Hartman and Seastone state that the relevant measurement of water use in a productive process such as agriculture is consumptive use, i.e. “the reduction in available supply incurred from the use” (p.167). Bain, Caves and Margolis go a step further by drawing attention to the problem “of placing any emphasis on gross, rather than net, demands for water, since the over-all adequacy of water supplies depends on the net consumption occurring in any given use” (p. 16). Despite these early insights, most research has concentrated on gross or withdrawal demands and paid little attention to net or consumptive use demands. This is not surprising because withdrawal is usually the farmers’ decision variable. Moreover, information on the consumptive use of irrigated crops (and, for that matter, return flows) is not readily obtained.

Analyses of the demand for irrigation withdrawal and its price-responsiveness have been presented in the literature since the early 1960s, but the elasticity estimates and related policy recommendations differ widely. Some studies suggest that farmers are very unresponsive to changes in the price of water. Therefore they commonly caution against the use of pricing policy to bring about reductions in withdrawals, because even for relatively small reductions large price

increases would be necessary—with large effects on agricultural income and wealth. Other studies indicate a more elastic demand and conclude that pricing policy would be an effective instrument since it would provide the necessary incentives for farmers to adjust to rising prices by using irrigation water more efficiently. Despite the importance of knowing farmers' withdrawal responsiveness to price changes, little systematic study has been carried out on the factors which cause these differing findings.

Several recent papers have used models incorporating both withdrawals and consumptive use to show that for river basin planning purposes the responsiveness of consumptive use to policy initiatives is often equally or more relevant than is responsiveness of withdrawals. With a focus on the western United States, these papers examined the impact of a number of policy measures such as improved on-farm irrigation efficiency, limits in withdrawals, and increases in withdrawal prices. Focusing on improvements in on-farm irrigation efficiency, Huffaker and Whittlesey illustrate that this policy measure appears to conserve water by reducing withdrawals, but in reality redistributes water between river and aquifer and does not necessarily change consumptive use. Agricultural water conservation legislation—in order to promote water supplies for alternative uses—thus needs to define 'conservation' not in terms of reduced withdrawals but in terms of reduced consumptive use. Bernardo et al. study the impact of limits in withdrawals using a farm-level crop simulation/mathematical programming model. They show that through better-timed irrigations large decreases in withdrawals may be attained with only marginal reductions in consumptive use and yields. Similarly, Burke et al. explore the effectiveness of limiting withdrawals with the goal of conserving water for alternative uses. By linking an on-farm economic decision model with a basin-wide hydrologic model of return flow, they demonstrate that when substitution of technology for withdrawals is allowed for (in addition

to crop switching and land fallowing), the resulting decrease in consumptive use is considerable less than the reduction in withdrawals; basin-wide water conservation is reduced due to the improvement in on-farm irrigation efficiency. The impact of price changes for withdrawals on agricultural water conservation is analyzed by Huffaker et al. with a basin-wide hydro-economic model. They show that the common presumption, that increasing prices for withdrawals lead to agricultural water conservation at levels directly related to the price elasticity of withdrawal demand, is valid only where water unconsumed by crops is irretrievably lost to the river basin. In that case instream flows are reduced by the withdrawal amount, and this reduction depends on the farmer's price elasticity of withdrawal. In the presence of return flows, however, instream flows decrease by the portion of the withdrawal that is consumptively used. Farmers are encouraged by increasing block prices to reduce withdrawals but, as improved irrigation technologies are adopted, they also increase the efficiency with which the reduced withdrawals are consumed in crop production. Thus the impact on instream flows is empirically uncertain. Huffaker et al. conclude that this uncertainty can only be resolved by assessing water price in terms of consumptive use instead of withdrawal.

The model we develop aims to address this issue raised by Huffaker et al.—and by Bain, Caves, and Margolis more than three decades earlier—by analyzing the effect of hypothetical price increases for irrigation water on both the demand for withdrawals and the derived demand for consumptive use. Our estimates are based on a two-stage crop simulation/linear programming model that was applied to the New Cache La Poudre Irrigation Company (NCLPIC), one of the dozen major irrigator-owned cooperatives in the lower South Platte Basin near Greeley in Weld County, Colorado. Flows from the South Platte River and its tributaries serve the major urban-industrial centers and the most important agricultural region of Colorado. Over 80% of the water

withdrawals are used for irrigation. NCLPIC has senior water rights for river flow, but reservoir water and groundwater from the unconfined alluvial aquifer along the South Platte River are also used for irrigation. The major crops are corn grain, alfalfa, edible dry beans, corn silage, and sugar beets. Farmers almost exclusively use surface technologies for distributing water, including open ditches with siphons, and gated and flexible pipes with and without surge. They typically apply several irrigations per crop and season, each with a more or less fixed amount of water.

A linear programming model was chosen to estimate withdrawal and consumptive use demands since it can be easily adapted to represent numerous options available to farmers for adjusting to increased water prices (Paris). To carefully reflect the yield effects of reduced withdrawals, the linear programming model incorporates water-crop production functions computed with a transient-state crop simulation model. An innovative feature of the water-crop production functions used in this analysis is that they show yield, and consumptive use, not only as a function of the amount of water applied during the season, but also as a function of the number and timing of irrigations. This allows us to estimate the responsiveness of withdrawals and consumptive use to price changes under a wide range of adjustment options, including the acreage irrigated, the cropping mix, irrigation technology, and irrigation scheduling.

Based on the model findings, we estimate the price-responsiveness of the demand for withdrawals and the derived demand for consumptive use. The estimates of price elasticities of consumptive use demand are, to the best of our knowledge, the first in the literature to date. A comparison between the price elasticities of withdrawal and consumptive use demand show that consumptive use demand tends to be significantly less responsive to increased water price than withdrawal demand. This confirms the insight of some of the more recent studies that although

price incentives involving higher costs of irrigation water may change the amount of water withdrawn, the amount of water consumed is likely to be relatively less affected. We also study the influence of different model assumptions on the estimated elasticities by formulating scenarios with varying options for farmers to adjust to higher water prices. The results indicate that the more flexibility assumed in a scenario, the larger the divergence tends to be between changes in withdrawals and consumptive use as irrigation water becomes more costly.

Previous Analyses of Price-Responsiveness of Withdrawals

Estimates of the shape of the withdrawal demand function are commonly based on the use of mathematical programming models, especially linear programming models. Gardner presents an overview of the studies carried out in California during the 1960s and 1970s. The early studies often have intended to show that the withdrawal demand is more price responsive than generally believed, and that even for very low prices it is not perfectly inelastic as the U.S. Bureau of Reclamation had claimed in the past (Moore and Hedges). Later studies have constructed subregional or regional demand functions from demands of representative farms, and commonly calculated elasticities by either arc-estimates along the stepped demand curve or by fitting continuous regression equations to the parametric data. The results typically show either an inelastic estimate for the whole price range considered, or an inelastic estimate for the lower prices and a less inelastic or elastic estimate for the higher prices. The shape of the demand function has been shown to be influenced by various factors considered in the model such as the quality of the soil (Hedges), the length-of-the-run (Yaron), the distinction between surface and groundwater (Hooker and Alexander), the product price (Gardner and Young), and the elasticity of the product demand curve (Howitt, Watson, and Adams).

Estimates of withdrawal demands have also been developed with econometric models based on data from field experiments. Early studies (Hexem and Heady; Kelly and Ayer) suggest that water applications per acre are very unresponsive to changes in price. A reason for this is that these studies have commonly relied on experimental data that allow changes in water applications for a few selected crops, but no shifts in the cropping pattern or possibilities for substituting alternative water application technologies. More recently, econometric studies have used data of actual farmer behavior (Niewiadomy; Ogg and Gollehon; Moore, Gollehon, and Carey). Yet the estimates from econometric models continue to be more inelastic than the mathematical programming models tend to suggest. This reflects at least in part the differing assumptions and limitations of the two model types. Econometric models produce positive estimates based on historical data that often show little fluctuations in water prices, while mathematical programming models produce normative estimates based on both historical and synthetic data. The latter can be adapted to represent a wide range of scenarios, and model the impacts of policies for which no historical observations need to exist.

Overall, elasticity estimates vary widely—not only between the two model types but also between mathematical programming models. Hartman and Whittlesey in an early study based on representative farms in Colorado already noted that besides factors such as input and output prices, the kind of adjustments farmers are allowed to make in the model in response to changes in water supply determines the value of additional water and thus the shape of the demand curve. This analysis builds on these findings and explores in more detail the effects of model formulation on the shape of both the withdrawal demand curve and the consumptive use demand curve.

Modeling Procedure

The Crop Simulation Model

The model developed to measure price-responsiveness of demand for withdrawals and consumptive use consists of two parts, an agronomic and economic model. With a lack of on-farm data on yield responses to different water supplies for the study area, water-crop production functions were computed using a transient-state crop simulation model originally formulated by Cardon. Its main features comprise the modeling of water and solute movement through the soil and the modeling of simultaneous water uptake by plants. With the model not formulated to calculate crop yield directly, values of water uptake were summed for the season and converted to yield following Doorenbos and Kassam who suggest a linear relationship between relative yield decreases and the deficit of relative evapotranspiration (consumptive use). A detailed description of the simulation model and its input parameters is given by Scheierling, Cardon, and Young.

While crop simulation models employed by economists typically treat the water input as a single value of water applied during the season, the transient-state model was adapted to capture the effects of irrigation timing as discrete-input events. The model outputs are water-crop production functions which show the impact of alternative irrigation schedules on consumptive use and yield. Using these production functions as an input in the economic model has two advantages: first, it allows us to incorporate irrigation scheduling as a decision variable of farmers faced with increasing water prices; and second, in addition to the conventional relationship between water application and yield, it provides estimates for the policy-relevant variable under consideration, i.e. the consumptive use associated with a given number and timing of irrigation water applications.

The simulation model was applied to the five main crops grown in the service area of NCLPIC. For predicting the effect of the potential range of numbers of irrigations, the model is formulated to allow up to nine irrigations on specified dates during the season. These values for the number of possible irrigations, though they represent the upper limit of the range of grower practice, are not uncommon. Thus alfalfa, corn grain, corn silage, and sugar beets may be irrigated from zero to nine times, while dry beans due to their shorter growing period are irrigated as many as eight times. On each of the nine specified irrigation dates an irrigation event may or may not occur. This results in $2^8=245$ alternative irrigation schedules for dry beans, and $2^9=512$ alternative irrigation schedules for the other crops. Each irrigation event was assumed to consist of the same amount of net water infiltration into the soil, becoming available for plant water uptake or deep percolation. Typical net infiltration in Weld County is about 3 inches per irrigation. The amount of water which actually needs to be applied to achieve this net infiltration is higher depending on the irrigation technology used. In the study area the average application efficiency of open ditch with siphons is 30%, of gated and flexible pipe 40%, and of gated pipe with surge and flexible pipe with surge 60%. The other inputs to the crop production process besides water were assumed to be managed at a level so that water is the only limiting factor.

Yields estimated with the simulation model were compared to crop yields reported for the study area. Table 1 presents estimated yields for the “extreme” cases with no irrigation and full irrigation (that is, eight irrigations for dry beans and nine irrigations for the other crops) and measured yields for non-irrigated (dryland) and irrigated crops. A comparison between computed and measured yields shows that the model predicts actual crop yields for the extreme cases reasonably well. Based on this result, the model estimates for the other cases are also believed to adequately represent actual conditions.

The Linear Programming Model

A deterministic single-period linear programming model was developed to incorporate the physical relationships between water application and yield/consumptive use derived with the simulation model. Formulated for the long run, the economic model computes the net income-maximizing water withdrawals in the study area in response to hypothesized alternative levels of water price—together with a derived demand for consumptive use. Changes in the output supply from the study area were not expected to be large enough to significantly affect regional product prices. Farmers were assumed to be well-informed not only about prices of inputs and outputs, but also about optimally timed irrigation schedules so that they apply limited irrigation water only in these combinations which result in the highest crop yields. Each crop can be irrigated with any of the five irrigation technologies. As in Caswell and Zilberman, possible yield differences between technologies were not considered. These assumptions generated 32 activities for dry beans and 45 activities for the other four crops, and a total of 212 activities.

Unit net returns were calculated for each activity based on the residual imputation approach (Young). These are total revenue per acre (calculated by multiplying the yield estimate from the simulation model with the crop price) minus variable costs (exclusive of irrigation water costs) and annual overhead and annualized capital costs (inclusive a land charge estimated at the value of the land in its next best use, which is assumed to be the growing of non-irrigated winter wheat). The resulting residual was imputed to the water resource and used as a value for unit net return in the objective function. Volatility and inflation were removed from crop prices by taking a five-year average of prices for the period 1989 to 1993 deflated with the GNP Implicit Price Deflator (Colorado Agriculture Statistics Service). Variable costs were taken from

crop budgets for the Nebraska Panhandle (Selley) and adjusted to Weld County conditions based on the advice of Colorado State University extension agents. Alfalfa establishment costs were amortized over the average stand life in northeastern Colorado.

Constraints in the model were defined for land (the service area of NCLPIC amounting to 40,000 acres) and water. The latter includes surface water (estimated as average annual water diversion from river flow and reservoir rights) and groundwater (annual well allotments and estimates of the Division Engineer), and amounts to a maximum of 120,324 acre foot available in a typical year. No adjustments were made for canal losses within the service area since they are roughly compensated by returns flows from the irrigation company upstream. Other constraints were formulated to reflect the cropping pattern in the study area. Dry beans were limited to 17% of the total irrigated area considering farmers' risk aversion as a result of highly variable bean prices. Sugar beets were allowed on no more than 7% of the area due to the availability of contractual quotas imposed by the processor. Corn silage may be grown on up to 12% of the area, and alfalfa on up to 27% taking into account the magnitude of demand for fodder from nearby feedlots. An accounting constraint was formulated for consumptive use.

Results and Policy Implications

Water-Crop Production Functions

Figure 1 displays estimates for alfalfa yield resulting from the possible 512 combination of irrigation events in the simulation model. Each point represents a relationship between yield (and, implicitly, consumptive use) and the number and timing of irrigations. Yield and consumptive use estimates as a function of irrigation events have similar shapes for the other crops, and are discussed in Scheierling. The results of the simulation model provide a number of

useful insights. First, depending on the timing of irrigation, the effect of a given number of irrigations on yield varies widely, particularly in the range between two and five irrigations. Second, when examining the optimally timed irrigation schedules (those which achieve the highest yield for a given number of irrigations), it becomes obvious that the increments in yield/consumptive use from additional irrigation events diminish as the number of irrigations increases. Third, there is only a weak correlation between the number of irrigations (the amount of irrigation water infiltrated) on the one hand and yield/consumptive use on the other. For example, when farmers have the option to optimally time irrigation events, an increase from seven to eight irrigations requires 3 inches of net water infiltration but contributes negligibly to an increase in yield/consumptive use; instead it results in increases in soil moisture and deep percolation. When considering the amount of irrigation water which—depending on the application efficiency of the irrigation technology used—actually needs to be applied to a achieve a net infiltration of 3 inches, the correlation is even less strong. This implies that farmers can to some extent substitute for additional irrigation water by reducing optimally timed irrigation events and by switching to irrigation technologies with higher application efficiencies without significantly impacting consumptive use and yield.

Price-Responsiveness of Withdrawal and Consumptive Use Demand

Computations from the economic model focus on the impact of hypothesized price increases on irrigation water withdrawals and consumptive use for the study area. Three scenarios with varying on-farm adjustment possibilities to changes in water price are analyzed. Scenario 1 limits adjustments to changes in irrigated acreage and crop mix. It assumes that the irrigation technology for the whole service area is open ditch with siphons, and that the number of

irrigations applied to each crop cannot be changed from the one which is optimal at the maximum water availability of 120,324 acre feet. Scenario 2 is similar to Scenario 1, except that the number of irrigations can be decreased up to zero. Scenario 3 allows for the widest range of adjustments including changes in irrigated acreage, the crop mix, the number of irrigations, and irrigation technologies.

Results from parametric programming are reported in figures 2 to 4 and tables 2 and 3. Withdrawal demand functions for the three scenarios are shown in figure 2. As water prices start to rise from very low levels, the model indicates that withdrawals are most quickly reduced in Scenario 3 which allows for the most adjustment possibilities. Farmers in Scenario 1 initially reduce withdrawals much more slowly, and each step in their demand curve represents a reduction in irrigated acreage. Farmers in scenarios 2 and 3 do not have to reduce irrigated acreage over a wide range of price increases because of the many other options available. As water prices reach very high levels, farmers in Scenario 1 are predicted to be the first to stop irrigating, whereas farmers in Scenario 3 continue to demand some irrigation water up to a water price of \$292.

Figure 3 plots the results for consumptive use as a function of withdrawals. In Scenario 1, where adjustment possibilities are limited to changing irrigation acreage and cropping mix, the model implies that farmers would use less and less land as water prices rise, and consumptive use would decline almost proportionally with withdrawals. But consumptive use values decrease only very gradually in Scenarios 2 and 3. In Scenario 3 this is because farmers can switch to irrigation technologies with higher application efficiencies without much effect on consumptive use (and yields). At least initially they can also reduce the number of irrigations without much impact on consumptive use. As figure 1 shows, the number of irrigations for alfalfa, for example,

can be reduced to five, or even four, before yields/consumptive use values change significantly. For Scenario 3 this stage is predicted to set in when withdrawals fall below about 52,000 acre feet. When prices are so high that withdrawals cease, farmers in Scenarios 2 and 3 are likely to continue to grow some crops such as alfalfa which have positive net returns for zero irrigations, and thus consumptive use does not drop to zero as in Scenario 1.

Derived demand functions for consumptive use are shown in figure 5. With an almost linear relationship between withdrawals and consumptive use, Scenario 1 exhibits a consumptive use demand that is very similar in shape to its withdrawal demand. In contrast, Scenarios 2 and 3 are predicted to have consumptive use demands that look very different from their respective withdrawal demands. This is although farmers with more adjustment options do respond to rising prices by decreasing withdrawals, their consumptive use values decrease at a much slower rate. At very high prices consumptive use in Scenario 1 falls to zero as crop production is stopped. Yet in Scenarios 2 and 3, where zero irrigations are possible, consumptive use coming from rainfall and drawdown of soil moisture is estimated to remain at about 20,000 acre feet. However, under existing conditions in the lower South Platte Basin where irrigation water cost is quite low, the effect of very high water prices was regarded of little importance for policy purposes.

Water price increases in the lower ranges were considered to be the ones relevant for examining the impacts of pricing policy on withdrawals and consumptive use implied by our analysis. The price changes included in table 2 comprise an increase from the respective initial marginal price to \$30, and to \$60 per acre foot of water. Changes in withdrawals and consumptive use were examined in both absolute and percentage terms. For a price increase to \$30 per acre foot, Scenario 1 shows a decrease in withdrawals of less than 3% while the more

realistic Scenarios 2 and 3 exhibit relatively large withdrawal reductions of 32% and 50%, respectively. For a price increase to \$60, all scenarios show very large withdrawal decreases ranging between 64% and 78%.

The changes in consumptive use resulting from the two price increases are likely to differ from the changes in withdrawals depending on the adjustments allowed for in the particular scenario. Only for Scenario 1 with limited adjustment options are the results for the percentage reductions in withdrawals and consumptive use similar over the two price increases. But the more adjustment options a scenario allows, the larger the difference between changes in withdrawals and consumptive use tends to be. The predicted difference is especially pronounced at a water price increase to \$60 per acre foot. For Scenario 2 withdrawals would be reduced by 78%, while consumptive use would only be halved. For Scenario 3, which allows for investments in improved water use efficiency, the reduction in consumptive use would be overwhelmingly smaller than the reduction for withdrawals (15% as compared to 67%).

To further illustrate the different effect of water price increases on withdrawals and consumptive use, arc elasticities were calculated for withdrawal and consumptive use demands. The arc formula computes an elasticity at an average between two points, and allows for easy comparison between different scenarios (Tomek and Robinson). Table 3 presents implied elasticities for various price ranges. In the lowest price range up to \$30 per acre foot, the demand for withdrawals is more inelastic for Scenario 1 than for Scenarios 2 and 3 with more adjustment options, because initially it requires relatively higher price increases for an adjustment, and thus a change in withdrawals, to take place. In the price range between \$30 and \$60 per acre foot, the withdrawal demands for Scenarios 1 and 2 become elastic, while the withdrawal demand for Scenario 3 remains inelastic. The model suggests that as prices rise to higher levels, the

withdrawal demands for all scenarios become elastic at some point. But for Scenario 1 withdrawal demand tends to become more elastic faster because as more and more irrigated acreage is given up, withdrawals decrease rapidly towards zero. (Switches to inelastic or perfectly inelastic estimates at some of the higher price ranges are caused by high “steps” in the demand curves, where withdrawals are estimated to remain unchanged even though prices continue to rise.)

Consumptive use demand also tends to become less inelastic as water prices start to rise. But again the effects of increasing water prices are predicted to depend on the scenario. For Scenario 1 the elasticity estimates for consumptive use demand are quite similar to the elasticity estimates for withdrawal demand, which is not surprising given the similar shapes of the respective demand curves. However, the consumptive use demands for Scenarios 2 and 3—which allow for more substitution possibilities as water cost increases—tend to be more inelastic in the higher price ranges than those of Scenario 1, and more inelastic than their respective withdrawal demands over all price ranges. Thus the findings for these more realistic scenarios suggest that the price elasticity of consumptive use demand generally cannot be assumed to equal the price elasticity of withdrawal demand and, in particular, that the demand for consumptive is likely to be much less price-responsive than the demand for withdrawals.

The results reported in table 3 provide evidence that elasticity estimates for both withdrawal demand and consumptive use demand are very dependent on the model framework within which they are derived. They are also influenced by the method used to calculate them. For example, most elasticity values would be different if the points in between which the arc elasticities are calculated, were changed. Therefore the emphasis here is not on particular

elasticity estimates, but on the direction of their change depending on the model formulation, the price range considered, and the focus on either withdrawal or consumptive use demand.

The findings on the price elasticities of withdrawal demand are in line with previous results of linear programming models which have indicated an inelastic demand for lower prices and a less inelastic demand for higher prices. However, our findings do not support the common presumption that an inelastic withdrawal demand would imply that the use of pricing policy would not be very effective in bringing about reductions in withdrawals because, as the argument goes, even for relatively small reductions large price increases would be necessary which in turn would cause large negative effects on income and wealth. Instead, this research suggests that, especially for the more realistic scenarios with a range of adjustment options, an inelastic withdrawal demand does not necessarily imply that withdrawals cannot be substantially reduced as the price rises. As tables 2 and 3 show for Scenario 3, for example, the withdrawal demand elasticity for a price increase up to \$30 per acre foot is estimated to be -0.36, but withdrawals would be reduced from 120,324 to 60,574 acre feet.

Overall, our findings indicate that there is a strong correlation between withdrawals and consumptive use for those scenarios which significantly limit farmers' adjustment options to changing water prices. In the case with irrigated acreage and crop mix as the only possible adjustments, the correlation is almost linear. Yet for the more realistically formulated scenarios the correlation between withdrawals and consumptive use is likely to be much weaker. The reason for this is that water withdrawals are an input factor which at least to some extent can be substituted with other input factors such as management (adaptation in the number of irrigations) and/or capital (change to irrigation technologies with higher application efficiencies). Model formulations which incorporate these substitutions indicate that they enable farmers to

significantly reduce withdrawals in response to increases in their price; at the same time they can prevent large reductions in consumptive use, and agricultural production, over a relatively wide price range.

In a river basin context the results for the more realistic scenarios suggest that even if price elasticities for withdrawal demand are inelastic, volumetric water charges could bring about large reductions in withdrawals. Yet such a pricing policy does not promote supplies for alternative uses to the same extent because it tends to have much less impact on consumptive use with farmers having incentives to substitute irrigation water with other input factors and sustain consumptive use, yields and agricultural production.

Conclusions

As water scarcity increases, it is often suggested that an appropriate pricing policy for irrigation water could reduce agricultural withdrawals by providing stimuli for farmers to use water more efficiently, and make water available for higher valued non-agricultural uses. While a number of studies have noted that basin-wide water conservation depends less on changes in agricultural withdrawals than on reductions in consumptive use, this analysis extends previous research by examining the effect of hypothetical price increases for irrigation water on both the demand for withdrawals and the derived demand for consumptive use. Data from an irrigation company in Colorado's South Platte River basin was used to formulate a crop simulation/linear programming model which takes into account a number of farmers' options for adjusting to increasing water prices. The results suggest that the estimated impact of the pricing policy depends on the particular model formulation. If adjustment options are limited to reductions in irrigated acreage and crop mix, the price-responsiveness of withdrawal demand and consumptive use demand

correspond relatively closely. But in more realistic model formulations with a wide range of adjustment possibilities, the consumptive use demand tends to be significantly less responsive to increasing water prices than the withdrawal demand. Thus a 1% increase in price would reduce withdrawals much more than consumptive use.

These results have important implications for water pricing policies in river basins where return flows constitute a significant part of the downstream water supplies. This would be the case in the South Platte Basin, where annual surface withdrawals are estimated to amount to about 2.5 times the annual native surface water flows (South Platte Research Team). Attempts to make additional water available for non-agricultural uses by rising irrigation water prices would be of little benefit. In the context of the irrigation company, a hypothetical price increase to \$30 per acre foot is predicted to reduce withdrawals by half. However, consumptive use would be expected to fall only by about 1% if farmers can change the crop mix and irrigated acreage, the irrigation schedule, and irrigation technologies. This implies that water pricing policy or other methods of encouraging reduced withdrawals while maintaining the agriculture base are not likely to make nearly as much additional water available for alternative urban or environmental uses as might be hoped.

The modeling approach presented focuses on farmers' response to hypothesized increases in irrigation water prices. To examine more broadly basin-wide effects of reduced agricultural withdrawals, a river basin optimization model would have to be used such as, e.g. Booker and Young. Basin-wide effects may include increased instream flows which could help restore river ecosystems. They could also involve improved water quality by leaving more native water instream for pollution dilution, and by reducing irrigation return flows with polluting chemical residuals.

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Table 1. Comparison between Measured and Computed Yields

Variable		Measured Yield	Computed Yield
Alfalfa (ton/acre)	No irrigation	2.0	2.7
	Full irrigation	5.1	4.9
Corn Grain (bu/acre)	No irrigation	54.8	58.2
	Full irrigation	153.0	150.8
Corn Silage (ton/acre)	No irrigation	N/A	9.6
	Full irrigation	24.5	24.8
Beans (cwt/acre)	No irrigation	9.0	10.9
	Full irrigation	22.1	22.3
Sugar Beets (ton/acre)	No irrigation	N/A	12.8
	Full irrigation	24.0	24.3

Note: Measured yield data are mean values for 1989-92 from Colorado Agriculture Statistics. Means for full irrigation are based on data for Weld County, Colorado. Means for no irrigation are based on data for northeastern Colorado. For corn silage and sugar beets no data on dryland yields are available.

Table 2. Impact of Water Price Increases on Withdrawals and Consumptive Use

Description	Initial Marginal Price (\$/af)	Withdrawals at Initial Marginal Price (af)	Withdrawals at \$30/af ^a	Withdrawals at \$60/af ^a
Impact on Withdrawals:				
Scenario 1	9.75	120,324	116,932 (-2.8%)	43,968 (-63.5)
Scenario 2	9.75	120,324	81,964 (-31.9%)	26,372 (-78.1%)
Scenario 3	1.21	120,324	60,584 (-49.6%)	37,676 (-68.7%)
	Initial Marginal Price (\$/af)	Consumptive Use at Initial Marginal Price (af)	Consumptive Use at \$30/af ^b	Consumptive Use at \$60/af ^b
Impact on Consumptive Use:				
Scenario 1	9.75	63,482	63,296 (-0.003%)	19,796 (-68.8%)
Scenario 2	9.75	63,482	57,479 (-9.5%)	31,596 (-50.2%)
Scenario 3	1.21	64,232	63,515 (-1.1%)	54,928 (-14.5%)

^a Values in parentheses are percentage changes from withdrawals at initial marginal price.

^b Values in parentheses are percentage changes from consumptive use at initial marginal price.

Table 3. Price Elasticities of Withdrawal and Consumptive Use Demand

Scenario	Range of Water Price (\$/af)									
	Up to 30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	270-300
Withdrawal Demand:										
Scenario 1	-0.03	-1.36	-3.25	0.00	-22.51	–	–	–	–	–
Scenario 2	-0.37	-1.54	-1.76	-0.71	-5.67	-14.43	–	–	–	–
Scenario 3	-0.36	-0.70	-2.13	-0.50	-1.61	-1.98	-6.04	0.00	0.00	-25.00
Consumptive Use Demand:										
Scenario 1	-0.003	-1.57	-2.93	0.00	-22.51	–	–	–	–	–
Scenario 2	-0.10	-0.87	-0.66	-0.08	-0.47	-0.31	–	–	–	–
Scenario 3	-0.01	-0.22	-1.30	-0.08	-1.01	-0.23	-0.61	0.00	0.00	-0.97

Note: Withdrawals are estimated to become zero as water price reaches \$131 per acre foot in Scenario 1, \$172 per acre foot in Scenario 2, and \$292 per acre foot in Scenario 3. Consumptive use in the respective scenarios is predicted to not change any further beyond these water prices.

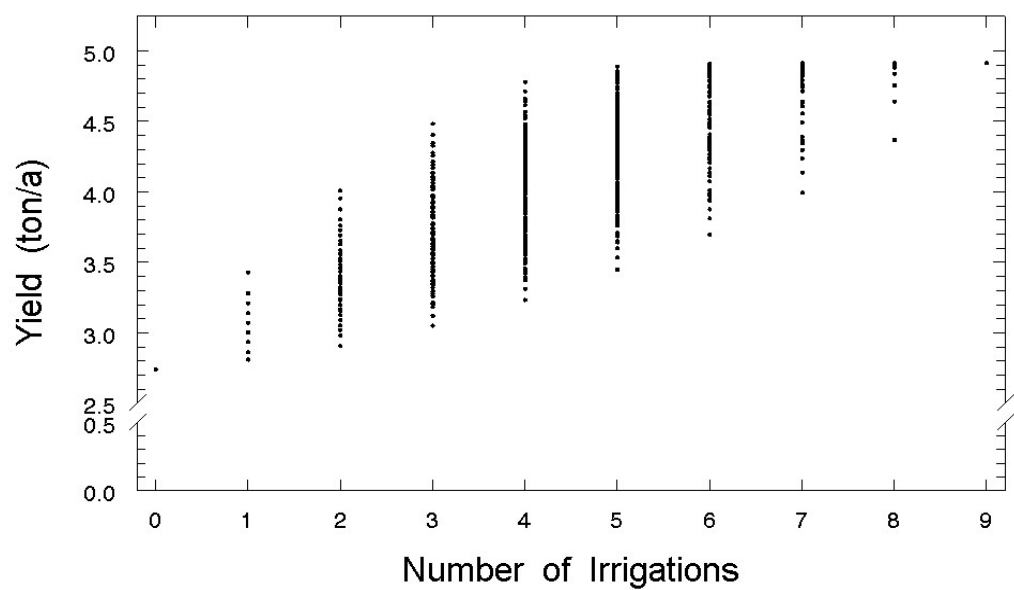


Figure 1. Computed Yield of Alfalfa as a Function of the Number and Timing of Irrigations

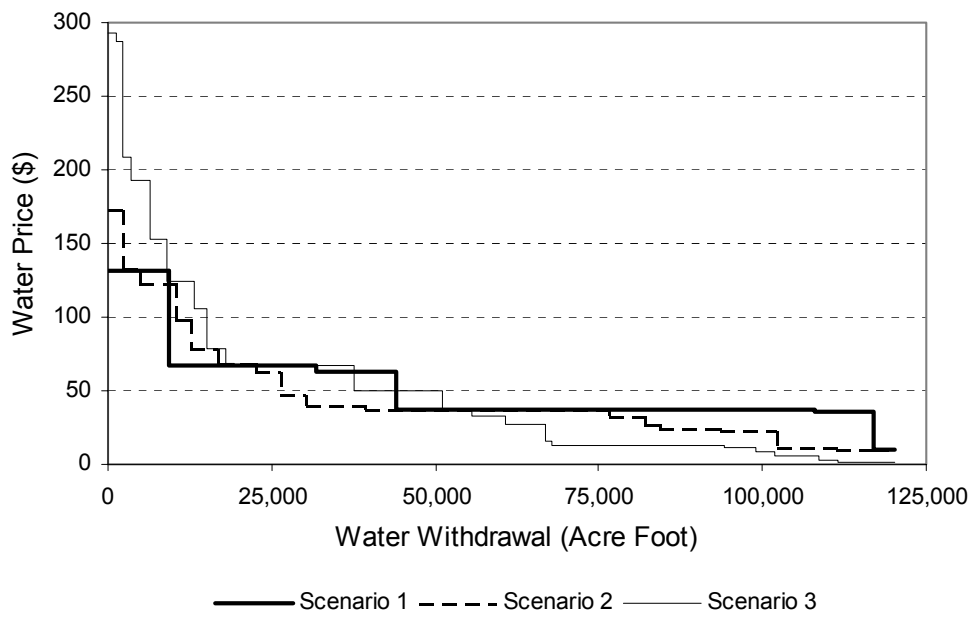


Figure 2. Demand Function for Water Withdrawals

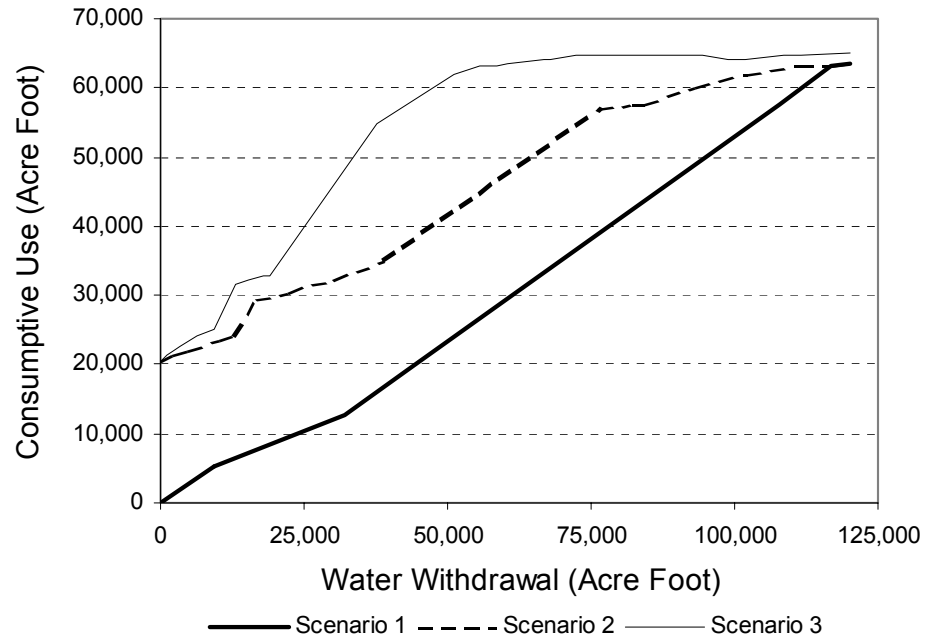


Figure 3. Consumptive Use as a Function of Water Withdrawals

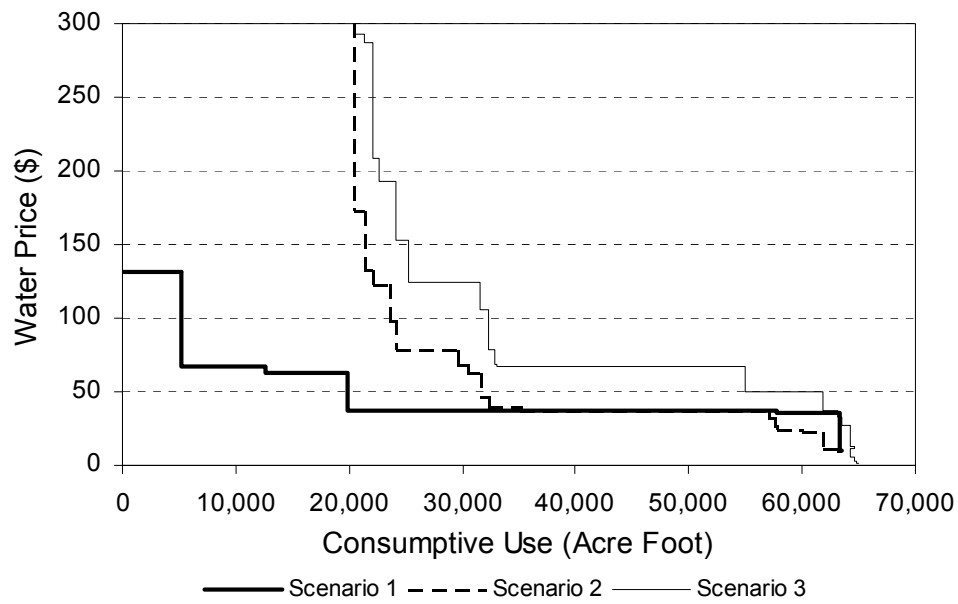


Figure 4. Derived Demand Function for Consumptive Use