AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search
http://ageconsearch.umn.edu
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

Conservation Pricing and Groundwater Substitution

by

Eric C. Schuck
Department of Agricultural and Resource Economics
Colorado State University
Fort Collins, CO 80523

and

Gareth P. Green
Department of Economics and Finance
Seattle University
Seattle, WA 98122

Contact: Eric Schuck
Department of Agricultural and Resource Economics
Colorado State University
Fort Collins, CO 80523

email: eschuck@lamar.colostate.edu
Phone: n/a
Fax: n/a

Paper presented at the Western Agricultural Economics Association Conference, Utah State University, Logan, UT on July 8-11, 2001.

The authors are both assistant professors. This research was supported by USDA Regional Project W-190 and a Challenge Grant from the United States Bureau of Reclamation in cooperation with the Natural Heritage Institute. The authors are extremely grateful for the cooperation of Tim Long of the Arvin Edison Water Storage District.

Introduction

Following recent policy changes by the United States Bureau of Reclamation (USBR) irrigation districts in the Central Valley Project of California (CVP) are now required to adopt volumetric pricing for irrigation water as a Best Management Practice (USBR, 1998). This requirement is also being promoted in other western regions and is the most recent in a series of USBR policies aimed at reducing agricultural water consumption in the arid west. Adoption of conservation pricing by irrigation districts has, however, been limited in both scope and effectiveness. A recent survey by Michelsen et al. (1999) found that most irrigation districts charge for water based on acreage served rather than water delivered, and that those districts which do have conservation pricing policies set water rates sufficiently low as to have no impact on demand.

It is not clear if conservation pricing actually reduces water consumption. Recent theoretical results by Huffaker et al. (1998) raise serious questions about the value of price as a conservation tool and suggest that more empirical analysis is needed. In particular, Huffaker et al. demonstrate how a combination of return flows and price-induced changes in irrigation efficiency can overcome the demand effects of a change in water price.

The work by Huffaker et al. covers two important aspects of water management, return flows and irrigation efficiency. What it does not address, however, is another equally important issue in irrigation water management: groundwater substitution. Groundwater substitution occurs when irrigators respond to water rate increases by reducing surface water demand and tapping into ground water. Groundwater substitution can lead to conserving one water resource at the expense of another, and is an important consideration when discussing adoption of conservation pricing as a policy tool.

An example of groundwater substitution can be seen in Figure 1. In this example,

irrigator water demand is given by curve *D* and the marginal costs of pumping groundwater are given by the curve *MCG*. The price of surface water is broken up into three tiers - *T1*, *T2*, and *T3* - and the first two tiers are cheaper than the marginal cost of pumping ground water. What this means is that the irrigator will demand surface water up to *S2,* the point where the price of surface water switches from *T2* to *T3*, and at that point will switch to ground water. As a result of this switch, irrigator ground water demand will equal (*W2*-S*2*) and the irrigator will have water demand equal to *W2*. If ground water were not available as a substitute, surface water demand would equal water demand at *W1*. Although the combined effects of tiered pricing and ground water substitution are to reduce surface water demand to *S2,* reductions in surface water diversions promote greater ground water pumping. As a result of the interplay between the two water sources, it is difficult to determine if moving to a conservation pricing system has actually promoted water conservation since surface water demand is down but ground water pumping is up. One water source is potentially being conserved at the expense of the other. This paper will show how ground water substitution relates to conservation pricing and will suggest some policy means of coping with this problem

Theoretical Model

Analysis of ground water substitution begins by examining the on-farm irrigation decision of an individual grower *i* in the time period *t*. The quantity of water applied by the irrigator to a crop is denoted AW_{it}. The irrigator can obtain water to apply to a crop in two ways. The first is to divert water from a surface water source, S_t, and diverted water is denoted s_{it}. The second source of water is an underlying aquifer, A_t, and water pumped by the irrigator from this source is denoted g_{it}. AW_{it} is then the sum total of surface water diversions and ground water pumping, or:

1) $AW_{it} = (s_{it} + g_{it})$

The technology used to apply water to crops is rarely perfect, so not all of AW_{it} is used beneficially by the crop to which it is applied. Some fraction of AW_{it} is lost to inefficiencies in the irrigation technology. The efficiency of the irrigation technology, that is the fraction of AW_{it} which the technology transmits to the crop for consumption, is denoted $._i$

Since irrigation technologies are not perfectly efficient, agricultural production is not a function of AW. Instead, production is a function of effective water, or EW_{it}. EW_{it} is given by:

2) $EW_{it} = {}_i s_{it} + {}_i g_{it}$

EW_{it} is a function of applied surface and ground water actually transmitted by the irrigation technology to the crop. As a result, surface water and ground water are both weighted by irrigation efficiency $_i$ This is an important distinction, because it clarifies the difference between water diversions (as measured by AW_{it}) and water consumption in production (as measured by EW_{it}). The fact that diversions and consumption are two different things will have important policy implications for the effectiveness of conservation pricing.

Grower production is a quasi-concave function of effective water demand and is specified as $f(EW_{it})$. The grower produces a single, representative crop with price p. Surface water is purchased by the grower from an irrigation district at the price r. The grower can provide herself with ground water by pumping from existing on-farm facilities. The cost to the grower of pumping ground water is the amount of energy consumed in pumping. The energy used in pumping is represented by the pumping energy function, $(g_{it};\ {}_i, A_t)$. Pumping energy is an increasing function of the quantity of groundwater pumped, of the unique attributes of the farm's capital (denoted $_i$), and of the pumping depth perceived by the grower at the wellhead. Pumping depth at the wellhead is represented by the aquifer level, A_t. Pumping energy increases in

groundwater pumping and decreases in the aquifer level. When energy used in pumping is weighted by the price of energy e, ground water pumping costs are e $(g_{it};\ _{i}\ \ _{t}$. Traditionally, irrigation districts set water prices artificially low, so it will be assumed that the price of surface water is less than the cost of pumping ground water.

The profit maximizing irrigator will demand water from either or both sources until the following conditions are met:

2) $Pf'(EW) \quad r$

3) $P\,f'(EW) \quad e\ _{g}(g_{it};\ _{i}\ \ _{t}$

where the marginal revenues from production equal the marginal costs of water. For surface water, the marginal cost of water is simply the price of surface water, r. The marginal costs for ground water do not involve a single price but rather reflect the marginal energy costs of pumping water from the aquifer.

The general interpretation of equations 3) and 4) is quite simple. Each equation is just the basic profit-maximizing requirement that the value of the marginal product of water equal the price of water. Recalling that the price of surface water is less than the costs of ground water pumping, the grower will demand surface water and ground water resources will be unutilized. If, however, surface water price changes, there may be a point at which ground water will be cheaper and the irrigator will switch water sources. This is groundwater substitution.

It is important to realize that groundwater substitution is non-marginal and is a function of the heterogeneous attributes of each farm contained in the vector $_{i}$. The effects of a change in the price of surface water will therefore be difficult to determine a priori since individual irrigators will not respond to price changes in the same way. Each irrigator may either reduce

surface water usage or switch to groundwater in response to a price change. Consequently, the effects on AW_{it} of a change in the price of surface water will depend upon the relative price of ground water for a particular irrigator. Using the marginal conditions in equations 2) and 3), it is possible to show that the marginal effects of a change in the price of surface water are:

$$4)\quad \frac{\partial s_{it}}{\partial r} = \begin{cases} \dfrac{1}{\dfrac{\partial^2 pf(\cdot)_{it}}{\partial AW_{it}^{\ 2}}\delta_i^2} \; if\ r < e\Gamma_g(\cdot) \\ \dfrac{1}{\dfrac{\partial^2 pf(\cdot)_{it}}{\partial AW_{it}^{\ 2}}\delta_i^2} - \dfrac{1}{\dfrac{\partial^2 e\Gamma(\cdot)_{it}}{\partial g_{it}^{\ 2}}} \; if\ r = e\Gamma_g(\cdot) \\ 0 \; if\ r > e\Gamma_g(\cdot) \end{cases}$$

and

$$5)\quad \frac{\partial g_{it}}{\partial r} = \begin{cases} 0 \; if\ r < e\Gamma_g(\cdot) \\ \dfrac{1}{\dfrac{\partial^2 pf(\cdot)_{it}}{\partial AW_{it}^{\ 2}}\delta_i^2} \; if\ r = e\Gamma_g(\cdot) \\ 0 \; if\ r > e\Gamma_g(\cdot) \end{cases}$$

Basically, equations 5) and 6) show that when surface water price is less expensive than ground water, no ground water substitution occurs and the effect of a rate change is to reduce water usage. Similarly, when the price of surface water exceeds the cost of pumping ground water, changing the price of surface water has no effect since the irrigator is already relying solely upon ground water.

Where the situation is uncertain, however, is when the two prices equal (or becomes equal due to a price change). In that case, surface water becomes more elastic than when the irrigator does not perceive ground water as a cost-effective option. Total applied water falls at the same rate as when the irrigator relies solely upon surface water, but surface water use falls more rapidly than when irrigators rely only on surface water. As a result, the composition of water use changes with ground water use rising to offset much of the reduction in surface water usage. Although conservation is being achieved, much of it is at the expense of ground water due to ground water substitution.

This problem becomes even more pronounced when individual water use decisions are aggregated to show how a rate change influences surface water flows and aquifer levels. Examining these effects begins by recalling that water applications (AW_{it}) and water consumption (EW_{it}) are not equal. This difference is due to the efficiency of the irrigation system. Since not all of AW_{it} is used effectively by the crop, the first law of thermodynamics requires that the difference between AW_{it} and EW_{it} be accounted for somewhere in the system. Water which is applied but not consumed is residual water that flows past the crop's rootzone

and either percolates into the aquifer, A_t, or returns to the surface water source, S_t. The water which flows to the aquifer is designated deep percolation (DP_{it}), while water which returns to the surface water source is denoted return flows (RF_{it}). DP_{it} and RF_{it} relate to AW_{it} and EW_{it} through the water balance equation:

6) $$DP_{it} + RF_{it} = AW_{it} - EW_{it}$$

DP_{it} and RF_{it} are functions of applied surface water and ground water weighted by irrigation efficiency $_i$, and are given by the functions $DP \quad {}_i s_{it} + \quad {}_i g_{it})$ and $RF \quad {}_i s_{it} + \quad {}_i g_{it})$. Note that both DP_{it} and RF_{it} are functions of EW_{it}.

Two externalities exist in this problem. The first is groundwater mining stemming from groundwater substitution, and the second relates to surface water flows used to supply surface water diversions. Groundwater mining will change the aquifer depth and increase the costs of pumping ground water. A_0 is the initial supply of aquifer water. The initial aquifer supply is drawn-down or raised by two competing forces. The first is deep percolation, or DP_{it}, as previously defined. Increased applications of water to crops increase DP_{it} and reduce pumping depth. The second factor which influences pumping depth is the effect of grower pumping on the aquifer. Grower pumping extracts water from the aquifer, and therefore increases pumping depth. Combining DP_{it} and g_{it} with the initial aquifer level A_t gives the draw-down equation:

7) $$A_{t+1} = A_t + \quad {}_i (DP_{it} - g_{it})$$

Flows related to the surface water source, S_t, are the other externality in this problem. For convenience, surface water flows will be represented as the difference between water stocks at two different points. The upstream point is designated j while the downstream point is denoted k. Combining the stock measurements return flows and grower diversions gives the surface water flow equation:

8) $S_{kt} = S_{jt} + {}_{i}(RF_{it} - s_{it})$

which simply states that the downstream stock of surface water equals the upstream stock S_{jt} plus return flows from irrigation RF_{it} and less diversions for surface water applications s_{it}.

Recognizing equations 7) and 8) have significant implications for changing the surface water price, r. The marginal effects on surface flows and aquifer levels of a change in the price of surface water are:

9) $$\frac{\partial S_{kt}}{\partial r} = \sum_i \frac{\partial DP}{\partial EW_i}\left(\frac{\partial s_{it}}{\partial r} + \frac{\partial g_{it}}{\partial r}\right) - \frac{\partial s_{it}}{\partial r} \geq 0$$

10) $$\frac{\partial A_{t+1}}{\partial r} = \sum_i \frac{\partial DP}{\partial EW_i}\left(\frac{\partial s_{it}}{\partial r} + \frac{\partial g_{it}}{\partial r}\right) - \frac{\partial g_{it}}{\partial r} \leq 0$$

Together, these imply that the effect on total water supplies, both surface and ground, of a change in surface water price is:

11) $$\frac{\partial\left(A_{t+1} + S_{kt}\right)}{\partial r} = -\sum_i \delta_i\left(\frac{\partial s_{it}}{\partial r} + \frac{\partial g_{it}}{\partial r}\right) \geq 0$$

Equation 11) suggests that the overall increase in water supply attributable to a change in surface water price will equal the reduction in water consumed by crop production and irretrievably lost to either the surface water system or the aquifer. While this means that the effects of a change in the price of surface water are water conserving, the reductions in the quantity of surface water demanded will be partially offset by increases in ground water demand. Consequently, the quantity of water demanded falls but the composition of water demand may change significantly and one water source may be conserved at the expense of another.

Empirical Model, Policy Implications and Conclusions

The theoretical model indicates that changing surface water price when ground water is available as a substitute may lead to reductions in observed water demand but that the composition of water demand may change dramatically. This change can lead to conserving one water source at the expense of another.

To analyze this issue empirically, alternative surface water prices are applied to the Arvin-Edison Water Storage District (the District) in California's southern San Joaquin Valley. The District was established in 1942 and encompasses approximately 132,000 acres, of which 90,000 are cultivated in an average growing year. The District's original mission was to import surface water to the region and to reduce the considerable groundwater overdraft then occurring. As a result, conservation of both surface and ground water resources is of paramount importance to the District.

The District abandoned a contract-quantity based allocation system in favor of a price based allocation system in 1995, leaving surface water price as their primary control over surface water use. Current District policy is to encourage growers to use surface water first and maintain groundwater levels by setting the volumetric component of the surface water rate below the pumping cost of growers. However, a key feature of the 1995 contract change was the adoption of drought-contingent pricing as a policy tool. The District defines drought-contingent pricing as a price which rises and falls with imported surface water supplies. Current District plans are to raise or lower the price of surface water by the change in marginal delivery costs attributable to drought (or flood) conditions. As such, the District's drought-contingent pricing program is a form of conservation pricing as encouraged by the USBR.

To date, the District has not implemented its drought contingent pricing program,

primarily due to concerns about the effects the program may have on aquifer levels. This research analyzes the potential effects of enacting the drought-contingent pricing program by developing a crop acreage allocation model for the District and simulating irrigator responses to changes in the price of surface water across the District's range of marginal delivery costs.

Using field-level crop acreage data for 1997 for the 10 primary crop groups in the District, a dynamic simulation model comparing District water demand and acreage allocations was developed to simulate irrigator responses to changes in the price of surface water.[1] Because fallowing is generally a short-run response to water shortage, it was assumed that perennials like citrus, deciduous, and vine crops will not be taken out of production. Reported crop acreage was taken from the District annual crop reports and represent total acreage for spring and fall cropping. Water costs were taken from District records. Crop prices and yields were taken from the Kern County Agricultural Commission while production costs came from the University of California Extension Service.(Kern County Agricultural Commission, 1997; UC Extension Service)

The model is programmed in the Generalized Algebraic Modeling System to determine optimal water usage for different levels of imported water supplies, aquifer levels, and financial reserves. The model utilizes the method of Positive Mathematical Programming developed by Howitt (1995) to calibrate the model to base level acreage in the District and ensure that the model adequately replicates District responses to policy changes.

The results of these simulations are shown in Figures 2 and 3. Figure 2 shows how the

---

[1]For its own record keeping, the District uses the following general crop categories: field, grain, pasture/alfalfa, truck, citrus, deciduous, and vine. In addition to these 7 categories, the three main crops in the District were segregated from their main categories to show how the District's primary crops would be affected by the proposed rate changes. These primary crops are: carrots, onions, and potatoes.

composition of water demand changed as the District implemented alternative surface water prices. As the figure shows, while overall water usage declines as the price of surface water rises, the proportion of total water use attributable to ground water rises. As a result, reductions in surface water use come almost completely at the expense of ground water. Indeed, nearly all of the reductions in water use come not from changes in marginal application rates, but from fallowing of acreage. This is in keeping with empirical work by Sunding et al. (1997) suggesting that fallowing is an irrigator's primary response to drought and increased water costs.

The effects of ground water substitution are further amplified in Figure 3. Figure 3 illustrates how increases in ground water usage increases the difference between initial and ending pumping depths in the District following adoption of a conservation pricing program. As surface water price rises, pumping depths increase at an increasing rate. Higher surface water prices translate to higher on-farm pumping costs as irrigators compensate for changes in the relative prices of water.

The ultimate conclusion from these results is that surface water price is of limited use as a policy tool when ground water is available as a substitute. Reductions in surface water use will occur only up to the point where ground water becomes a cheaper source of water. While this means that higher surface water prices can conserve surface water, simulation results suggest that most of these reductions are compensated for through higher ground water usage. The general assumption that increasing the price of surface water will lead to water conservation is not valid when ground water is available as a substitute.

References

.

Arvin-Edison Water Storage District. 1993. "The Arvin-Edison Water Storage District Water Resources Management Program," Arvin Edison Water Storage District, Arvin, CA.

Browne, G. T. 1995. "Sample Costs to Produce Carrots in Kern County," Cooperative Extension, University of California, KC 9370.

Browne, G. T. 1995. "Sample Costs to Produce Potatoes in Kern County," Cooperative Extension, University of California, KC 9371.

Howitt, Richard E. 1995. "Positive Mathematical Programming," *American Journal of Agricultural Economics*. 77(2):329-342.

Huffaker, R., N. Whittlesey, A. Michelsen, R. Taylor, and T. McGuckin. 1998. "Evaluating the Effectiveness of Conservation Water-Pricing Programs." *Journal of Agricultural and Resource Economics*. 23(1): 12-19.

JMLord Inc. 1998. "Arvin Edison Water Storage District Reasonable Water Requirements (Addendum to Report Dated July 1994): October 1998", JMLord Inc., Fresno, CA.

Kern County Agricultural Commission. 1998. "Kern County 1998 Agricultural Crop Report," Bakersfield: Kern County Agricultural Commission, 1998.

Michelsen, A, R. G. Taylor, Ray G. Huffaker, and J. Thomas McGuckin. "Emerging Agricultural Water Conservation Price Incentives." *Journal of Agricultural and Resource Economics*. 24(1): 222-238

O'Connell, N., et. al. 1995. "Sample Costs to Establish an Orange Orchard and Produce Oranges," Cooperative Extension, University of California, KC 9366.

Sunding, D., D. Zilberman, R. Howitt, A. Dinar and N. MacDougall. 1997. "Modeling the Impacts of Reducing Agricultural Water Supplies: Lessons from California's Bay/Delta Problem," in D. Parker and Y. Tsur, eds., *Decentralization and Coordination of Water Resource Management*, New York: Kluwer.

Sutter, S., et. al. 1990. "Sample Costs to Produce Double Cropped Barley in the San Joaquin Valley," Cooperative Extension, University of California.

UC Extension. 1993. "Iceberg Lettuce Projected Production Costs, 1992-1993," Cooperative Extension, University of California.

UC Extension. 1993. "Imperial Sweet Onion Projected Production Costs, 1992-1993," Cooperative Extension, University of California.

United States Bureau of Reclamation. 1998. "Incentive Pricing Best Management for Agricultural Irrigation Districts," Report Prepared by Hydrosphere Resource Consultants, Boulder, CO.

Vargas, Ron, et. Al. 1995. "Sample Costs to Produce 40-inch Row Cotton in the San Joaquin Valley," Cooperative Extension, University of California, KC9372.

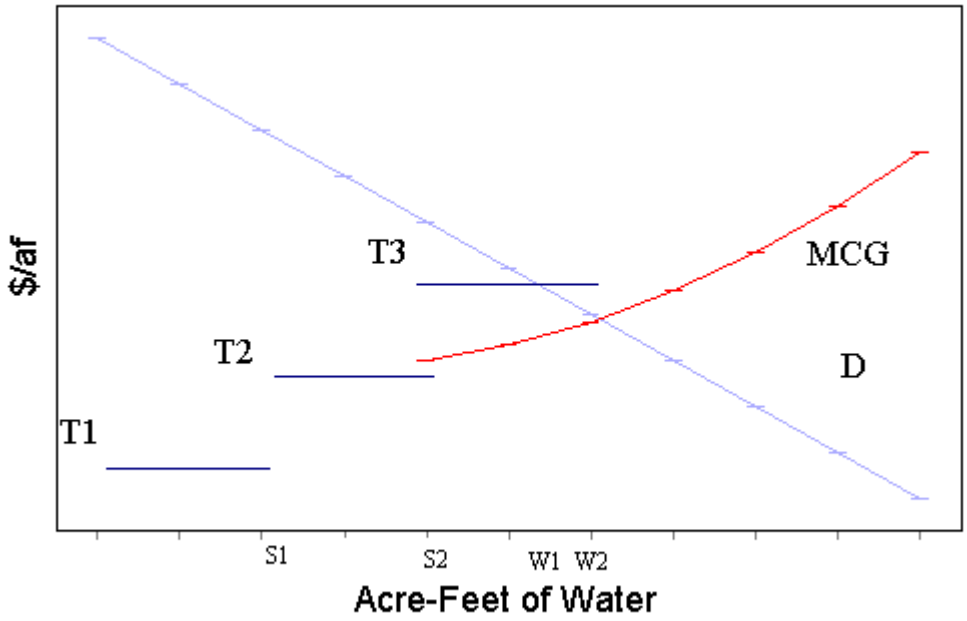

Figure 1: Tiered Water Pricing and Ground Water Substitution

Figure 2: Ground Water Substitution

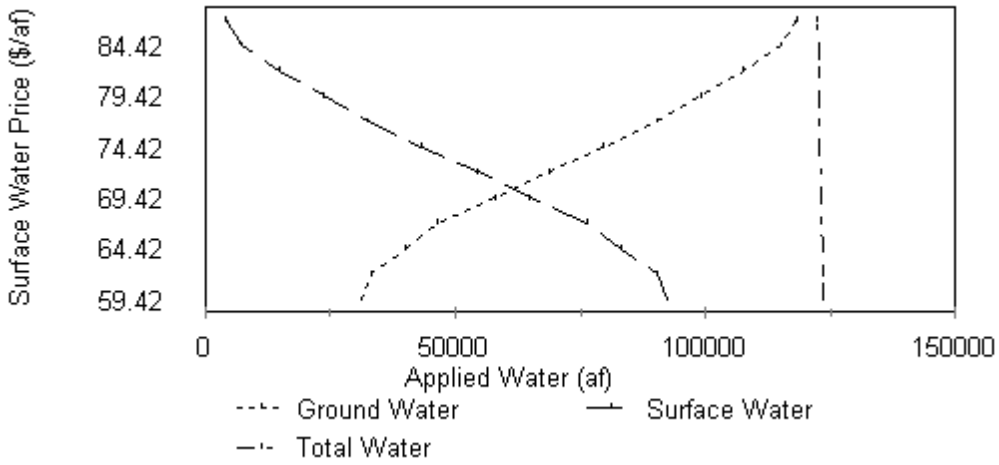
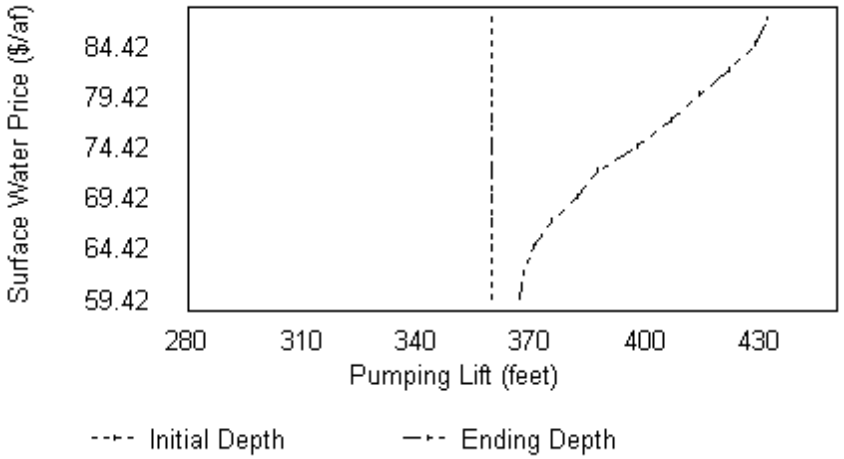
Figure 3: Aquifer Drawdown