Potential Water Use Conflicts Generated by Irrigated Agriculture in Rhode Island

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This study constructs a simulation model to evaluate the potential for conflict among residential and agricultural users of water in southern Rhode Island. The model estimates the profitability of irrigation of turf farms and projects the total use and the economic value of irrigation water. The results indicate that the economic value of irrigation water compares favorably with current residential water prices in the area. In addition, substantial demand for irrigation water is projected. Given current rates of growth in turf acreage and residential water use, there appears to be a significant potential for conflict, particularly given the absence of well developed institutions for allocating water among users.

I. Introduction

In recent years agricultural practices in New England have undergone dramatic changes. Traditional dryland crops such as potatoes and silage corn have been replaced by irrigated "landscape" crops; specifically turf and nursery crops. For example, commercial sod production in Rhode Island has risen from 200 acres in 1972 to over 2,500 acres in 1986, while potato acreage has shown a similar decline over this period. Landscape crops command high market values and appear to represent a long term trend in land use for the relatively densely populated southern New England rural areas because these crops can compete with residential uses for high priced land.

Landscape crops have shallow root systems (15–20 cm) that utilize only the moisture in the upper portion of the soil profile. Drought stress regularly occurs in turf and nursery crops planted on loam and sandy loam soils. Epstein has estimated that drought stress on these shallow rooted plants can occur after only 4 days without rain in the summer for sandy loam soils and after 6 days without rain on silt loam soils. Supplemental irrigation is becoming increasingly common in southern New England. Typical application rates for turf farms are 1 inch per week. This implies water use on an irrigated 160 acre turf field equal to the demand of a town of 8,000, assuming water use of 75 gallons per capita per day.

Unlike arid areas of the west, the humid New England region has had little recent conflict between users over water quantity issues. However, water quantity is emerging as a priority management topic with increased residential demand, reductions in supply due to contamination, and difficulties and costs associated with development of new sources. The high values of landscape crops that enable them to compete with residential uses for land may also imply a comparable value of irrigation and municipal water, unlike the situation elsewhere in agriculture. Imprecisely defined property rights and the absence of well developed institutions for water allocation leave market forces which exclude consideration of water scarcity to dictate the extent of irrigated land and the associated water use. If irrigation is profitable on larger scale, turf growers will use an increasing proportion of the water supplies. The potential for water supply problems needs to be anticipated in order to avoid loss of significant irreversable investments currently underway.

This study examines the profitability of irrigation of landscape crops in Rhode Island and the potential for water conflict if irrigation spreads. In so doing, the study determines the economic value of water for turf farm irrigation, and compares this value to current residential water prices in the area. Although water is not sold in a competitive market and the price faced by the consumer is determined by a number of factors, including political concerns, price should be demand revealing. That is, the marginal value of water in residential use will

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be equal to the price if residential users view the price of water as fixed and purchase water so as to maximize utility subject to their income constraint. Thus, comparing the value of irrigated water to the price will provide some measure of the relative value for irrigation versus municipal use of water.[1] If water is scarce and the value of water in irrigated use is greater than the marginal value in residential use, then some reallocation of water from residential to agricultural uses would be Pareto efficient.

The analysis will be done under two alternative irrigation strategies. The first strategy is the current practice of applying an inch of water whenever soil moisture level falls below a fixed level. The second strategy is to apply a smaller, variable amount of water, depending on conditions, such that the root zone is moistened, but water loss through percolation is negligible. Under the second strategy, lower levels of water use can be attained without loss in turf growth rates.[2] For each of these cases, the average value of water is calculated and compared to the municipal water prices.

II. Modelling Approach

A simulation model determines the economic viability of irrigation, and the resulting demand for supplemental water by farmers. The inputs and assumptions of the model are based on daily climatic conditions, crop and soil characteristics, and cultural practices of farmers in southern New England over a 15 year period. The rate of evapotranspiration and plant growth is diminished under conditions of drought stress. By timing irrigation to soil moisture, farmers can decrease or eliminate these periods of stress, leading to shorter times to harvest, and more crops within a given time horizon. However, irrigation implies additional capital and operating costs. Thus, the decision to irrigate, as well as the choice among alternative irrigation technologies, depends upon the impact of irrigation on growth and the capital and operating costs of the technologies.

The simulation model has three components: soil moisture, plant growth and economic valuation. Each component is briefly discussed below.

Soil Moisture Model

Based on the work of Sudar et al. and Hill et al. a soil moisture model simulates available moisture for plant growth. Estimates of daily changes in soil moisture are made by dividing the soil profile of the root zone into layers and keeping an inventory of the water inputs and outputs for each layer. Inputs include infiltration from precipitation and irrigation, while outputs are transpiration, evaporation and percolation. The soil moisture model is depicted in Figure 1. Soil moisture (SM) is estimated daily using

$$SM(i,t) = SM(i,t-1) + INF(i,t) - TA(i,t) - EA(i,t) - PERC(i,t)$$

where INF is infiltration from precipitation and irrigation, TA is transpiration, EA is soil evaporation, and PERC is percolation. The root zone is divided into two layers of equal depth to approximate spatial and temporal variations in infiltration, moisture extraction by roots, and percolation (Sudar et al.).

Infiltration is calculated as the portion of irrigation and precipitation that does not leave the field as overland runoff. Runoff is computed from the Soil Conservation Service (SCS) curve number method (Mockus). Infiltration water is added to the upper soil layer until saturation occurs. Any additional infiltration is then distributed to the remainder of the root zone and soil profile. Drainage from the root zone (PERC) is computed when soil moisture content exceeds field capacity. The water

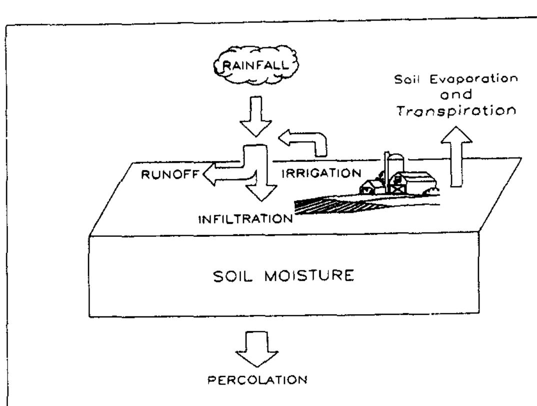

Figure 1. Depiction of the Soil Moisture Model

[1] Note, however, that price will reflect the marginal value of water delivered to the household, which includes treatment and delivery, and thus will tend to overstate the marginal net social value of residential water. Gibbons calculates consumer surplus for small changes in supply for three cities and finds net marginal values (i.e. consumers surplus) that range from about 2% to 90% of the price. This will tend to decrease the value of water in residential use relative to that in turf irrigation.

[2] Under the water conservation strategy virtually 100% of water use is consumptive, by definition. Most of the additional water applied under current practices will percolate to the groundwater and hence be available for future use. However, recharge is not immediate, and summer use can be thought of as a withdrawal that will decrease the accessible water in that summer.

content above field capacity is assumed to remain in that soil layer for one day before draining to the next layer.

Transpiration is estimated by

$$TA(t) = (TP(t)/.5) * AW(t)/TAW \quad \text{if } AW(t)/TAW < 0.5,$$
$$TA(t) = TP(t) \quad \text{if } AW(t)/TAW > 0.5,$$

where TA is actual transpiration, TP is potential transpiration, AW(t) is the available soil moisture in period t, and TAW is the maximum possible available soil moisture for the specific soil type. Under this model actual transpiration equals potential transpiration unless 50% of the available moisture is depleted (Hill et al.; O'Neil et al.; Peterson and Hill; Sachs et al.).

Potential transpiration is defined as "the amount of water transpired in unit time by a short green crop, completely shading the ground of uniform height and never short of water" (Epstein). TP is estimated as

$$TP(t) = KC(t) * ETP(t),$$

where KC is the crop coefficient and ETP is potential evapotranspiration. The crop coefficient is dependent upon the stage of crop growth and is subject to upper and lower constraints. For the present model, KC is calculated as

$$KC(t) = 0.01188 * SGRDAY(t),$$

where SGRDAY is the number of growth days since planting. At full ground cover, maximum KC is assumed to be 0.95 (O'Neil et al.). Once the maximum KC value is reached, it is assumed to remain unchanged until growth begins the following year.

Estimated ETP is obtained by the modified Penman method (see, for example, Schwab et al.), which was found to give the best estimates for a wide range of climates (Doorenbos and Pruitt; Grabow).

Soil evaporation is computed using the method described by Hill et al., who estimate soil evaporation (EA) by

$$EA(t) = EP(t)/(N^{d-1}),$$

where EP is potential evaporation, N is a constant which determines decay time of EA after each soil wetting, and d is the number of days since the last wetting. Evaporation is confined to the top four inches of soil and is subject to the constraint that the surface layer cannot be drier than the air. Potental evaporation is determined by

$$EP(t) = AS(t) * ETP(t),$$

where AS is a soil coefficient, equal to 1.0 minus KC. Substantial EA occurred only during periods of crop establishment following precipitation.

Wind speed, temperature and relative humidity were obtained from the weather station at Kingston, Rhode Island maintained by the Agricultural Experiment Station at the University of Rhode Island. Records of daily global radiation were obtained from the Eppley Labs, located 20 Km east of Kingston.

Plant Growth Model

DeWit and others demonstrate that a specific level of transpiration is associated with a given level of yield. This study assumes that a specific amount of transpiration must be accumulated before the turf can be harvested. Hill et al. make this assumption in estimating the cutting times for alfalfa. Soil moisture can limit ET when moisture is below a critical level (Aronson). For this study, soil moisture is considered limiting to ET when 1/2 of the available water in the root zone is depleted. To account for the uneven distribution of patterns of roots with depth (Hillel), soil moisture is extracted separately from the two soil layers with the upper layer contributing a larger portion to ET.

A linear relationship between evapotranspiration (ET) and dry matter production, as demonstrated by numerous researchers, is used (Stewart et al.; Weaver; Hanks; Doorenbos et al.). Thus, dry matter yield (Y) is estimated as

$$Y = TA/TP * YP,$$

where TA is actual transpiration, TP is potential transpiration, and YP is potential yield.

In the model, the field is irrigated when soil moisture limits TA. Two different application rates are simulated: 2.5 cm/irrigation; and an application rate sufficient to moisten the soil to field capacity. Growers typically apply 2.5 cm/irrigation (1″). Because of the shallow root system, this rate results in routine leaching losses. For a 20 cm root zone, 2.1 and 1.2 cm/application were used to avoid leaching losses on silt loam and sandy loam soils respectively.

The two types of soil, silt loam and sandy loam, have an available water content of 0.21 cm/cm and 0.12 cm/cm, respectively. These soils account for 70% of the agricultural land in Rhode Island (Rector). Crop specific information regarding germination, root growth, temperature stress and field activities, such as planting and harvesting dates, are detailed in Porter.

To determine the total quantity of actual transpiration required prior to turf harvest, planting and harvest data for 13 separate turf crops raised by a single manager were obtained. Of these 13 crops, 9 were irrigated and 4 were not. For each crop, the total accumulated transpiration was estimated from the model, using daily weather records and the specific irrigation regimes applied to each field. Although the average growing period for the irrigated and nonirrigated crop differed by 40% (12 months vs. 17 months, respectively), the average transpiration from planting to harvest varied by only 7% (20.5 vs. 22″/crop). Thus, the accumulated transpiration approach for predicting plant growth appears to be consistent with local data on time to harvest, and, if anything, is a conservative measure of benefits of irrigation since total transpiration is slightly lower on irrigated turf crops. A requirement of 21″ of transpiration is used to represent a mature turf crop.

Economic Valuation

To evaluate the impact of irrigation on profitability of turf production at the farm level, the net present value of the crop is calculated with and without irrigation. Clearly the price of sod for an individual farm is independent of whether irrigation is used, since quality is not affected by irrigation and since no individual farmer has a significant impact on the quantity supplied at the market level. Thus, benefits from irrigation result solely from the shorter crop cycles. Since Rhode Island supplies a small portion of total sod in the northeastern market, price is viewed as invariant to irrigation within the state. Of course, if irrigation leads to increased supply throughout the region, sod prices may fall as a result. However, this would not necessarily reduce the incentive for an individual farmer to irrigate, since the farmer would face the lower price independent of whether he chooses to irrigate. In any case, examination of price response is beyond the scope of the study.

Revenues and costs are estimated using data from local growers, from published literature, and from the soil moisture and plant growth submodels. Returns to irrigation are calculated for three types of low pressure, gasoline powered irrigation systems: hand moved, center pivot, and linear move. Water supply is from surface sources. Irrigation system sizes chosen for evaluation are based on system limitations and field sizes currently worked by local growers.

Capital and operating costs for several irrigation systems were obtained from equipment dealers and farmers currently irrigating. Production cost data for turfgrass production were obtained from local growers. The data are described more fully in Porter. This information, along with the simulation model, is used to determine the net pressent value of production returns from turf farming with and without irrigation. The benefit to irrigation is calculated as the difference between these two. Sensitivity analysis is performed to determine the changes in returns to irrigation from changes in different key economic variables.

Calculating the Economic Value of Irrigation Water

The economic value of irrigation water is the difference in the net present value of returns from turf farming with and without the use of irrigation, under each of the two irrigation regimes. This return to irrigation is then divided by the total amount of water used to determine the average value of water used for irrigation.

The net present value of profits without irrigation is

$$\Pi^{ni} = \sum_{j=1}^{N^{ni}} (1+r)^{-t^{ni}(j)} \left[V - C^{ni} \right]$$

where Π represents profits, superscript ni represents no irrigation, N represents the total number of harvests within the time horizon, t(j) represents the time to the jth harvest in years, V represents the value of the crop at time of harvest, and C represents the costs faced by the farmer. The price of turf varies with the quantity purchased and the condition of the sod. The real price of turf is presumed to be fixed at $0.16 per square foot, the average price in Rhode Island in 1984, and the discount rate for turf farmers is presumed to be 12%. In the case with irrigation profits are

$$\Pi^{i} = \sum_{j=1}^{N^{i}} (1+r)^{-t^{i}(j)} \left[V - C^{i} \right] - K,$$

where i represents the case with irrigation and K represents the initial capital cost of the irrigation equipment. Note that the irrigated turf is harvested sooner than the non-irrigated turf, so that

$$t^{ni}(j) > t^{i}(j)\ ,\ t^{i}(N^{i}) \equiv t^{ni}(N^{ni}),\ \text{and}\ N^{i} > N^{ni},$$

which are interpreted as follows: The time when the jth crop is harvested in a non-irrigated field is later than the time the jth crop is harvested in an irrigated field. The two cases have the same time horizon (the time of harvest of the last crop). The number of crops harvested from the irrigated field is greater than the number of crops from a non-irrigated field, for the fixed time horizon.

The economic desirability of irrigation can be determined by:

$$\Pi^{i} - \Pi^{ni} \gtrless 0,$$

and the average present value of irrigation water discounted over the full time horizon is

$$\frac{\left[\Pi^{i} - \Pi^{ni}\right]}{\left[\sum_{j=1}^{N} W(j)\right]},$$

where W(j) is the amount of irrigation water applied in period j. The economic value of irrigation water per unit applied can be calculated as the increased annualized profit due to irrigation divided by total water use. However, since this value will depend upon the simulated daily rainfall pattern, averaging over a number of crop cycles is appropriate. A total of 13 years of simulated production were used to calculate the average value of water.

This value of irrigation water is then compared to prices of water for residential uses to determine the potential social desirability of water use for irrigation, under conditions of water scarcity in the absence of institutions for allocating water. Although residential water is not sold in a competitive market, the price will be demand revealing if consumers purchase water so as to maximize utility subject to their budget constraint. A more difficult issue relates to whether consumers behave as 'rational' utility maximizers when choosing how much water to consume. A vast literature seems to suggest that there is at least response to price (Howe and Linaweaver, Foster and Beattie, among others). Although some behavioral tests have been suggested (see, for example, Opaluch 1982, 1984), it is generally difficult to determine whether the response results from utility maximization. The relative values of water are also indicative of the potential for competition between residential and agricultural uses within a market environment.

III. Empirical Results

The model is used to simulate daily patterns of rainfall and soil moisture over a thirteen year time horizon. This information is used to determine the time path of irrigation water use under each irrigation strategy and the resultant change in the present value of profits compared to the no irrigation case. Table 1 contains the variable costs per acre of turfgrass production for farms of various sizes. Table 2 contains capital and operating costs of various irrigation techniques. Using this information the increase in the present value of profits over a thirteen year time horizon is calculated by soil type, field size and irrigation technology (Table 3). Farmers are assumed to choose the irrigation technology which maximizes profits for the field size and soil type. The increased profit from irrigation is calculated for each soil type by taking the simple average of profits over field size.

The economic value of water is then calculated. Average irrigation water use and value per thousand gallons are presented in Table 4. The economic value of water varies with irrigation strategy and soil type. Under current irrigation practices, irrigation water is worth $0.80 per thousand gallons on sandy loam soil and about $1.50 on silt loam. Under the water conservation strategy water is worth about $1.50 on sandy loam soil and $1.90 on silt loam soil. These values are comparable to current residential water prices which vary between $0.50

Table 1. Variable Costs per Acre of Turfgrass Production by Farm Size

Activity	50	Farm Size (Acres) 100	200
		(Dollars)	
Planting	188	170	163
Fertilization			
Spring	144	130	125
Fall	283	256	246
Rolling	6	5	5
Mowing (84 Times)	121	109	105
Harvesting	639	610	592
Total	1,381	1,280	1,240

Source: Data for 200 acre farm: Personal communication with Robert Ensign. Costs for other sizes calculated using percentage differences per acre from Gilbert and Lessley.

Table 2. Costs of Three Types of Irrigation Systems for Turf Production

	System						
	Hand Moved		Center Pivot			Linear Moved	
Size (Acres)	25	50	50	100	200	100	200
				(Dollars)			
Fixed Costs							
Initial	16,953	31,844	46,267	56,863	91,660	62,600	100,000
Maintenance (annual)	878	1,574	2,926	3,612	5,800	3,956	6,300
Operating Costs *(per acre inch applied)*							
Fuel and Oil	74	148	185	370	740	370	740
Labor	234	360	36	48	84	48	84
Total operating	308	508	221	418	824	418	824

Table 3. Net Present Value of Returns per Acre by Technology and Soil Type

	System						
	Hand Moved		Center Pivot			Linear Move	
	25	50	50	100	200	100	200
				(Dollars)			
Silt Loam Soils	2,812	2,926	2,862	3,359	3,519	3,289	3,469
Sandy Loam	2,096	2,373	2,637	3,144	3,310	3,075	3,260

Table 4. Model Outputs for Irrigation Application Rates and Economic Value of Water

	Silty Loam	Sandy Loam
Strategy A: Current Practices		
Water Application Rate (Inches/Yr)	12.4	21.5
Total Water Use (Million Gal/Day)[A]	4.9	8.4
Economic Value ($/Thousand Gals.)	1.51	0.80
Strategy B: Water Conservation Strategy		
Water Application Rate (Inches/Yr)	9.8	11.5
Total Water Use (Million Gal/Day)[A]	3.9	4.7
Economic Value ($/Thousand Gals.)	1.91	1.51

Note: Figures for water use are averaged geographically for three Rhode Island towns considered by Porter, and are averaged over spring and fall planting dates.

[A]Based on the assumption of 1,250 acres of each soil type. Note this daily application rate occurs during the growing season only.

and $2.50, depending on the water supply system and useage.

At current acreage of turf farms, substantial potential demand for water exists. As shown in Table 4, total projected water use on turf farms is 13.3 million gallons per day (MGD) under current irrigation practices, where users apply 1 inch of water when soil moisture limits growth. This equals the daily water use for approximately 175,000 residential consumers, or approximately one-sixth the population of Rhode Island. Total water use is 8.6 (MGD) under strategy B, where users apply only the necessary amount of water when soil moisture limits growth. Thus, substantial amounts of water can be saved by application of only the amount of water that will remain in the root zone.

Given current growth rates of turf acreage and residential population in southern Rhode Island, a significant potential for conflict exists among water users. Quantification of this potential requires an estimate of total water available for agricultural and residential uses. Allocating all available water would have a dramatic impact on instream water uses, such as recreational fishing. Hence, a basin-wide hydrogeologic model and a study of the impact of reduced stream flows would be required to provide a full analysis of water use in the area. To the knowledge of these authors, these studies have not been done in the region, and are beyond the scope of the present effort. However, given the significant investments in agricultural and residential water supply capital, careful consideration should be given for the potential future supply.

The potential for conflict will likely be greater during drought periods when turf farmers and residential users will desire more water and stream levels will be relatively low. Further, water use for irrigation is concentrated in the summer, a relatively dry period with high residential water use. Thus, timing will tend to make water conflict more severe.

The analysis in this study uses only expected value of returns from irrigation. In the literature, it is often argued that risk aversion plays a stronger role in motivating the farmers decision to irrigate than does the mean value of returns. To the extent that risk aversion is a significant factor in the decision to irrigate, this analysis may understate the benefits of irrigation to turf farmers. All of this implies that conflict among water users may occur, and that a well-developed institutional framework for allocating water may be desirable. Such a framework should recognize the needs and relative value of instream water use, in addition to residential and agricultural use.

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