THE RESPONSE OF AGRICULTURAL WATER USE TO CHANGES

IN PUMPING COSTS

by

YASSERT ARAFAT GONZALEZ-ALVAREZ

(Under the direction of Dr. Jeffrey Mullen)

ABSTRACT

Water is a scarce good without a price in riparian doctrined-governed Georgia. Differences in pumping costs are used to infer how farmers will respond to water price changes. Water demand equations have been estimated using OLS procedures. Price and quantity are pumping cost per unit and total acre-feet per acre applied, respectively. Inelastic water demand estimates obtained ranged from -0.15 to -0.27.

INDEX WORDS: Water demand, Pumping costs, Irrigation, Georgia

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A todos los que me ayudaron a trillar este camino,

A mi querido hermano Kamal Ernesto González, que en paz descanses.

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CHAPTER 1

INTRODUCTION

Background

Georgia is blessed with abundant rainfall and numerous permanent rivers and streams. As a consequence, it has taken time for water scarcity to become an issue. Water has historically been considered a free good. Beneficiaries have had little or no incentives to use water efficiently. However, previously plentiful hydrological resources have come under increased pressure. Presently, the agricultural sector, a major user of water, is attempting to cope with higher pumping costs, increased competition for water resources from other sectors in the economy, and environmental concerns. These factors are placing considerable pressure on irrigators to improve their water use efficiency.

Water demand from various sectors of the economy has increased dramatically. The US Geological Service reported that between 1960 and 1995, the latest year of available figures, water demand by thermoelectric, industry, urban household, and rural/irrigation grew 153%, 12%, 307%, and 723%, respectively. The bulk of the increment in water demand by the rural/irrigation sector resulted from widespread adoption of irrigation systems across the state. For example, as of 1960, Georgia's agricultural landscape was typified by rainfed crop production. Comparatively, 2.2 million permitted acres were being irrigated by the year 2000 (Board of Natural Resources). Bramblett (2002) observed that agricultural lenders from 1970 onwards required all applicants to have an irrigation system on site. This precipitated a boom in the irrigation equipment sales and installation. The rationale behind the lenders' policy is that irrigation is a form of crop insurance. It drastically minimizes the risk of crop failure. In the rush to adopt irrigation technology, the acquisition and installation costs and their effects on crop production costs received a fair amount of attention. Nonetheless, per unit pumping costs were essentially ignored.

As time passes, the competition for water between rural water users and the urban sector intensifies. Depletion and pollution have significantly undermined environmental conditions in many areas. Future development of surface water supplies (e. g., large public projects) faces feasibility, fiscal, and environmental constraints. Moreover, there is a great deal of concern regarding the rate at which groundwater is being harvested. Uncertainty in the water supply picture and incessant demand growth have rendered the notion of “free water” an anachronism.

Given the aforementioned supply constraints, approaches aimed at reining in water demand seemingly hold the most promise. Water quantity demanded and per unit price of water are likely to be inversely related. Therefore, how price changes affect water use merits consideration. Direct observation of water price changes is not possible because there are no water markets operating in Georgia today. If we assume that changes in pumping costs have the same effect on marginal cost of water use as changes in the price of water to users, then pumping cost shifts may be considered a proxy for water price fluctuations. Parting from this assumption, this study seeks to infer irrigators’ reactions to changes in water price through observation of their responses to pumping cost fluctuations. Individual farmers, as profit maximizing/cost minimizing economic agents, will make input/output and land allocation decisions to minimize any adverse impact on the bottom line.

Problem Statement

Undoubtedly, the proliferation of irrigation technology has intensified the exploitation of Georgia's water resources. As previously noted, total demand by the statewide rural/irrigation sector expanded sevenfold in the past 35 years. There is however a dearth of information on how much water is being applied on a per acre basis to the various crops currently in cultivation in Georgia.

Moreover, there is the question of how much was the cost of pumping such irrigation volumes. Economic theory dictates all scarce resources ought to have a price. Nevertheless, water is a scarce good without a price of its own. Typically, rural water users pay pumping costs. Pumping costs comprise extraction, conveyance, pump maintenance, and fuel costs. To the average irrigator, the "price" of water is nothing more than an amalgamation of these costs. In practice, this arrangement creates serious distortions. The compelling reason behind adequate pricing of scarce resources is to promote their efficient use. Scant attention has been paid to the question of per unit pumping costs. At present, there are no reliable estimates of the cost of pumping an acre-foot of water in Georgia.

Lastly, agriculture activity comprises 16 percent of Georgia's gross domestic product. Additionally, this sector occupies 15 percent of Georgia's labor force (Doherty and McKissick). Any adjustments made by irrigators as a result of changes in pumping costs will generate a ripple effect on Georgia's economy. There is a necessity to know what will happen in terms of water demand if farmers were required to pay the price of water. The question is not whether they will respond to changes in pumping costs but the magnitude of such a response.

Objectives

- First, this study examined, compared, and contrasted water use patters across the state of Georgia. This study accounted for how much water per acre is being used by irrigators.
- Second, pumping costs in terms of acre-feet per acre were calculated. This study includes a thorough explanation on how to compute defensible estimates of pumping costs for each acre-foot per acre delivered.
- Third, this study ascertained the responsiveness of irrigators to changes in pumping cost. Water demand elasticity estimates with respect to changes in pumping cost were generated.

Procedure

A demand equation was fitted using the ordinary least squares statistical estimation technique. Linear and log-log functional forms of the demand equation were estimated. The dependent variable is irrigation water use by crop in acre-feet per acre. The independent variables are pumping costs and Blaney-Criddle crop irrigation requirements.

At the University of Georgia, the National Environmentally Sound Production Agriculture Laboratory is conducting the Agricultural Water Pumping Study. Water meters have been installed at 800 farm subfields. These devices are gathering data on water use patterns. The Agricultural Water Pumping Study is an expanding database. For each subfield, the data contains crop name, water source, subfield acreage, length of observation period, total irrigation volume applied, etc. This data set is the backbone of the analysis herein presented. Other data sources include the National Oceanic and Atmospheric Administration, and the U. S. Department of Energy.

Organization of the Thesis

Chapter 1 introduces the research problem and objectives. Relevant theoretical background on the model is presented in the second chapter. Chapter 3 addresses the first objective: To investigate water use patterns using data from Agricultural Water Pumping Data Study being conducted by the National Environmentally Sound Production Agriculture Laboratory. Chapter 4 details efforts to meet our last two objectives. The particulars of modeling and estimation attempts are specified in this chapter. Chapter 5 discusses results, policy implications and directions for future research.

CHAPTER 2

THEORETICAL FRAMEWORK

Water: What kind of good is it?

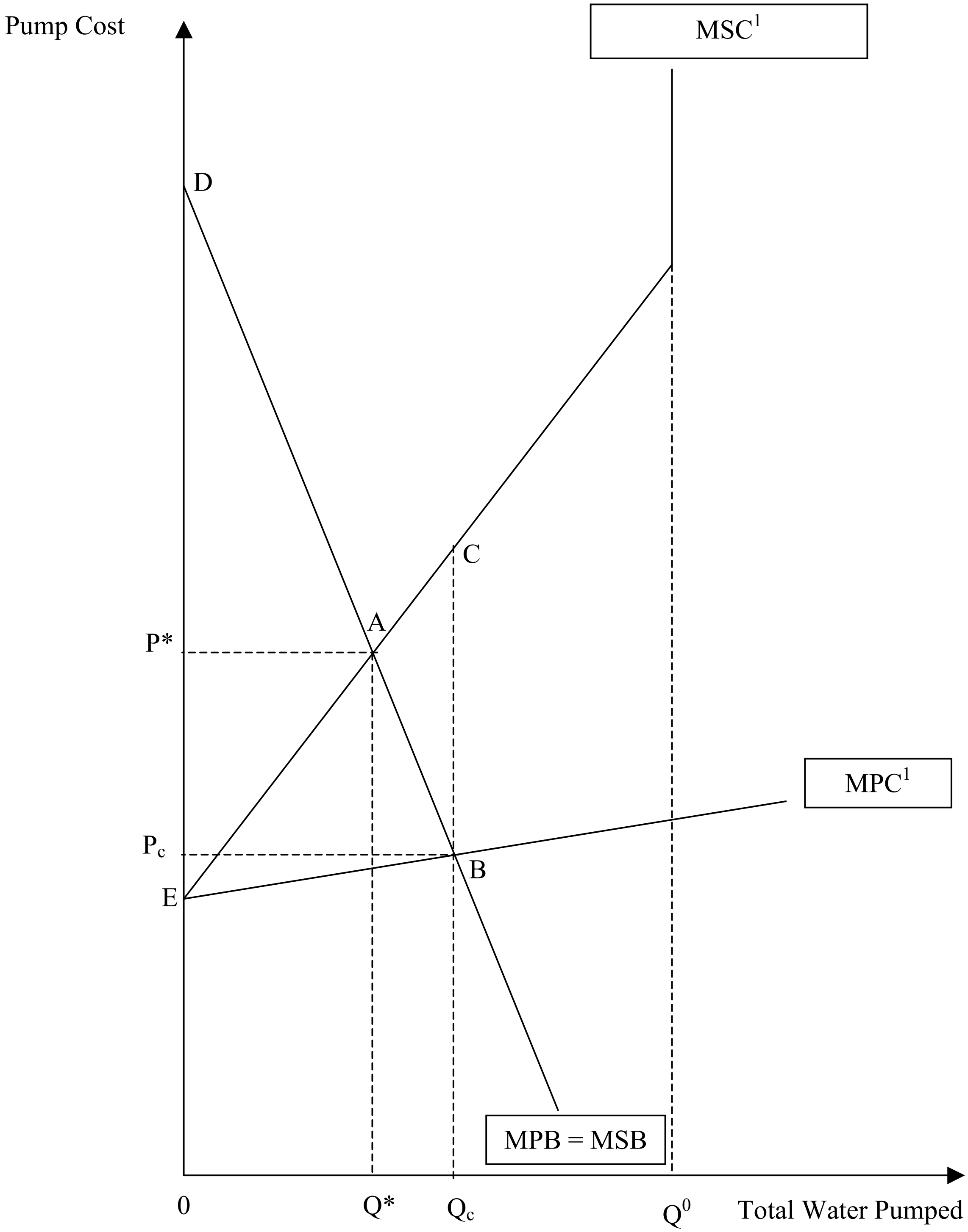
Sixty five percent of the world's fresh water goes to irrigate our crops (Postel 1999). Water is in constant flux from solid to liquid to gas as it makes its way through the hydrologic cycle. This is how water recycles itself. Hydrologists estimate the average water molecule spends 5,000 years in the subsurface. The inhabitants of the Earth have been using the same water since time immemorial (Jordan). The hydrologic cycle is closed; no water is added on each successive round. Water found at the surface can be considered a renewable resource in large part because of its direct contact with the atmosphere. Groundwater may or may not be renewable. This depends on depth of aquifer, current precipitation rates, infiltration rates, etc. Deep groundwater deposits in some parts of Africa and the Middle East, for instance, no longer replenish. Postel (1992; 1999) points out that water has been stored for hundreds of millennia in "fossil" or Pleistocene aquifers in the Arabian Peninsula and the Maghrib. Today these underground water bodies are not recharging at an adequate rate because of insignificant precipitation and infiltration rates. The water therein percolated through the porous underground formations before the Sahara turned to desert wasteland. Only 2.5% of the all the fresh water reserves in the U. S. are renewable water resources (Jordan).

In economic terms, there are chiefly two kinds of value: Use and exchange. Use value is the pleasure or satisfaction that the owner derives from a given good. The exchange value is measured in terms of quantity of other commodities, be it money or anything else, that a good can be traded for. In places where water is scarce water has both high use and exchange value. Acute fresh water scarcity is becoming the rule rather than the exception in most of the world. Jordan lists "six causes of water scarcity: drought (climate changes), degradation of water quality, depletion of resource faster than recharge, redistribution, consumption, and out-of basin diversion or shortage" (pp. 1-2). Jordan stresses that inadequate pricing regimes exacerbate water scarcity. These price regimes do not encourage conservation of our water resources.

Figure 2.1 depicts a situation where an irrigator draws water from a well. Currently, pumping cost P_c is the established market price. Pumping costs are low since they do not include the scarcity value of water. The irrigator pumps Q_c acre-feet of water per acre. At Q_c the marginal private benefits (MPB) are equal to the marginal private costs (MPC) of pumping. This is a partial equilibrium. At any point before Q_c, the irrigator has an incentive to increase water extraction. The MPB derived from each additional unit exceed the MPC incurred in its procurement. At any point beyond Q_c, the MPC of pumping each additional unit are greater than the MPB. It makes no economic sense to pump the next unit. Therefore, the irrigator is content to pump Q_c.

The fact that marginal social costs (MSC) are not equal to marginal private costs (MPC) highlights the distortion embedded in this partial equilibrium. If MSC and MPC were equal then the equilibrium quantity would be Q*. The irrigator will consume Q* and pay P*. The irrigator consumes less water at a higher price ($Q^* < Q_c$, $P^* > P_c$). A price ceiling, denoted by the upward sloping MPC line, is in effect. A price ceiling encourages overconsumption and thereby aggravates the shortage of the resource. Although the irrigator is consuming at the point where MPC equals MPB, society is less well off.

Figure 2.1. Private and Social Costs and Benefits



[1]There is some controversy regarding the shape of MSC and MPC. Certainly, the functions are non-decreasing in water use. Moreover, the total amount of water available, Q^0, serves as an asymptote. Farmers can not pump more than what is available.

At current price P_c, total social benefits accrued encompass the area $0DBQ_c$ and total social costs incurred are $0ECQ_c$. The difference between total benefits and costs is the triangle ECB. This triangle represents the external costs borne by society due to lack of price on water. It is a cost burden imposed on society as a result of inefficient use of the scarce water resources.

If pumping costs were to reflect the scarcity value of water, the predominant price will be P*. This is the socially optimal price. At price P*, social and private benefits are equal and the same goes for social and private costs. The triangle ABC represents the net welfare gains from the reduction in water use to Q*. Water is being efficiently allocated. It is yielding the greatest net social benefit.

Scarcity is economics' *raison d'être*. Ever since the International Conference on Water and the Environment in 1992 (a. k. a. the Dublin Conference), there have been incessant calls to let the market settle any water pricing and allocation issues (Perry, Rock and Seckler). Water can qualify as an economic good. As in the case of oil, the economic value, or use value, of water springs from its myriad uses. These uses are often incompatible and thus rival one another (Perry, Rock and Seckler). Perry, Rock, and Seckler can not conceive water being strictly a private good or a public good. They argue that water is a bit of each. One should not equate the "economic value" (use value) and the "financial value" (exchange value) of water. Perry, Rock and Seckler explained their reasoning through an examination of the debate in terms of "values and facts." In Perry, Rock and Seckler's terminology "the value domain or universe" refers to what type of good is water. The "facts domain or universe," on the other hand, concerns how such a good should be allocated in order to yield the greatest societal benefit (Perry, Rock and Seckler).

Water has the characteristics of an economic good. Therefore, it need not be treated any different from any other economic good such as oil. Consumer preferences, not state planning, should dictate how water is allocated. Each person should consume enough water to satisfy his or her utility. Rational individuals will consume the next unit of water if and only if the benefits derived are greater than equal to the cost incurred. Market-determined prices are uniquely able to mirror the true value of water to those that purchase it (Perry, Rock and Seckler).

Water is also a social good. Adequate consumption by the greatest number in society will yield unparalleled benefits. Social justice and environmental concerns should be considered first and foremost. Therefore, arguments in favor of water markets will largely be based on oversimplications. Markets accommodate only those in the position to afford water. The water necessities of low-income individuals or farmers will not be met. In all fairness, the “deadweight loss” (triangle ECB in Figure 2.1) associated with below market prices ought to be contrasted with societal gains accrued from access to the resource by the greatest number (Perry, Rock and Seckler).

Perry, Rock and Seckler disagree in part with market proponents and contend that provisions must be made to guarantee access to the resource to those that can least afforded. Market advocates place too much faith in consumer sovereignty. Nevertheless, there remains a viable role for markets in serving the needs of high volume users. The best solution will be reached when both sides need to come to the middle. The specter of market failure haunts the realm of facts in this discussion. Markets fail and not infrequently. Consequently, all solutions offered should take this into account (Perry, Rock and Seckler).

Perry, Rock and Seckler add that "markets reflect marginal values, and function best where such values are relatively stable, or change progressively. Water is not such a good" (p. 5). Water violates the consumer preference axioms of strong monotonicity and local nonsatiation. In other words, more is not better. Indifference curves are circular and thick. Sandra Postel (1992) illustrates a repercussion of overallocation:

> Each year some irrigated land comes out of production entirely as a result of waterlogging and salting of the soil brought about by poor water management. Without adequate drainage, seepage from unlined canals and overwatering of fields raise the level of underlying groundwater. Eventually, the root zone becomes waterlogged, robbing plants of oxygen and curtailing their growth. In dry climates, evaporation of water near the soil surface leads to a steady accumulation of salt that also reduces crop yields and, if not corrected, can ruin the land. Aerial views of some abandoned irrigated areas show vast expanses of glistening white salt, land so destroyed by irrigation that it is essentially useless (p. 53).

The absence of monotonicity and the presence of satiation in consumer preference discredit the notion that water is a purely economic good. All too frequently, inability to obtain water may lead to death or economically ruinous crop failure. In such circumstances, the marginal utility of water can not be computed. On the other hand, once the necessity has been met, only disutility is gained from the consumption of an extra unit (Perry, Rock, and Seckler).

Furthermore, Perry, Rock and Seckler assert that choice is one of the characteristics that distinguish humans from other animals. Death is not a choice worthy of consideration. "Humane," or modern, societies value water as a "merit good" rather than a purely "economic good." Merit goods (same as social goods such as education, health services, housing, etc.) are goods whose consumption by the greatest number of individuals improves society as a whole. These societies would endorse price discrimination. Those individuals who can least afford water will be able to purchase it at an artificially low price (price P_c in Figure 2.1) and others will procure it in the open market. Modern societies favor an approach that will not leave anybody without water even if they can not afford it. There is no one right answer to the question of whether to treat water as an economic good or not. Most of the discussion surrounding this topic is permeated with normative statements. This is the classic case of the end justifying the means. In order to ensure a more equitable distribution, the government must intervene. Nevertheless, high volume users could greatly benefit from the existence of water markets (Perry, Rock, and Seckler).

As we have seen, the attributes of water place it under various categories. This debate appears far from settled. In the mean time, farmers may experience fluctuations in pumping costs. Agriculture is a highly competitive industry. Most participants are only making normal profits. Agricultural commodities markets are known for their volatility. There is very little room for error in terms of how high an increase in operating cost the average farmer can bear. Given the importance of irrigated agriculture in the state of Georgia, it is worthwhile to uncover how responsive this sector is to changes in pumping costs. The following section reviews the empirical evidence detailing the experience of irrigators in other states.

Water Demand and Pumping Costs: How are they related?

An irrigator's demand for water is mathematically represented as follows:

$$w_i = f_i\left(X_{i1}, X_{i2}, \ldots, X_{in}\right) \tag{2.1}$$

Where, *i*, *i* = 1,..., m, indexes crops. Water demand, w, is measured acre-feet. An irrigator's demand for water is a function a number of factors (X_{i1}, X_{i2}, ..., X_{in}). More specifically, the irrigator demand for water will depend on the number of acres to be planted, water requirements or evapotranspiration needs of the crop, soil characteristics, pumping costs and temperature, precipitation, desired yield, and crop prices, etc (Kindler and Russell). The scarcity value of water is anticipated to enter into the picture through an increase in pumping costs. Consequently, this relationship holds the most relevance to this study. As a rule, the demand for water is expected to be downward sloping. If pumping costs go up, the irrigator will be less likely to purchase the next acre-feet of water, and vice versa.

Given an inverse relationship between quantity demanded and the price or pumping costs, water price elasticity refers to the degree of responsiveness exhibited by irrigators to changes in pumping costs. Elasticity is expressed in terms of percentages. The pump cost elasticity of water demand is defined as:

$$\eta_{w,p} = \frac{\partial w}{\partial p} \quad \frac{p}{w} \quad = \quad \frac{\partial \ln w}{\partial \ln p} \tag{2.2}$$

Where, w is the irrigation volume demanded and p is the per unit irrigation costs. Elasticity may move in the direction of either positive or negative infinity. In most cases however, Equation (2.2) will yield an elasticity value less than zero.

If demand is perfectly elastic, (i.e., $\eta_{wp} = 0$), total expenditures, defined as per unit pumping costs times total volume of water consumed, will drop to zero in response to a change in price. Figure 2.2 reveals that the perfectly elastic demand curve is a horizontal line. In the particular case of the average irrigator, even small increases in the pumping costs, from P_1 to P_2, will result in ceasing irrigation altogether. The irrigator is willing and able to consume any water if and only if pumping costs are equal to P_1. In practice, this scenario does not apply. Very few farmers will be willing to relinquish irrigation at the slightest increase in prices.

A pumping cost elasticity of -1 indicates that a rise in pumping cost by one percent will trigger a decline in water demand that is equal in magnitude. There is no change in total expenditures regardless of the price. The demand is a rectangular hyperbole. Figure 2.3 showcases the unitary demand. An irrigator's demand for water can not be unitary elastic. The reason is that the irrigator is expected to be less than willing to do without it.

According to economic theory (Nieswiadomy 1985, Nieswiadomy 1988, Ogg and Gollehon 1989), the most reasonable expectation is that the pumping cost elasticity of water demand will be greater than –1 (Figure 2.4). In response to an increase in pumping costs, total expenditures will rise. Irrigators will reduce their consumption only gradually. Pumping costs shifts will have to be substantial in magnitude in order for irrigators to start consuming less water. The change in quantity demanded will be a fraction of the change in pumping costs. Theory predicts demand for groundwater is inelastic.

Figure 2.2. Perfectly elastic water demand curve.

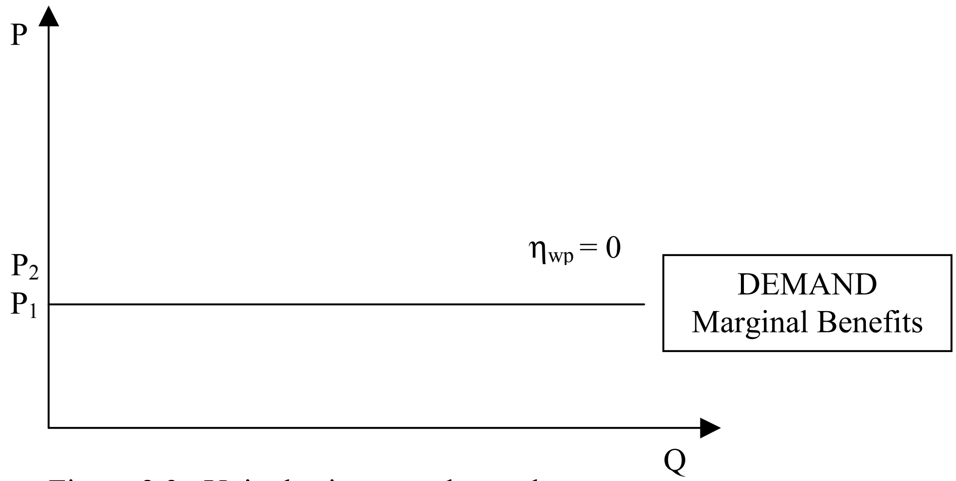


Figure 2.3. Unit elastic water demand curve

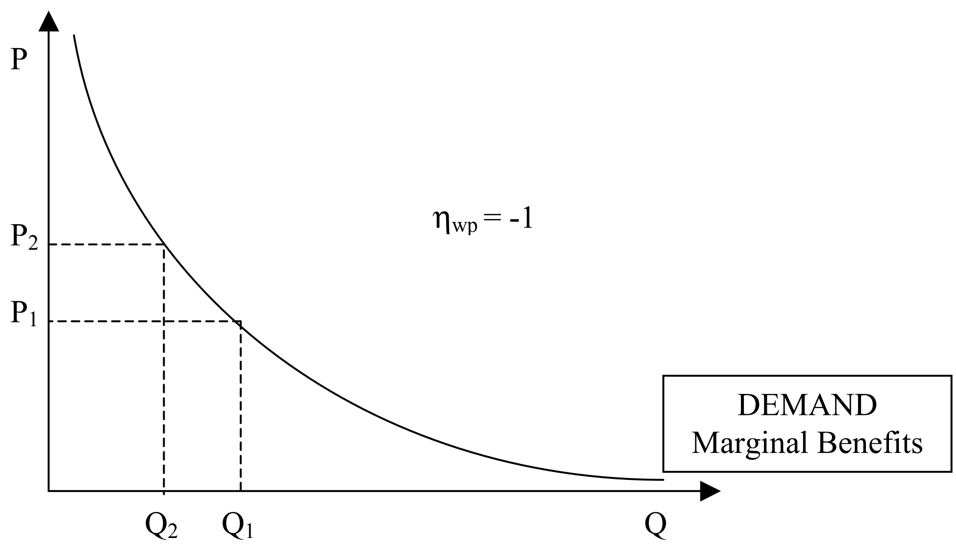
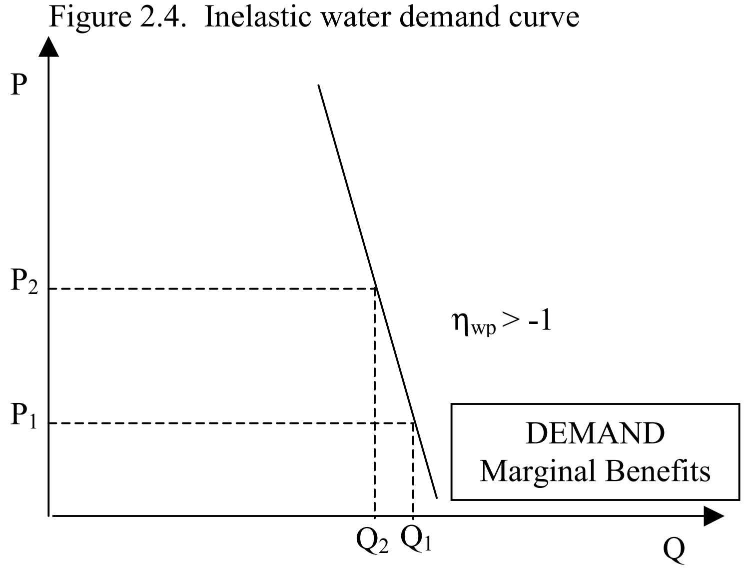


Figure 2.4. Inelastic water demand curve



Water Demand: How inelastic is it?

Nieswiadomy (1985) estimated a water demand using primary data from the Texas Department of Water Resources (TDWR). The panel data set comprised observations of groundwater irrigators from 1957-1980. Irrigators operated farms growing mainly cotton and grain sorghum in seven counties in the High Plains region of Texas. Preliminary examinations of the data set uncovered that there has been a structural shift. Therefore, the data was subdivided into two periods 1957-72 and 1973-80. Relatively constant pumping costs and intensification in sorghum cultivation characterized the first period (1957-72). Pumping costs are reported to have increased 116%, which occasioned a fall in irrigation volumes of 50% in the second period. Moreover, grain sorghum output plummeted (-81%) (Nieswiadomy 1985). It is important to note that the decline of irrigation volume, which occurred in the period 1973-1980, is a fraction of the increase in pumping costs. This suggests an inelatic water demand curve.

The water demand equation model consists of a two-step GLS procedure. The two steps were necessary in order to eliminate potential autocorrelation built into the longitudinal data set. The literature is not clear as to the best functional form for the water demand equation. Both log-log and linear functions were estimated. The F-test confirmed a priori evidence that there exist a change in structure within the panel data set (Nieswiadomy 1985). The log-log estimation based on the 1973-1980 data furnished a water demand elasticity of –0.80. This falls in line with the a priori evidence and our previous assumptions.

As of 1988, Nieswiadomy inferred that the future prosperity of Western farmers faced the double threat of high input costs and low output prices. Consequently, Nieswiadomy (1988) sought "to understand the flexibility of farmers in adapting to irrigated agriculture" (p. 63). To this end, an attempt was made to estimate Allen elasticities for various inputs. As in the previously cited study (Nieswiadomy 1985), the data is based on groundwater irrigators in the High Plains region of Texas. Farmers also grew cotton and sorghum. Only this time, the data set spanned the decade of 1970-1980. During said period, pumping costs, measured in dollars per acre-foot, more than doubled. Expectedly, water use was halved (Nieswiadomy 1988).

Only five inputs were considered in the production of both cotton and sorghum: Water, center pivot irrigation system, furrow irrigation system, wheel roll irrigation system, and labor. A translog cost function was estimated which also included rain as a fixed factor. Two water demand elasticities were computed. Water's own and output constant water demand elasticities are -0.95 and –0.25, respectively. The former number is a confirmation of the inverse relationship between quantity demanded and pumping costs. At –0.25, the output-constant elasticity reveals strong reluctance from irrigators to use less water despite sharply higher pumping costs (Nieswiadomy 1988).

Finally, Nieswiadomy (1988) cautions:

> First, even though this study attempts to decompose aggregate technology, the individual technologies themselves (e.g., center pivots) were not perfectly homogenous. Innovations were made over time in center pivots, for example. Unfortunately, there is no further detailed data available. Second, as with other translog cost studies, the adjustment to price changes are modeled as though nearly perfect adjustment occurs instantaneously. Obviously, many lagged effects as the result of price changes (and tax changes) could be considered. Unfortunately, the data are not rich enough to describe the ages and types of

> equipment analysis. Third, the separability argument is crucial. Since several inputs such as fertilizer chemicals and other capital inputs were not measured, the results may be biased if the level of usage of these inputs affects the ratios of marginal products of the inputs included in this study (1988, p.68).

This long disclaimer does not threaten the reliability of the elasticity estimates generated by Nieswiadomy (1988). Water demand is inelastic with respect to pumping costs. The following study confirms the findings of Nieswiadomy (1985,1988).

Ogg and Gollehon employed data from the 1984 Farm and Ranch Irrigation Survey (FRIS) in the estimation of groundwater demand elasticities. The sample comprised 1,927 irrigators spread across 16 Western states. This study is one of the first that is based on actual farmer behavior as reflected in responses to the FRIS. The goal is to isolate farmers' reactions in terms of water demand adjustments to pumping costs hikes.

Given the immense size of the region under study, differences in weather patterns are to be expected. In order to sequester the effect of such regional differences, observations were classed into three groups. Observations within a given group showed similar consumptive irrigation requirement (CIR) for the reference crop alfalfa (Ogg and Gollehon).

As suggested by Nieswiadomy (1985), the literature offers little guidance in terms of the best functional form in which to render the water demand equation. Three functional forms for the demand equation where thus estimated:

Linear: $$Q = 41.88 - 0.083\ P + \varepsilon \tag{2.3}$$

Log-log: $$\ln(Q) = 4.23 - 0.262\ \ln(P) + \varepsilon \tag{2.4}$$

Quadratic: $$Q = 45.29 - 0.212\ P + 0.000234\ P^2 + \varepsilon \tag{2.5}$$

Expectedly, the pumping cost variables, P, are preceded by a negative coefficients in all three equations. Equation 2.4 reveals the water demand elasticity for the entire sample, -0.262. As previously cited studies have shown (Nieswiadomy 1985, 1988), water demand is inelastic. When estimation was conducted at the regional level, in each region all observations shared a similar CIR for alfalfa, the inelastic groundwater demand estimates ranged from –0.22 to -0.34. Consequently, Ogg and Gollehon conclude that demand-side policy instruments exclusively aimed at influencing water price face serious limitations due to the low level of responsiveness of irrigators to pumping costs hikes.

Table 2.1 summarizes the finding of the water demand elasticity studies herein cited. All three studies concluded that water demand for irrigation water is inelastic with respect to pumping costs.

Table 2.1. Estimated water demand elasticities

Study	Function	Water Demand Elasticity
Nieswiadomy (1985)	Two step GLS	-0.80
Nieswiadomy (1988)	Translog cost	-0.25
Ogg and Gollehon (1989)	Log-log demand	-0.26

CHAPTER 3

WATER USE

Agricultural Water Pumping Study Data

This chapter addresses the first of the three objectives. This chapter's comprehensive scrutiny of the Agricultural Water Pumping Study data provides insight into irrigators' water use patterns. More specifically, the tables in this chapter categorize observations according to geographical location, crop choice, fuel type, horsepower rating of pump, size of permitted holding, and water source. This chapter seeks to enhance our understanding of inter- and intra-regional water use patterns.

Location may determine how much water an irrigator applies. This is especially true in those areas of the state with a high concentration of water thirsty crops (e.g., cotton). Particular attention will be paid to water use patterns in the Flint River Basin (FRB). The FRB is loacated in western third of the state of Georgia. The Flint River is 349 miles long and drains an area of 8,460 square miles. As Doherty and McKissick noted, "the 18 county [FRB] region represents 36 percent of [Georgia's] total harvested crop acreage but has 54 percent of the total irrigated acreage in the state" (p. 2). Water-thirsty crops such as cotton, peanuts, and sod production typify agricultural production in the FRB. Recently, there has been a great deal of concern regarding the level of in-stream flows in the Flint River. The ecological health of the Flint River appears doubly threatened by prolonged drought and increased agricultural water use. There is something to be learned from comparing and contrasting the mean water use of irrigators inside and outside the FRB (Table 3.1).

The type of crop being grown is a key determinant of the volume of water applied by an irrigator. Tables 3.2, 3.7, and 3.12 display mean water application levels for different crops in acre-feet per acre. Another set of tables (Tables 3.3, 3.8, and 3.13) present information on irrigators classified according to the type of fuel used by their pumping systems. Grouping observations by fuel type unveils which fuel categories encompass high and low water users. The higher the horsepower rating of a pump, the more powerful it is. A high horsepower pump will be able to draw water from a greater depth and cover a greater area than its lower rated counterpart. In tables 3.4, 3.9, and 3.14, observations were sorted according to the horsepower rating of the pumping systems. These tables show mean water use for cohorts of irrigators with similar pump horsepower ratings. The size of the permitted holding refers to the acreage of the subfield under observation. A subfield is the section of a farm being serviced by a metered irrigation pump. Information on mean water use by irrigators grouped according to the size of the permitted subfield is found on Tables 3.5, 3.10, 3.15. Lastly, there are comparisons amongst observations grouped in accordance to the source of water. The mean water use in acre-feet per acre of surface water irrigators will be contrasted with their groundwater counterparts (Tables 3.6, 3.11, and 3.16).

The Agricultural Water Pumping data set includes total water used for the duration of the observation period measured in inches or millions of gallons. It was necessary to convert millions of gallons to acre-feet. There are 325,851 gallons of water in one acre-foot. All figures are expressed in acre-feet of water per acre irrigated.

Table 3.1 presents mean water use in acre-feet per acre for the entire data set. The average irrigator applied 0.42 acre-feet per acre (a little over 5 inches of water). Dividing the data set according to geographical location of observations uncovered an interesting fact. Mean water use in acre-feet per acre is lowest in the Flint River Basin. One would expect that mean water use to be higher in this region given the preponderance of irrigated agriculture and the types of crops planted here (e.g., cotton, peanut, sod, etc.). From Table 3.1, it is apparent that FRB irrigators are not using more water than irrigators in other regions.

Table 3.1. Water used in acre-feet per acre 1999-2002.

Data Set	N	Mean	Std. Dev.	Minimum	Maximum
All	4860	0.42	1.24	0.00	17.45
Non-Flint River Basin	2611	0.52	1.51	0.00	7.00
Flint River Basin	2249	0.31	0.83	0.00	17.45

Source: Agricultural Water Pumping Study

Tables 3.2 breaks down water use by crop and year. For an observation to fall under a given a year, its observation period end date had to fall within 1999, 2000, 2001, and 2002. All data points with observation periods longer than 360 days were not considered. A number of observations began in one year and ended in the next. Winter wheat, for instance, may be planted in November and harvested in June of following year. It is important to note the high number of fallow fields and refilling ponds. As far as can be discerned, irrigation did occur in some of these fallow fields.

Table 3.2 details water consumption by crops for all available years. There are 4,860 observations in the data set. Where planting occurred, the bulk of plots were dedicated to cotton, peanut, field corn, winter forage, tobacco, onions, and soybeans. Nevertheless, almost two-fifths of all subplots were fallow for the duration of the observation period. Moreover, a significant number of plots (3%) were refilling ponds. The sample data comprises a total of 302,636 acres. Amongst cultivars, cotton occupies the largest number of acres. Over 18% of total acreage was devoted to cotton production. Peanut, field corn, winter forage, winter cover crops, sweet corn, soybean, wheat grain, and pecan populate the remaining nine spots for the ten most popular crops.

Table 3.2. Mean water used in acre-feet per acre by crop

Crops	N	1999	2000	2001	2002	1999-2002
Birdseed	3			0.05		0.05
Blueberry	2				0.01	0.00
Cabbage	16		0.43	0.45		0.44
Cantaloups	11	0.48	0.66	0.59		0.59
Carrot	14		0.1	0.19	0.65	0.25
Collard	13		0.37	0.22		0.24
Cotton	720	0.41	0.45	0.33		0.38
Cucumber	30	0.03	0.3	0.23		0.25
Effluent Application	6			0.4		0.40
Fallow	1910	0.17				0.01
Field Corn	250	0.39	0.72	0.39		0.50
Golf Course	8		0.49	0.32	0.45	0.38
Grapes	2			0.5		0.50
Irrigated Non-Crop	10		7	0.21		1.56
Millet	5		1.47	0.07		0.35
Nursery Tree Seedling	27	1.97	1.34		1.8	1.37
Nursery Plants	8		0.36	1.49		1.36
Oat Grain	2			0.27		0.27
Onion	86	0.11	0.33	0.46	0.24	0.33
Peanut	483	0.4	0.55	0.37		0.43
Pecan	54	0.03	0.18	0.53	0.2	0.40
Pepper	13		0.52	0.78		0.70
Permanent Forage	49		0.08	0.2	0.09	0.15
Pine Trees	1					0.00
Refill Pond	142	7	7	7	7	7.00
Rye Grain	8			0.08		0.08
Silage	29	0.87	0.94	0.39	0.19	0.49
Small Grain	15		0.12			0.07
Snap Bean	42	0.45	0.39	0.23		0.30
Sod Production	65		0.06	1.01	0.55	0.79
Sorghum	8		0.5	0.5		0.50
Southern Peas	1			0.3		0.30
Soybean	81	0.28	0.42	0.32		0.35
Summer Forage	12		0.16	0.03		0.08
Summer Squash	32	0.39	0.48	0.78		0.67
Sunflower	2			0.41		0.41
Sweet Corn	45	0.5	1.02	0.29		0.55
Tobacco	91	0.08	0.36	0.28		0.29
Tomato (staked)	8	0.96	1.22	0.97		1.03
Vegetables mixed	71	1.02	0.49	0.36	0.34	0.41
Watermelon	37	0.25	0.47	0.42		0.42
Wheat Grain	54		0.01	0.06	0.02	0.05
Winter Cover Crop	178	0.45	0.04	0.01		0.02
Winter Forage	216		0.1	0.06	0.07	0.07

Source: Agricultural Water Pumping Study

Table 3.2 exhibits mean water use by crop for years 1999-2002. Nursery plants, nursery tree seedlings, and tomatoes averaged over 1 acre-foot per acre of water. When viewed across time, mean water use seesawed for nursery tree seedlings and tomatoes. The only upward trend amongst the highest water users was witnessed in nursery plants. Other important crops such as corn, cotton, peanuts, sod, and soybeans received 0.50, 0.38, 0.43, 0.79, and 0.35 acre-feet per acre, in that order. The data revealed no definite trend in mean water use for any these crops.

In Table 3.3, observations were organized according to fuel type. The majority of irrigators used diesel-power pumps to irrigate. Propane pumps made up less than 3 % of the pumping plants in service. The data suggest that electric pump operators applied the highest amount of water on a per acre basis. All of 904 observations did not include fuel type data. In these records, the fuel name field was populated by “unknown” or “unspecified type,” or simply left blank. Their numbers were included for comparison purposes.

Table 3.3. Water used in acre-feet per acre by fuel type 1999-2002

Fuels	N	Mean	Std Dev	Minimum	Maximum
Diesel	2340	0.22	0.47	0.00	7.00
Electric	1481	0.31	0.73	0.00	17.45
Propane	135	0.16	0.28	0.00	1.47
Unknown	904	0.12	0.35	0.00	5.22

Source: Agricultural Water Pumping Study

Table 3.4 details water use for irrigators grouped according to the horsepower rating of their water pumping equipment. Most of the pumping plants in the sample were rated less than 200 horsepower. The mean water use was only 15% larger than the lowest mean water use.

Table 3.4. Water use in acre-feet per acre by horsepower ratings of pumps 1999-2002

Horsepower	N	Mean	Std Dev	Minimum	Maximum
0-100	1238	0.29	0.77	0.00	17.45
100-200	1901	0.22	0.44	0.00	7
200-300	635	0.27	0.55	0.00	7
300+	55	0.25	0.51	0.00	1.82

Source: Agricultural Water Pumping Study

Table 3.5 catalogues observations according to the size of the observation plot. Most observations are for subfields within a farming operation. Over half of these subfields measured fewer than 50 acres. The highest mean water use was found in the 0-50 acres group. There is no positive relation between field size and water use.

Table 3.5. Water use in acre-feet per acre by size of permitted holdings 1999-2002

Acreage	N	Mean	Std Dev	Minimum	Maximum
0-50	2502	0.63	1.67	0.00	17.45
50-100	1448	0.19	0.36	0.00	5.22
100-150	516	0.22	0.36	0.00	2.22
150-200	202	0.19	0.36	0.00	2.65
200+	192	0.25	0.42	0.00	2.36

Source: Agricultural Water Pumping Study

According to Table 3.6, the majority of the farmers irrigated directly from wells or surface water. The third category “Well-to-Pond” indicates those plots where the pumping plant takes water directly from a refilling pond. Groundwater irrigators applied 19% more water on a per acre basis then surface water irrigators.

Table 3.6. Water use in acre-feet per acre by water source 1999-2002

Water Source	N	Mean	Std Dev	Minimum	Maximum
Groundwater	2455	0.32	0.91	0.00	17.45
Surface Water	1868	0.26	0.78	0.00	7.00
Well-to-Pond	523	1.48	2.67	0.00	7.00

Source: Agricultural Water Pumping Study

Irrigation Outside the Flint River Basin

Tables 3.7-3.11 are devoted to observations outside the FRB. Observations number 2,611. Total irrigated acreage is 117,297. Fallow fields make up the majority of the observations. They tally up to 987 or 37.8% of the total. Cotton, peanut, refill ponds, winter cover crops, field corn, winter forage, onion, tobacco, and soybean remain the most popular agricultural activities in the non-FRB subsample. In terms of total acreage devoted to crops, the largest acreage ranges from 2,400 (tobacco) to 17,610 (cotton). Fallow acreage totals 47,787.

Nursery tree seedlings is the only crop which received over one acre-foot per acre (Table 3.7). Mean water use for nursery tree seedlings followed a familiar pattern. It dropped from 1.93 to 1.34 between 1999 and 2000. In observations whose monitoring period ends in the 2002, it rebounded to 1.8 acre-feet per acre. Tomato was not planted in these subfields. Glancing horizontally across the Table 3.7 shows that cotton, peanut, soybean, and sod irrigation show no discernible trend.

Table 3.8 confirms the predominance of diesel pumps in fields outside the FRB. Electric pumps, which are a distant second in prevalence, siphoned the highest amount of water, 0.24 acre-feet per acre. Table 3.9 groups observations according to horsepower rating of pumps. The outright majority of pumps are less than 200 horsepower. Table 3.8 suggests a positive correlation between horsepower and mean water use. This relationship does not hold for plants rated below 100 horsepower. The numbers reported in Tables 3.10 and 3.11 resemble those in Tables 3.5 and 3.6.

Table 3.7. Non-Flint River Basin Mean water used in acre-feet per acre by crop

Crops	N	1999	2000	2001	2002	1999-2002
Birdseed	2			0.05		0.05
Blueberry	2				0.01	0.01
Cabbage	15		0.43	0.46		0.45
Cantaloups	9	0.54	0.39	0.59		0.54
Carrot	13		0.1	0.21	0.65	0.27
Collard	13		0.37	0.22		0.24
Cotton	311	0.38	0.26	0.28		0.28
Cucumber	27	0.03	0.28	0.25		0.25
Fallow	987	0.32	0.01			0.01
Field Corn	107	0.26	0.45	0.45		0.43
Golf Course	6		0.49	0.38	0.45	0.42
Grapes	2			0.5		0.50
Irrigated Non-Crop	2		7	0.1		3.55
Millet	3		1.47	0.07		0.53
Nursery Tree Seedling	8	1.97	1.34		1.8	1.36
Nursery Plants	20		0.36	0.37		0.37
Onion	86	0.11	0.33	0.46	0.24	0.33
Peanut	201	0.57	0.31	0.41		0.39
Pecan	36	0.03	0.13	0.31	0.2	0.22
Pepper	9		0.52	0.6		0.57
Permanent Forage	34		0.06	0.28	0.09	0.18
Pine Trees	1					0.00
Refill Pond	125	7	7	7	7	7.00
Rye Grain	8			0.08		0.08
Silage	10		1.28	0.5	0.19	0.63
Small Grain	3			0		0.00
Snap Bean	17	0.5	0.37	0.31		0.37
Sod Production	45		0.09	1.13	0.55	0.79
Sorghum	1					0.00
Southern Peas	1			0.3		0.30
Soybean	72	0.32	0.44	0.32		0.37
Summer forage	2					0.00
Summer Squash	22	0.31	0.48	0.29		0.34
Sweet Corn	5		0.53			0.53
Tobacco	84	0.08	0.35	0.26		0.27
Vegetables (mixed)	58	1.02	0.61	0.36	0.34	0.42
Watermelon	29	0.73	0.51	0.43		0.47
Wheat Grain	29			0.09	0.02	0.08
Winter Cover Crop	114		0.06			0.02
Winter Forage	92		0.03	0.02	0.07	0.03

Source: Agricultural Water Pumping Study

Table 3.8. Non-Flint River Basin Mean Water use in acre-feet per acre by fuel type 1999-2002

Fuels	N	Mean	Std Dev	Minimum	Maximum
Diesel	1417	0.17	0.41	0.00	7.00
Electric	850	0.24	0.45	0.00	4.99
Propane	105	0.11	0.25	0.00	1.47
Unknown	239	0.16	0.30	0.00	1.68

Source: Agricultural Water Pumping Study

Table 3.9. Non-Flint River Basin Mean Water use in acre-feet per acre by horsepower ratings of pumps 1999-2002

Horsepower	N	Mean	Std Dev	Minimum	Maximum
0-100	805	0.23	0.46	0	4.99
100-200	1088	0.16	0.41	0	7.00
200-300	305	0.20	0.34	0	2.29
300+	55	0.25	0.51	0	1.82

Source: Agricultural Water Pumping Study

Table 3.10. Non-Flint River Basin Mean Water use in acre-feet per acre by size of permitted holding 1999-2002

Acreage	N	Mean	Std Dev	Minimum	Maximum
0-50	1733	0.70	1.81	0.00	7.00
50-100	662	0.16	0.27	0.00	2.29
100-150	146	0.15	0.25	0.00	1.44
150-200	45	0.11	0.22	0.00	0.91
200+	25	0.15	0.27	0.00	0.98

Source: Agricultural Water Pumping Study

Table 3.11. Non-Flint River Basin Mean Water use in acre-feet per acre by water source 1999-2002

Water Source	N	Mean	Std Dev	Minimum	Maximum
Groundwater	775	0.37	1.10	0.00	7.00
Surface Water	1330	0.23	0.75	0.00	7.00
Well-to-Pond	501	1.50	2.70	0.00	7.00

Source: Agricultural Water Pumping Study

Irrigation in the Flint River Basin

The FRB observations are showcased in Tables 3.20-3.27. FRB observations span 185,339 acres. Close to 78,000 of those acres remained fallow. Cotton, peanut, field corn, winter forage, winter cover crop, sweet corn, wheat grain, snap bean and sod production are leaders in term of occurrences. Over 1,100 fields reported to have farmed one of these crops. The total number of observations within the boundaries of the FRB is 2,249. Expectedly, ranking crops in terms of acreage yielded similar results to the previous list. Acreage rankings are comparable to the previous incidence rankings. Cotton production claimed 37,304 acres. Pecan replaced snap bean in the ninth position. Pecan observations encompassed 2,260 acres.

As can be seen in Table 3.12, the FRB subsample included no observation whose monitoring period ended in 2002. In terms of mean water use, nursery plants were the most irrigated crops. On average the volume of irrigation administered to nursery plants exceeded four acre-feet per acre. Summer squash, tomato and peppers all received over an acre-foot per acre of irrigation. In the case of nursery plants and pepper, year-to-year comparisons are not possible. All observations begin and end in 2001. Soybeans and summer squash water applications show an upward trend. Between 1999 and 2001 mean water use by soybean and summer squash farmers doubled to 0.34 acre-feet per acre and more than quadrupled to 2 acre-feet per acre, respectively. As before, no trend is manifest in the water use patterns for cotton, peanut, and tomatoes.

Table 3. 12. Flint River Basin Mean water used in acre-feet per acre by crop

Crops	N	1999	2000	2001	1999-2001
Birdseed	1			0.06	0.06
Cabbage	1			0.33	0.33
Cantaloups	2	0.42	1.21		0.81
Carrot	1				0.00
Cotton	409	0.41	0.71	0.37	0.46
Cucumber	3		0.43	0.07	0.19
Effluent Application	6			0.4	0.40
Fallow	923	0.02			0.02
Field Corn	143	0.44	1.01	0.35	0.55
Golf Course	2			0.23	0.23
Irrigated Non-Crop	8		7	0.22	1.07
Millet	2			0.08	0.08
Nursery Plants	7			4.23	4.23
Oat Grain	2			0.27	0.27
Peanut	282	0.36	0.76	0.34	0.46
Pecan	18		0.84	0.75	0.76
Pepper	4			1.01	1.01
Permanent Forage	15		0.12	0.08	0.09
Refill Pond	17		7	7	7.00
Silage	19	0.87	0.61	0.34	0.42
Small Grain	12		0.12		0.09
Snap Bean	25	0.41	0.49	0.2	0.25
Sod Production	20			0.87	0.78
Sorghum	7		0.63	0.5	0.57
Soybean	9	0.17	0.21	0.34	0.20
Summer Forage	10		0.19	0.03	0.10
Summer Squash	10	0.44	0.51	2	1.39
Sunflower	2			0.41	0.41
Sweet Corn	40	0.5	1.26	0.29	0.55
Tobacco	7	0.09	0.71	0.44	0.43
Tomato (staked)	8	0.96	1.22	0.97	1.03
Vegetables (mixed)	13		0.31	0.42	0.36
Watermelon	8	0.01	0.24	0.37	0.25
Wheat Grain	25		0.01	0.02	0.02
Winter Cover Crop	64	0.45	0.01	0.01	0.03
Winter Forage	124		0.13	0.08	0.09

Source: Agricultural Water Pumping Study

Expectedly, diesel pumps represent the majority of the pumps in the FRB subsample (Table 3.13). As previous tables have shown, electric pump operators are the most avid irrigators. Tables 3.14 and Tables 3.15 confirm previous findings. There were no pumps rated over 300 horsepower in the FRB (Table 3.14). In the FRB, there was no significant difference in the irrigation volumes applied by surface water and groundwater irrigators.

Table 3.13. Flint River Basin Water use in acre-feet per acre by fuel type 1999-2002

Fuels	N	Mean	Std Dev	Minimum	Maximum
Diesel	923	0.29	0.55	0.00	7.00
Electric	631	0.40	0.98	0.00	17.45
Propane	30	0.30	0.35	0.00	0.90
Unknown	665	0.11	0.36	0.00	5.22

Source: Agricultural Water Pumping Study

Table 3.14. Flint River Basin Water use in acre-feet per acre by horsepower ratings of pumps 1999-2002

Horsepower	N	Mean	Std Dev	Minimum	Maximum
0-100	433	0.41	1.13	0.00	17.45
100-200	813	0.30	0.47	0.00	7.00
200-300	330	0.34	0.68	0.00	7.00

Source: Agricultural Water Pumping Study

Table 3.15. Flint River Basin Water use in acre-feet per acre by size of permitted holding 1999-2002

Acreage	N	Mean	Std Dev	Minimum	Maximum
0-50	769	0.45	1.28	0.00	17.45
50-100	786	0.22	0.42	0.00	5.22
100-150	370	0.25	0.39	0.00	2.22
150-200	157	0.21	0.39	0.00	2.65
200+	167	0.26	0.44	0.00	2.36

Source: Agricultural Water Pumping Study

Table 3.16. Flint River Basin Water use in acre-feet per acre by water source 1999-2002

Water Sources	N	Mean	Std Dev	Minimum	Maximum
Groundwater	1680	0.30	0.80	0.00	17.45
Surface Water	538	0.31	0.84	0.00	7.00
Well-to-Pond	22	0.88	2.01	0.00	7.00

Source: Agricultural Water Pumping Study

Interregional Comparisons

Table 3.17 summarizes differences in water application rates between the subregions. FRB farmers were found to irrigate more in 14 out of 24 crops. The fact that FRB irrigators applied 11 times more water to their nursery plants is more than likely an aberration. On the other hand, FRB millet received 85% less water than elsewhere. On average, FRB farmers either lead their peers by as much as 6 inches or trailed them by close to 2 inches water per acre in terms of irrigation volumes. In half the instances where differences occurred, Non-FRB irrigation volumes were 1.44 inches higher or 1.68 inches lower for each irrigated acre.

Table 3.17. Regional Mean Water use in acre-feet per acre by crop 1999-2002

Crops	Non-FRB	FRB	Difference
Birdseed	0.05	0.06	0.01
Cabbage	0.45	0.33	-0.12
Cantaloups	0.54	0.81	0.27
Cotton	0.28	0.46	0.18
Cucumber	0.25	0.19	-0.06
Fallow	0.01	0.02	0.01
Field Corn	0.43	0.55	0.12
Millet	0.53	0.08	-0.45
Nursery Plants	0.37	4.23	3.86
Peanut	0.39	0.46	0.07
Pecan	0.22	0.76	0.54
Pepper	0.57	1.01	0.44
Permanent Forage	0.18	0.09	-0.09
Silage	0.63	0.42	-0.21
Snap Bean	0.37	0.25	-0.12
Sod Production	0.79	0.78	-0.01
Soybean	0.37	0.2	-0.17
Summer Squash	0.34	1.39	1.05
Sweet Corn	0.53	0.55	0.02
Tobacco	0.27	0.43	0.16
Watermelon	0.47	0.25	-0.22
Wheat Grain	0.08	0.02	-0.06
Winter Cover Crop	0.02	0.03	0.01
Winter Forage	0.03	0.09	0.06

Summary

In this chapter, we have studied a segment of the Agricultural Water Pumping Data. The overriding theme of this chapter was the examination of water use patterns in accordance to the first objective of this thesis. The findings are decidedly mixed.

Overall, the data suggest that FRB irrigators are administering less water to their crops on a per acre basis than farmers outside the FRB. There are striking differences in individual crop irrigation patterns. Moreover, interregional comparisons of water use across time did not furnish any evidence of an underlying trend. Water applications outside the FRB to field corn, for instance, increased from 1999 to 2000 but remained flat in the preceding period. Still, FRB field corn water applications rate first went up then declined. Similar discrepancies prevailed in the cases of cotton, peanut, soybean and others. This finding discounts the strength of crop choice as a predictor of water use. Other factors must affecting the irrigation decision.

Electric pump operators delivered the highest levels of irrigation in the fuel type categories. Fields serviced by pumps rated below 100 horsepower got the most acre-feet per acre. This same relationship applies to smaller subfields. Irrigation pumps were most active in fields whose area did not exceed 50 acres. Lastly, FRB surface water irrigators pumped as much water as well owners within this very region. Outside the FRB, surface water irrigators lead in terms of water consumption. Groundwater resources are being exploited with a higher degree of intensity.

The remaining two objectives were pursued in the next chapter. Specifically, pumping costs and crop water requirements were computed. A water demand model with pumping costs and crop water requirements as independent variables is introduced and estimated using statistical techniques. Lastly, Chapter 4 will explain in detail the concept of the pump cost elasticity of water demand.

CHAPTER 4

THE MODEL

Water Demand

As seen in Chapter 2, multiple elements affect water demand. Kindler and Russell suggest three ways in which to render the water demand equation:

Linear: $$w = \beta_0 + X_1\beta_1 + X_2\beta_2 + \ldots + X_n\beta_n + \varepsilon_n \qquad 4.1$$

Log-Log: $$\ln w = \beta_0 + \ln X_1\beta_1 + \ln X_2\beta_2 + \ldots + \ln X_n\beta_n + \varepsilon_n \qquad 4.2$$

Semi-Log: $$w = \beta_0 + \ln X_1\beta_1 + \ln X_2\beta_2 + \ldots + \ln X_n\beta_n + \varepsilon_n \qquad 4.3$$

Where, w is the vector of the dependent variable (water use). Water demand is contingent upon a number of independent vectors, $X_1,\ldots, X_n$. These can be any number of items: Pumping costs, soil type, acreage, crop water requirements, precipitation, etc. The number of parameters to be estimated using OLS consist of the intercept, β_0, and the coefficients of each of the independent variables, $\beta_1,\ldots, \beta_n$. The right hand side also includes the vector of stochastic disturbances or statistical error terms (ε_n). These terms captures any unexplained variation in the dependent variable vector (w). No predilection for the functional form of the demand equation exists amongst researchers (Nieswiadomy 1985, Ogg and Gollehon, Kindler and Russell).

There is no hard and fast rule for determining which independent variables should populate the right hand side of the water demand equation. Nieswiadomy (1985) included expected crop prices (cotton, sorghum), cost of pumping, wage rate, cost of furrow irrigation equipment, and seasonal precipitation. Only precipitation and pump costs were found to be instrumental (i. e., statistically significant) in explaining the variation in water demand. Ogg and Gollehon opted for a single constituent of water demand (energy cost of providing water). The results obtained by Ogg and Gollehon confirmed the primacy of the energy (pumping) cost independent variable. So far, we know no to include expected price variables or farm wage rate in our model formulations. All irrigators in the data set own pressurized pumping equipment (e.g., center pivot). Thus, furrow equipment costs are irrelevant. Efforts to include other water demand determinants (e.g., soil type, yield) were hampered by lack of data.

Our model involved a pumping cost variable and a water requirement variable as the only two determinants of water demand. Both linear and log-log functional forms were modeled. The equations to be computed using statistical techniques were as follows:

Linear: $$w = \beta_0 + p\,\beta_1 + \varepsilon_n \tag{4.4}$$

Linear: $$w = \beta_0 + p\,\beta_1 + r\,\beta_2 + \varepsilon_n \tag{4.5}$$

Log-Log: $$\ln w = \beta_0 + \ln p\,\beta_1 + \varepsilon_n \tag{4.6}$$

Log-Log: $$\ln w = \beta_0 + \ln p\,\beta_1 + \ln r\,\beta_2 + \varepsilon_n \tag{4.7}$$

Where, w is total irrigation volume applied (water demand). Irrigation is exclusively a function of the cost of operating the pumping plant, p, in Equations 4.4 and 4.6. The crop water requirement, r, is an additional explanatory variable in Equations 4.5 and 4.7. The signs of the estimated coefficients are expected to be negative and positive for pumping costs and water requirements, in that order.

The rest of this chapter consists of four sections. First, there is an explanation of the computation procedure for pumping costs. Second, water requirements for each crop were calculated using the Blaney-Criddle method. The third part of this chapter introduces the linear and log-log functional forms of the water demand equation. There is also a discussion on the statistical procedure used to estimate these equations. Furthermore, there is an outline of the steps for calculating the elasticity of water demand with respect to pumping costs. The last part of this chapter describes the data set at the heart of the statistical procedures.

Pumping Cost Estimation

The first piece of information required to compute pumping costs is the type of pumping plant in service at the site (e.g., center pivot, hard hose traveler, etc.). Pumping pressure figures, in pounds per square inch (PSI), were absent from the original data set. Lamont Jr. et al. (2001) provided the guidelines for the pressure numbers used in the calculations that follow. Pumping plant pressure is expressed as a range from low (LOWPSI) to high (HIGHPSI). Medium pressure (MIDPSI) is an average of the two extremes. The pressure estimates are found in Table 4.1.

Table 4.1. Operating Pressure of Various Pumping Plants

PUMP SUBTYPE	LOWPSI	MIDPSI	HIGHPSI
Cable tow traveler	70	85	100
Hard hose traveler	70	85	100
Permanent buried (SDI) drip	5	12.5	20
Permanent center pivot	30	50	70
Permanent drip/trickle w/above ground emitters	5	12.5	20
Permanent solid set	50	60	70
Temporary drip/trickle under plastic	5	12.5	20
Towable center pivot	30	50	70

Source: Lamont Jr. et al. (2001)

Rogers and Alam (1999) arrived at an estimate of fuel cost using the succeeding four-step procedure.

1. Estimation of Total Dynamic Head (TDH) in feet

$$TDH = \left[psi * \left(\frac{2.31\, ft}{1\ psi} \right) \right] + Lift \tag{4.8}$$

Three items are needed in order to calculate pressure head: Pressure of pumping plant in pounds per square inch, the height of a column of water weighing one pound per square inch, and the intake depth in feet. Pressure figures, expressed in pounds per square inch (PSI), are found in Table 4.1. A column of water 2.31 feet high weighs one PSI. Feet of head is the product of PSI estimates times 2.31. Adding intake depth (or lift) to feet of head supplies TDH in feet.

2. Estimation of fuel usage in unit of fuel per acre-foot of water

$$\frac{Fuel\ usage}{acre-feet} = \left(\frac{Fuel\ unit}{acre-feet\ /\ feet} \right) * TDH \tag{4.9}$$

Fuel usage is derived from the multiplication of TDH by the fuel required to move one acre-foot of water 1 foot. Table 4.2 details amount of fuel needed to lift on acre-foot of water for the different fuel types:

Table 4.2. Pumping Fuel Use Required for Lifting 1 acre-foot of water 1 foot in height

Fuel Type	Fuel Unit	Fuel Units /ac-ft/ft
Electricity	Kilowatt-hour	1.551
Natural Gas (925 BTU/cf)	1000 cubic feet	0.0223
Natural Gas (1000 BTU/cf)	1000 cubic feet	0.0206
Diesel	Gallons	0.1098
Propane	Gallons	0.1993

Source: Rogers and Alam (1999

3. Estimation of amount of water to be pumped in acre-feet if not already included in the data set

The calculations so far have yielded fuel usage in units of fuel per acre-feet and water delivered in acre-feet. Multiplying these two generates total fuel consumed at the three levels of pumping pressure (namely, LOFUUSE, MIFUUSE, and HIFUUSE) by pumping plant in the process of delivering said volume of water.

4. Estimation of total cost using unit price of fuel

$$\text{Total Fuel Cost} = \text{Total Fuel Consumed} * \text{Fuel per unit Price} \tag{4.10}$$

Finally, fuel cost is the product of multiplying the price of the fuel times the aforementioned fuel depletion computations. Diesel prices paid by farmer were gleaned from the 2001 edition of Georgia Agricultural Facts. Propane and electricity prices were obtained from the United States Department of Energy website. Table 4.3 catalogues the price data for the various fuel types. In the end we have low, medium, and, high fuel total expenditure estimates (i.e., LOWFCST, MIDFCST, and HIGFCST).

Table 4.3. Fuel Prices in constant 1999 dollars

FUEL	UNIT	1999	2000	2001
Diesel	Gal.	0.728	1.045	1.016
Electric	Kwh	0.067	0.0678	0.056
Propane	Gal.	0.808	1.014	1.069

Sources: 2001 Georgia Agricultural Facts, United States Department of Energy.

Blaney-Criddle Irrigation Water Requirements

The Blaney-Criddle method was used to generate water requirement figures for a given crop during the length of the observation period. Blaney-Criddle calculations yield crop water need estimates in inches. The Blaney-Criddle formula is a follows:

$$\text{Irrigation Demand} = \left\{\left[\frac{\text{Temperature} * P\text{-}value}{100}\right] * Kc\right\} - \text{Precipitation} \tag{4.11}$$

Where,

Temperature = Mean daily or monthly temperature for the length of observation in degrees Fahrenheit.

P-value = Mean daily or monthly percentage of daytime hours for a given latitude. The selected latitude for Georgia is 30°N.

Kc = Total crop factor.

Precipitation = Total daily or monthly precipitation for the length of observation in inches.

Weather data were furnished by the National Oceanic and Atmospheric Administration's National Climatic Data Center. The data set included daily and monthly temperature and precipitation records for all stations in the state of Georgia. These were dated between January 1999 to January 2002. Stations had to include both precipitation and temperature data spanning the whole time period. Only 44 stations, out of a total of 457, were considered. Given that the data set comprised observations spread out in 75 counties, a significant number of counties were assigned weather stations outside their boundaries. Care was exercised to assign the closest weather stations to the county in question. Table B.1, in Appendix B, catalogues all counties and the weather stations use to approximate weather conditions in that county.

Daily precipitation is the sum of the total precipitation recorded each day for the entire duration of the observation period. Daily average temperature equals the sum of the day's high and low temperatures divided by 2. Precipitation is expressed in hundredths of an inch. Daily temperature is the sum of all the daily average temperatures divided by the length of the observation period. Temperatures are expressed in degrees Fahrenheit.

Sunshine, temperature, humidity, and wind speed are the four key climatic factors affecting a crop's water needs. Crop water needs are positively correlated with heat, dryness, wind speed, and daily hours of sunshine. The reference crop evapotranspiration (ET_0) number relates climate to the water requirement of a pasture. ET_0 is measured in millimeters per unit of time (e.g., day, month, season, etc.). Grass is the reference or standard crop. All other crop water requirements are measured vis-a-vis grass. Consequently, knowledge of the relationship between the crop to be planted and grass will facilitate calculation of the crop water requirement. The number used to express the relationship between grass and any other crop is called the crop factor (K_c). The K_c is determined by the type of crop, the growth stage of the crop, and the climate. Table C.1, in Appendix C, lists the crop water requirements for the selected crops.

Water Demand Equations

At this point, all the elements are in place to proceed with statistical estimation of the water demand equations. An inventory of all relevant variables is found in Table 4.4. The Sign column reveals our a priori assumptions regarding the relation between each regressor and the regressand IRRFACR. Pumping cost (LOCSTAF) and irrigation (IRRFACR) are anticipated to be inversely related. This is relationship is equivalent to the classical relationship between price and quantity demanded. High water requirements (BLACRID) will translate into high demand for irrigation and vice versa. BLACRID ought to be directly related to the dependent variable (IRRFACR). Therefore, its coefficient should be positive.

Table 4.4. Model Variables: Definitions, Units and Expected Signs.

Variable	Definition	Unit	Expected Sign
BLACRID	Blaney-Criddle evapotranspiration	Inches	+
IRRFACR	Total water volume delivered at end of observation period	Acre-feet/acre	N/A
LBLACRI	Log of Blaney-Criddle evapotranspiration	Inches	+
LIRRFAC	Log of total irrigation water volume applied	Acre-feet/acre	N/A
LLOCSTA	Log of per unit pumping cost estimate	\$/acre-feet	-
LOCSTAF	Pumping costs per unit of water	\$/acre-feet	-

The linear functional forms of the water demand equation are presented below. LOCSTAF is the independent pumping cost variable. Linear equations are characterized by a constant slope and shifting elasticities. Equation 4.12 is guided by Ogg and Gollehon. Water demand is depicted solely as a function of pumping cost (LOCSTAF). The following equation, Equation (4.13), adds Blaney-Criddle water requirement (BLACRI) as a regressor. The addition of water requirement on the right side is expected to strengthen the model. Equation 4.13 captures a larger share of the variation in the dependent variable.

$$IRRFACR = \beta_0 + \beta_1\ LOCSTAF + \varepsilon \tag{4.12}$$

$$IRRFACR = \beta_0 + \beta_1\ BLACRID + \beta_2\ LOCSTAF + \varepsilon \tag{4.13}$$

Where, ε and β_0 represent the error term associated with each observation and the intercept of the demand equation, respectively. Table 4.5 exhibits the descriptive statistics for all the model variables.

In order to estimate the water demand equations in the log-linear functional form, the following computations are in order:

$$LIRRFAC = \ln\ (IRRFACR) \tag{4.14}$$

$$LLOCSTA = \ln\ (LOCSTAF) \tag{4.15}$$

$$LBLACRI = \ln\ (BLACRID) \tag{4.16}$$

In Equations 4.14, 4.15, and 4.16, the left-hand side variables are natural logarithmic transformations. Descriptive statistics for all variables are found in Table 4.5. The range of the regressor BLACRID, as shown in Table 4.5, includes negative values. In cases where the water requirement was negative or zero, the natural logarithm was undefined. The total number of observations where the log of the BLACRID estimates is undefined is 189. These observations can not be discarded considering they convey valuable information. Given that the lowest Blaney-Criddle estimate is –12.58, the addition of 14 leaves no value less than zero for BLACRID. In Thus, we were able to obtain the natural log of all BLACRID observations. Moreover, this procedure does not alter the fundamental relationship between water demand and water requirements. Lastly, comparison between the functional forms remains a possibility.

Table 4.5. Descriptive Statistics for Regressors and Regressands

Variable	Mean	Std.Dev.	Minimum	Maximum	N
BLACRID	5.26	6.58	-12.58	22.00	707
IRRFACR	0.58	0.43	0.00	2.72	707
LBLACRI	2.89	0.40	0.35	3.58	707
LIRRFAC	-0.93	1.12	-8.17	1.00	707
LLOCSTA	3.00	0.37	2.14	4.12	707
LOCSTAF	21.54	8.63	8.54	61.28	707

The water demand equation has been rendered in the log-log functional form in equations 4.17 and 4.18.

$$\text{LIRRFAC} = \beta_0 + \beta_1 \text{ LLOCSTA} + \varepsilon \quad (4.17)$$

$$\text{LIRRFAC} = \beta_0 + \beta_1 \text{ LLOCSTA} + \beta_1 \text{ LBLACRI} + \varepsilon \quad (4.18)$$

Unlike linear functional forms, in the log-log forms, the elasticities are held constant while the slopes may vary. The beta coefficients of the log-linear functional form are elasticities. The pump cost elasticity does not vary with the independent variable. Therefore, the elasticity of water demand (IRRFACR) with respect to changes in pumping costs (LOCSTAF) are

$$\eta_{w,p} = \frac{\left(\dfrac{\partial IRRFACR}{\partial LOCSTAF}\right)}{\left(\dfrac{IRRFACR}{LOCSTAF}\right)} = \frac{\partial LIRRFAC}{\partial LLOCSTA} = \beta_1 \tag{4.19}$$

Streamlining the Data Set

The Agricultural Water Pumping Study data consist of 4,860 observations recorded from February 3, 1999 to January 17, 2002. Out of these, only 707 were deemed valid observations. The validity criteria is as follows:

- First, irrigation volume had to be greater than zero and less than 6 acre-feet per acre. If no irrigation took place, no pumping costs were incurred.
- Second, the length of observation had to be between 40 and 360 days. The reason for this limitation is that we are interested in looking at planting and harvesting cycles.
- Third, the observation must have included type of pumping systems (e. g., center pivot). Lack of knowledge of the type of pumping system hampered the ability to calculate pumping costs.
- Fourth, pumping plant information had to include the type of fuel used. This is another requirement for the pumping cost computation.
- Fifth, there had to be an actual or approximated pump intake depth measurement. Pump intake depth populates the lift variable in Equation 4.8.

- Sixth, the observation had to have enough information to permit computation of crop water requirement (Blaney-Criddle). For instance, fallow fields do not have K_c crop factors. Fallow fields observation had to be set aside.
- Lastly, the irrigation pump had drawn water directly from a well. Groundwater observations were the only ones to include reliable intake depth measurements.

All valid observations met all of the above criteria. A total of 4,153 observations did not meet one or more of these criteria.

A total of 30 different crops were found at any of the 205 unique observation sites. They included permanent forage, cotton cultivation, peanut production, sod production, nursery tree seedling operations, etc. A list of the all activities, arranged alphabetically, is found in Table 4.6.

From Table 4.6, it is evident that the top 10 crops, in terms of total acreage, were cotton, peanut, field corn, winter forage, sweet corn, pecans, snap bean, vegetable mixed, soybean, and watermelon. Percentage of total acres dedicated to these top activities ranged from 0.95% to 40.82%. Cotton was the cultivar of choice both in terms of number of plots and acreage. Peanut, field corn, winter forage, soybean, pecans, sweet corn, watermelon, snap beans, and tobacco production made up the remaining nine most common activities in terms of number of dedicated fields.

Pumping plants in this subsample burned two types of fuel (FUEL): Diesel and electricity. They were almost evenly divided between the two. There were 380 diesel pumps and 382 electric systems. Table 4.7 presents the different types of pumping equipment being utilized at the various sites. There were a total of 13 different pumping plant types in the original data set. Only eight of those were present in the current subsample. Permanent and towable center pivot irrigation systems dominated the landscape. They were present in over 93.17% of the sites. The traveler pumping plants in its various versions were a distant second in terms of popularity. Again, all pumping plants drew water directly from a well. The majority of groundwater-fed field observations included intake depth information. The remaining cases were populated using county averages for depth measurements.

Table 4.6. Activities: Name, number of cases, acreage and percentages

Crops	Number of Cases	Percent of Cases	Acreage	Acreage Percent
Cabbage	3	0.42	57	0.10
Cantaloupe	1	0.14	53	0.09
Carrot	4	0.57	121	0.22
Collard	3	0.42	180	0.32
Cotton	252	35.64	22798	40.82
Cucumber	7	0.99	267	0.48
Field Corn	77	10.89	5941	10.64
Millet	1	0.14	13	0.02
Oat Grain	1	0.14	42	0.08
Onion	6	0.85	81	0.15
Peanut	151	21.36	11756	21.05
Pecan	17	2.40	1234	2.21
Pepper	3	0.42	153	0.27
Permanent Forage	4	0.57	252	0.45
Silage	9	1.27	678	1.21
Small Grain	2	0.28	215	0.38
Snap Bean	13	1.84	1231	2.20
Sod Production	4	0.57	377	0.68
Sorghum	1	0.14	34	0.06
Soybean	18	2.55	862	1.54
Summer Forage	4	0.57	121	0.22
Summer Squash	4	0.57	218	0.39
Sweet Corn	17	2.40	1862	3.33
Tobacco	13	1.84	531	0.95
Tomato (staked)	6	0.85	564	1.01
Vegetables Mixed	13	1.84	1013	1.81
Watermelon	16	2.26	689	1.23
Wheat Grain	4	0.57	612	1.10
Winter Cover Crop	8	1.13	604	1.08
Winter Forage	45	6.36	3289	5.89
TOTAL	**707**	**100.00**	**55848**	**100.00**

Table 4.7. Pumping Plants subtypes: Number and percentage of total cases

Subtype	CASES	PERCENT
Cable tow traveler	2	0.28
Hard hose traveler	8	1.13
Permanent buried (SDI) drip	7	0.99
Permanent center pivot	628	88.83
Permanent drip/trickle w/above ground emitters	6	0.85
Permanent solid set	4	0.57
Temporary drip/trickle under plastic	6	0.85
Towable center pivot	46	6.51
Total	**707**	**100.00**

In the Agricultural Water Pumping Study data set, described in Chapter 3, the number of fields being irrigated from surface water sources amounted to 3,307. In these observations, the source was listed as pond, creek, or left blank. It was not possible to arrive at defensible estimates of intake depth in these surface water observations. Consequently, they were set aside. Undoubtedly, this figure conveys the importance of this segment of the population of irrigators. This is a serious limitation in this study.

Estimation of the aforementioned equations is the last remaining step. The results and conclusion of this work will be presented in Chapter 5.

CHAPTER 5

RESULTS AND CONCLUSION

This chapter has two parts. The presentation of statistical results is done first. The last section is the summary and conclusions of this study. The water demand equations were estimated using the LIMDEP (Version 7.0) statistical package. The LIMDEP output is found in Appendix D.

Estimation Results

Table 5.1 shows the signs of the estimated coefficients. The directions of the signs are in tune with our a priori assumptions as expressed in Table 4.4. The regression results are presented in tables 5.3 and 5.3.

Table 5.1. Model Variables: Definitions, Units and Actual Signs of Estimated Coefficients

Variable	Definition	Unit	Actual Sign
BLACRID	Blaney-Criddle evapotranspiration	Inches	+
LBLACRI	Log of Blaney-Criddle evapotranspiration	Inches	+
LLOCSTA	Log of per unit pumping cost estimate	$/acre-feet	-
LOCSTAF	Pumping costs per unit of water	$/acre-feet	-

In Equation 4.12, water demand is assumed to be exclusively a function of pumping cost. In other words, the only basis for making the decision on whether to irrigate is the cost of doing so. The coefficient on the cost variable was both negative and significant. Given that this is a demand equation, this result is to be expected. If pumping cost increase by a dollar, the irrigator is expected to decrease water use by 0.007 acre-feet per acre. The high t-test score (-4.70) attests to the coefficient being statistically different from zero. Not surprisingly, this sole regressor explains little, in percentage terms, of the total variation in water demand (Adj. R^2 = 1.8%). These figures replicate Ogg and Gollehon (1989). Although the equation merited a high F statistic (13.94), this only confirms the results of the t-test. Namely, the pumping cost coefficient is significantly different from zero.

Equation 4.12 may be suffering from an underspecification problem. Water demand is not solely depending on pumping costs. This was too simplistic an explanation for irrigator behavior. Equation 4.13 addresses this shortcoming. The independent variable crop water requirements (BLACRID), expressed in inches of water, was added. As the results indicate, Equation 4.13 is a vast improvement over its predecessor. The number of observations is the same as in Equation 4.12 (N = 707). The signs of the coefficients are positive for BLACRID and negative for LOCSTAF. They conform to a priori assumptions. Farmers whose crops required more water did irrigate more. An increase in a crop water requirement (BLACRID) by one inch will lead to an increase in water demand by 0.0224 acre-feet per acre. An inch of water is equal to 0.0833 acre-feet per acre. Thus, there appears to be no one-on-one correspondence between water requirement and irrigation. In terms of costs, the typical irrigator will decrease water use by 0.0041 acre-feet per acre in response to a dollar increase in the cost of pumping one acre-foot. From their t-statistics, the finding is that independent variable coefficients are significantly different from zero. Their t-statistics for the coefficient of the independent variables are 8.963 (BLACRID) and –2.860 (LOCSTAF). The adjusted R^2 for Equation 4.13 is 13.3%. This is fraction of the variance of the dependent variable (IRRFACR) explained by the independent variables (LOCSTAF, BLACRID) adjusted for degrees of freedom. The null hypothesis that all coefficients are equal to zero is rejected given the high F-statistic (55.08).

Table 5.2. Summary of regression results for linear equations

Functional Form	Equation	Constant	BLADCRID Coefficient	LOCSTAF Coefficient	Elasticity	Adj. R^2
Linear	4.12	0.727	N/A	-0.006885 (-4.704)***	-0.26	1.80%
Linear	4.13	0.5496	0.02239 (8.963)***	-0.004122 (-2.860)***	-0.15	13.28%

Legend: Numbers in parentheses are the t statistics.
***-significant @ α=0.01, **-significant @ α=0.05, *-significant @ α=0.10

In Equations 4.17 to 4.18 the regressand (LIRRFAC) and the regressors (LLOCSTA and LBLACRI) are natural logarithmic transmutations of IRRFACR and LOCSTAF, and BLACRID, respectively. The sample size stands at 707.

Degrees of freedom for Equation 4.17 are 705. Only the intercept and the pump cost coefficients are estimated. A t-statistic of –2.694 evidences the strong significant of the pump cost coefficient (-0.2754). There is 99% confidence that this coefficient is significantly different from zero. This result suggests that an increase in pump cost of an acre-foot (LOCSTAF) by 1% will trigger a decrease in water demand (IRRFACR) by 0.27%. It affirms the inelastic nature of water demand amongst Georgia farmers. As in Equation 4.12, the adjusted R^2 is low (0.682%).

Equation 4.18 incorporates the logarithm of the crop water requirements (LBLACRI). Thus, there are three parameters to be estimated. Again, we see the crop water requirement coefficient (0.8325) is statistically significant and positive (t = 6.721). Caution must be exercised in interpreting this coefficient. As explained in the previous chapter, the logarithm of BLACRID is undefined in 189 cases. In order to circumvent this problem 14 was added to all observations. As a result, no observations were lost in the transformations. In this instance, the pump cost coefficient (-0.1582), although negative, is not statistically significant (t = -1.579).

Equations 4.12, 4.13, and 4.18 had heteroskedastic residuals. In other words, the error terms, ε, were not drawn from a distribution with a constant variance. In the presence of heteroskedasticity, the estimated coefficients, β_n, remain unbiased and consistent. Nonetheless, they are inefficient and asymptotically inefficient. Their variances are not minimized. Under these circumstances, the validity of statistical significance tests is questionable. This problem was addressed by computing residual variances with White's heteroskedasticity-consitent robust covariance estimator. As a result, all the regression parameter estimates herein presented are BLUE and the standard errors are unbiased (Appendix D).

Table 5.3. Summary of regression results for log-log equations

Functional Form	Equation	Constant	LBLACRI Coefficient	LLOCSTA Coefficient	Elasticity	Adj. R^2
Log-Log	4.17	-0.1015	N/A	-0.2754 (-2.694)***	-0.27	0.68%
Log-Log	4.18	-2.8571	0.8325 (6.721)***	-0.1581 (-1.579)	-0.16	9.52%

Legend: Numbers in parentheses are the t statistics.
***-significant @ α=0.01, **-significant @ α=0.05, *-significant @ α=0.10

If an equation were to be chosen as the best available estimate of the true water demand equation, it will have to be Equation 4.13. In this equation both water requirements and pumping costs are present. Their coefficients have the appropriate signs and proved to be statistically significant. Equation 4.13 does the best job at explaining the water demand. A numerical example best illustrates our findings. First, Equation 4.13 is populated with the estimated coefficients from Table 5.2. The new equation is Equation 5.1:

$$IRRFACR = 0.5496 + 0.0224*BLACRID-0.0041*LOCSTAF \quad (5.1)$$

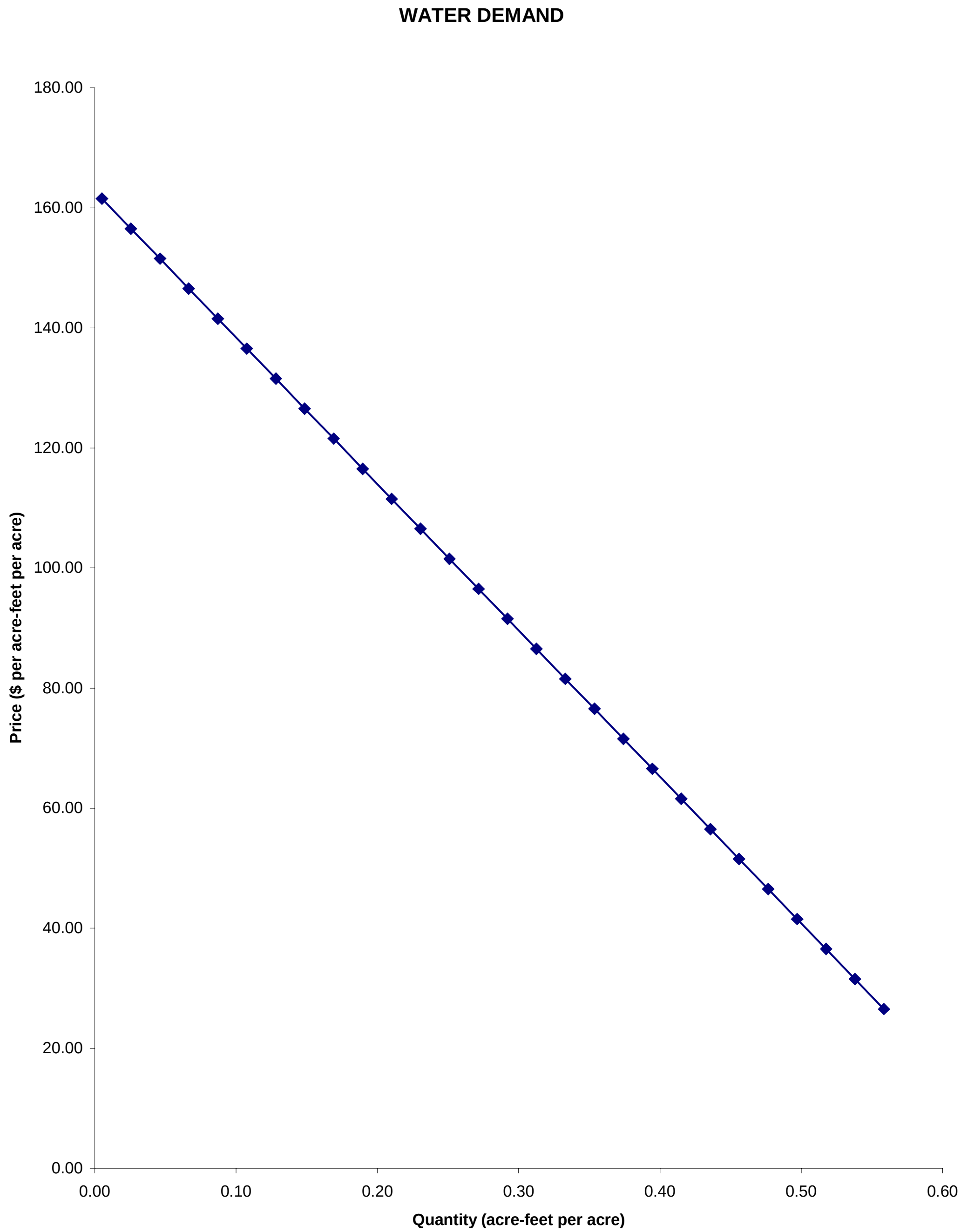
The example assumes that water requirements (BLACRID) are held constant at the mean (5.2644 inches). Mean pumping costs are equal to $21.54 per acre-feet per acre. If we insert these two numbers into Equation 5.1, we obtain a water demand equal to 0.58 acre-feet per acre (6.95 inches). Table 5.4 itemizes changes in demand as a result of increases in mean pumping costs while holding water requirements constant at its mean. Pumping costs are expressed in dollars per acre-feet per acre. Water demand is measured in acre-feet per acre. Table 5.4 uses dollars and cents to depict the relationship between pumping costs and quantity of irrigation demanded. If pumping costs would double, irrigators would apply an inch (0.0833 acre-feet per acre) of water less to each irrigated acre. It will take a sixfold increase in pumping costs in order for irrigators to stop pumping altogether.

Figure 5.1 shows the water demand curve based on Equation 5.1. As anticipated, Figure 5.1 resembles Figure 2.4. They are both sharply downward-sloping inelastic demand curves.

Table 5.4. Water demand reduction in response to pumping costs increases

Pumping Cost $/ac-ft/ac.	Pumping Cost Increase $/ac-ft/ac	Percent Increase	Water Demand Ac-ft/ac	Water Demand Decrease	Percent Decrease
26.54	5.00	23.21%	0.56	-0.02	-3.47%
31.54	10.00	46.43%	0.54	-0.04	-7.01%
36.54	15.00	69.64%	0.52	-0.06	-10.56%
41.54	20.00	92.85%	0.50	-0.08	-14.10%
46.54	25.00	116.06%	0.48	-0.10	-17.64%
51.54	30.00	139.28%	0.46	-0.12	-21.18%
56.54	35.00	162.49%	0.44	-0.14	-24.73%
61.54	40.00	185.70%	0.42	-0.16	-28.27%
66.54	45.00	208.91%	0.39	-0.18	-31.81%
71.54	50.00	232.13%	0.37	-0.20	-35.35%
76.54	55.00	255.34%	0.35	-0.23	-38.90%
81.54	60.00	278.55%	0.33	-0.25	-42.44%
86.54	65.00	301.76%	0.31	-0.27	-45.98%
91.54	70.00	324.98%	0.29	-0.29	-49.52%
96.54	75.00	348.19%	0.27	-0.31	-53.07%
101.54	80.00	371.40%	0.25	-0.33	-56.61%
106.54	85.00	394.61%	0.23	-0.35	-60.15%
111.54	90.00	417.83%	0.21	-0.37	-63.69%
116.54	95.00	441.04%	0.19	-0.39	-67.24%
121.54	100.00	464.25%	0.17	-0.41	-70.78%
126.54	105.00	487.47%	0.15	-0.43	-74.32%
131.54	110.00	510.68%	0.13	-0.45	-77.86%
136.54	115.00	533.89%	0.11	-0.47	-81.40%
141.54	120.00	557.10%	0.09	-0.49	-84.95%
146.54	125.00	580.32%	0.07	-0.51	-88.49%
151.54	130.00	603.53%	0.05	-0.53	-92.03%
156.54	135.00	626.74%	0.03	-0.55	-95.57%
161.54	140.00	649.95%	0.01	-0.57	-99.12%

Figure 5.1. Water Demand



Conclusions

This study was a series of climbs towards a higher plateau in our understanding of how price changes affect water use in Georgia. The first ascent involved an analysis of Agricultural Water Pumping Study data. In the second, these water consumption data served to generate pumping cost figures. The underlying assumption is that changes in pumping costs have the same effect on the marginal costs of water use as would changes in water price. The third ascent called for the estimation of a water demand equation relating water use to both pumping costs and crop water requirements. This study culminated in an inquest into how farmers act in response to fluctuations in pumping costs.

As we have seen in Chapter 2, our special relationship with water makes for passionate debate. Underlying the debate is the divergence between the marginal private cost and marginal social cost of pumping water. The benefits are accrued privately by the irrigator while a significant portion of the costs of using water is borne by the rest of society. There is no incentive on the irrigator to use water efficiently. The literature reviewed in Chapter 2 buttressed the claim of an inelastic water demand with respect to price. Nieswiadomy (1988) and Ogg and Gollehon (1989) produced elasticity estimates of –0.25 and –0.26, respectively. Earlier, Nieswiadomy (1985) found it to be –0.80. Irrigators are slow to respond to changes in pumping costs.

In Chapter 3, the chief goal was to probe water use by irrigators grouped according to various categories. The Agricultural Water Pumping Data are the matrix of this study. This is a unique data set with invaluable information about Georgia's agricultural water use pattern. These data indicated the Flint River Basin (FRB) irrigators are not the top water users. Despite the persistent drought that began in Georgia in 1998, no apparent upward trend in crop water use was found.

The analysis did reveal interregional differences in irrigation volumes administered to crops like cotton, nursery plants, peanut, and millet. In many cases, the differences were significantly large. This evidence does not support the notion of crop choice being a significant determinant of water use.

Electric pump owners both inside and outside the FRB led all other irrigators in terms of water volume applied to their irrigated acreage. When grouped by water source, both surface and groundwater irrigators were pumping at the same rate within the FRB. Groundwater favored overwhelmingly outside the FRB.

The utility of Agricultural Water Pumping Data set could be greatly enhanced. The following key items warrant collection for each field being monitored:

- Crop yield per acre,
- Water table depth,
- On-site measurements of intake depth, and
- Detailed water pump system data (e.g., brand, type pressure, capacity, fuel type, etc.).

Table 3.6 conveyed the importance of surface water irrigation. They comprise 38% of the observations in the master data set. Yet, none of these observations could be included in the model sample set. There was no information in regards to intake depth for surface water irrigators. Under these circumstances, surface water irrigators' pumping cost estimates could not be generated and the full informational potential of this data set remains unexplored. Future research should attempt to remedy this problem.

Estimation results are found in first part of this chapter. Four equations were estimated. Three equations are of particular interest. In Equations 4.12, 4.13, and 4.17, the independent variables are correctly signed and statistically significant. These results validated our a priori assumptions and confirmed the results of preceding research efforts by Nieswiadomy (1985), Nieswiadomy (1988), and Ogg and Gollehon (1989). For this study in particular, the elasticity of water demand with respect to pumping costs ranges between -0.15 and -0.27. Water demand will contract between 0.15% and 0.27% in reaction to a 1% increase in pumping costs. In other words, if mean pumping costs were to increase $20 per acre-foot, mean water demand will drop 0.96 inches per acre.

In Equation 2.1, we learned that an irrigator's demand for water hinges on many factors. This study was narrowly focused on the inverse relationship between pumping cost and quantity of water demanded. Once acreage has been selected and the crop has been planted, the farmer has very little choice in the matter for irrigation. The crop will need water at certain intervals during the crop period in order to ensure an acceptable yield. Although Georgia gets a fair amount of rain, precipitation can rarely be counted on sufficiently to meet the crop water requirements. The farmer depends on irrigation to succeed. Not surprisingly, the farmer's demand for water is inelastic.

Supply-side solutions will not adequately address the problem of water scarcity. Such initiatives are only capable of providing a short-term solution to the long-term problem of water allocation. Policies aimed at affecting the behavior of consumers appear to be the most viable alternative. Nevertheless, as Ogg and Gollehon (1989) suggested, an inelastic water demand presents a serious dilemma to policy makers at least in the short run. As we have seen, even modest reductions in water demand require substantial price hikes. The reality is that agriculture is a very competitive sector of the economy. Many farmers are working this year to pay last year's debt. Their ability to afford water at far higher prices is questionable at best and preposterous at worst. Given the large multiplier effect of the agricultural sector in the state of Georgia, any adverse impact in agriculture will be felt across the land.

Demand elasticity tends to change over time. Future studies should look into the impact of the adoption of new technology on water demand elasticities in the specific case of Georgia. It's plausible that water demand may become more elastic as a response to efficiency gains achieved as a result of better management practices and new technology adoption.

In conclusion, this study found divergent water patterns amongst irrigators. Moreover, irrigators are not very responsive to changes in pumping costs. This implies that, at least initially, farmers will reduce their water use only gradually in response to changes in water price.

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APPENDIX A

REGRESSION DATA SET

Tables A.1-A.2. Water use and pumping cost estimates

Table **Title**

Tables A.3-A.10: Water used in acre feet per acre (N = 707)

Table **Title**

Tables A.11-A.18: Low acre-feet per acre pumping cost estimates (N = 707)

Table **Title**

Tables 19-26: Non-Flint River Basin water used in acre-feet per acre (N = 280)

Table **Title**

Tables 27-34: Non-Flint River Basin low acre-feet per acre pumping cost estimates (N = 280)

Tables 35-41: Flint River Basin water used in acre-feet per acre (N = 482)

Tables 42-48: Flint River Basin low acre-feet per acre pumping cost estimates (N = 482)

Tables 49-54: Summary Tables

Tables A.1-A.2. Water use and pumping cost estimates

Table A.1. Water use in acre-feet per acre for various regions 1999-2002

Data Set	N	Mean	Std Dev	Minimum	Maximum
All	707	0.58	0.43	0.00	2.72
Non-Flint River Basin	253	0.47	0.39	0.00	2.72
Flint River Basin	454	0.64	0.43	0.00	2.16

Table A.2. Low acre-feet per acre pumping cost estimate for various regions 1999-2002

Data Set	N	Mean	Std. Dev.	Minimum	Maximum
All	707	21.54	8.63	8.54	61.28
Non-Flint River Basin	253	27.50	9.14	8.69	61.28
Flint River Basin	454	18.22	6.22	8.54	41.21

Tables A.3-A.10: Water used in acre feet per acre (N = 707)

Table A.3. Water used in acre-feet per acre by crop observation periods ending 1999

CROPS	N	Mean	Std Dev	Minimum	Maximum
Cantaloupe	1	0.54	.	0.54	0.54
Cotton	57	0.49	0.28	0.00	1.35
Field Corn	18	0.56	0.49	0.00	1.80
Onion	1	0.52	.	0.52	0.52
Peanut	35	0.45	0.31	0.01	1.29
Snap Bean	2	0.47	0.28	0.27	0.66
Soybean	2	0.22	0.16	0.11	0.33
Summer Squash	1	0.65	.	0.65	0.65
Sweet Corn	3	0.56	0.34	0.26	0.93
Tobacco	1	0.09	.	0.09	0.09
Tomato Staked	2	0.96	0.52	0.59	1.33
Watermelon	1	0.73	.	0.73	0.73
Winter Cover Crop	2	0.45	0.00	0.44	0.45

Table A.4. Water used in acre-feet per acre by crop observation periods ending 2000

CROPS	N	Mean	Std Dev	Minimum	Maximum
Cabbage	1.00	1.00	.	1.00	1.00
Carrot	1.00	0.10	.	0.10	0.10
Cotton	89.00	0.66	0.39	0.02	2.02
Cucumber	2.00	0.42	0.42	0.13	0.71
Field Corn	27.00	1.12	0.61	0.00	1.98
Millet	1.00	1.47	.	1.47	1.47
Peanut	52.00	0.77	0.33	0.01	1.73
Pecan	1.00	0.84	.	0.84	0.84
Pepper	1.00	1.71	.	1.71	1.71
Silage	4.00	0.94	0.74	0.44	2.03
Small Grain	2.00	0.51	0.39	0.24	0.79
Snap Bean	1.00	0.49	.	0.49	0.49
Soybean	7.00	0.86	0.45	0.33	1.47
Summer Forage	3.00	0.26	0.17	0.12	0.45
Summer Squash	2.00	0.34	0.05	0.30	0.37
Sweet Corn	9.00	1.29	0.21	1.02	1.59
Tobacco	6.00	0.60	0.61	0.16	1.81
Tomato Staked	2.00	1.22	0.47	0.89	1.55
Vegetables Mixed	3.00	0.36	0.26	0.18	0.65
Watermelon	5.00	0.45	0.29	0.17	0.85
Winter Cover Crop	2.00	0.15	0.13	0.06	0.25
Winter Forage	19.00	0.16	0.13	0.02	0.59

Table A.5. Water use in acre-feet per acre by crop observation period ending in 2001

CROPS	N	Mean	Std Dev	Minimum	Maximum
Cabbage	2	0.40	0.11	0.32	0.48
Carrot	3	0.32	0.27	0.08	0.60
Collard	3	0.41	0.25	0.12	0.58
Cotton	106	0.50	0.30	0.03	1.38
Cucumber	5	0.36	0.12	0.22	0.53
Field Corn	32	0.73	0.39	0.08	1.74
Oat Grain	1	0.15	.	0.15	0.15
Onion	1	0.25	.	0.25	0.25
Peanut	64	0.60	0.43	0.02	2.72
Pecan	16	0.60	0.61	0.00	2.02
Pepper	2	0.77	0.09	0.71	0.83
Permanent Forage	3	0.36	0.28	0.04	0.56
Silage	5	0.49	0.22	0.21	0.72
Snap Bean	10	0.43	0.21	0.08	0.77
Sod Production	4	1.53	0.74	0.64	2.16
Sorghum	1	0.64	.	0.64	0.64
Soybean	9	0.44	0.19	0.20	0.75
Summer Forage	1	0.03	.	0.03	0.03
Summer Squash	1	0.28	.	0.28	0.28
Sweet Corn	5	0.99	0.41	0.26	1.22
Tobacco	6	0.37	0.27	0.11	0.73
Tomato Staked	2	1.54	0.31	1.33	1.76
Vegetables Mixed	10	0.40	0.13	0.19	0.63
Watermelon	10	0.42	0.24	0.17	0.98
Wheat Grain	4	0.17	0.18	0.03	0.43
Winter Cover Crop	4	0.04	0.05	0.00	0.11
Winter Forage	24	0.12	0.10	0.00	0.39

Table A.6. Water use in acre-feet per acre by crop observation period ending in 2002

CROPS	N	Mean	Std Dev	Minimum	Maximum
Onion	4	0.46	0.45	0.18	1.13
Permanent Forage	1	0.03	.	0.03	0.03
Winter Forage	2	0.09	0.02	0.07	0.11

Table A.7. Water use in acre-feet per acre by crop 1999-2002

CROPS	N	Mean	Std Dev	Minimum	Maximum
Cabbage	3	0.60	0.36	0.32	1.00
Cantaloupe	1	0.54	.	0.54	0.54
Carrot	4	0.26	0.24	0.08	0.60
Collard	3	0.41	0.25	0.12	0.58
Cotton	252	0.56	0.34	0.00	2.02
Cucumber	7	0.38	0.20	0.13	0.71
Field Corn	77	0.83	0.54	0.00	1.98
Millet	1	1.47	.	1.47	1.47
Oat Grain	1	0.15	.	0.15	0.15
Onion	6	0.43	0.36	0.18	1.13
Peanut	151	0.62	0.39	0.01	2.72
Pecan	17	0.61	0.59	0.00	2.02
Pepper	3	1.08	0.54	0.71	1.71
Permanent Forage	4	0.27	0.28	0.03	0.56
Silage	9	0.69	0.53	0.21	2.03
Small Grain	2	0.51	0.39	0.24	0.79
Snap Bean	13	0.44	0.20	0.08	0.77
Sod Production	4	1.53	0.74	0.64	2.16
Sorghum	1	0.64	.	0.64	0.64
Soybean	18	0.58	0.38	0.11	1.47
Summer Forage	4	0.20	0.18	0.03	0.45
Summer Squash	4	0.40	0.17	0.28	0.65
Sweet Corn	17	1.07	0.40	0.26	1.59
Tobacco	13	0.45	0.46	0.09	1.81
Tomato Staked	6	1.24	0.43	0.59	1.76
Vegetables Mixed	13	0.39	0.15	0.18	0.65
Watermelon	16	0.45	0.25	0.17	0.98
Wheat Grain	4	0.17	0.18	0.03	0.43
Winter Cover Crop	8	0.17	0.19	0.00	0.45
Winter Forage	45	0.14	0.12	0.00	0.59

Table A.8. Water use in acre-feet per acre by fuel type 199-2002

Fuel	N	Mean	Std Dev	Minimum	Maximum
Diesel	362	0.58	0.44	0.00	2.72
Electric	345	0.58	0.41	0.00	2.02

Table A.9. Water use in acre-feet per acre by horsepower rating of pumps 1999-2002

Horsepower	N	Mean	Std Dev	Minimum	Maximum
0-100	193	0.57	0.41	0.00	1.98
100-200	323	0.53	0.42	0.00	2.72
200-300	151	0.65	0.44	0.00	2.10
300+	8	1.13	0.46	0.30	1.74

Table A.10. Water use in acre-feet per acre by size of permitted holdings 1999-2002

Acreage	N	Mean	Std Dev	Minimum	Maximum
0-50	283	0.58	0.46	0.00	2.72
50-100	216	0.55	0.40	0.00	1.76
100-150	115	0.57	0.40	0.00	2.02
150-200	37	0.60	0.41	0.04	2.16
200+	56	0.67	0.40	0.08	2.02

Tables A.11-A.18: Low acre-feet per acre pumping cost estimates (N = 707)

Table A.11. Low acre-feet per acre pumping cost estimate by crop 1999

CROPS	N	Mean	Std Dev	Minimum	Maximum
Cantaloupe	1	27.98	.	27.98	27.98
Cotton	57	16.52	5.24	10.34	40.77
Field Corn	18	13.81	3.07	9.54	19.67
Onion	1	24.66	.	24.66	24.66
Peanut	35	16.77	4.91	11.13	28.32
Snap Bean	2	14.72	1.12	13.93	15.51
Soybean	2	22.44	8.32	16.55	28.32
Summer Squash	1	13.93	.	13.93	13.93
Sweet Corn	3	15.51	1.57	13.93	17.07
Tobacco	1	12.41	.	12.41	12.41
Tomato Staked	2	18.51	0.00	18.51	18.51
Watermelon	1	25.39	.	25.39	25.39
Winter Cover Crop	2	13.93	0.00	13.93	13.93

Table A.12. Low acre-feet per acre pumping cost estimates by crop 2000

CROPS	N	Mean	Std Dev	Minimum	Maximum
Cabbage	1	24.61	.	24.61	24.61
Carrot	1	28.29	.	28.29	28.29
Cotton	89	23.88	8.81	11.69	52.45
Cucumber	2	40.07	0.00	40.07	40.07
Field Corn	27	21.06	7.24	11.48	40.65
Millet	1	30.90	.	30.90	30.90
Peanut	52	21.47	7.87	11.48	52.45
Pecan	1	37.34	.	37.34	37.34
Pepper	1	20.00	.	20.00	20.00
Silage	4	33.19	2.65	30.90	35.49
Small Grain	2	15.56	5.47	11.69	19.42
Snap Bean	1	20.00	.	20.00	20.00
Soybean	7	27.50	4.35	21.98	30.90
Summer Forage	3	21.42	4.23	18.98	26.31
Summer Squash	2	32.49	0.00	32.49	32.49
Sweet Corn	9	18.75	1.68	15.68	20.93
Tobacco	6	30.18	10.18	19.88	43.79
Tomato Staked	2	26.57	0.00	26.57	26.57
Vegetables Mixed	3	18.56	2.49	15.68	20.00
Watermelon	5	28.79	8.17	19.88	36.69
Winter Cover Crop	2	18.94	3.12	16.73	21.14
Winter Forage	19	20.17	8.13	11.48	40.65

Table A.13. Low acre-feet per acre pumping cost estimates by crop 2001

CROPS	N	Mean	Std Dev	Minimum	Maximum
Cabbage	2	20.51	0.00	20.51	20.51
Carrot	3	27.53	13.46	16.65	42.58
Collard	3	22.98	6.12	19.44	30.04
Cotton	106	21.15	8.16	8.69	61.28
Cucumber	5	37.18	3.99	30.04	38.97
Field Corn	32	22.58	12.80	8.69	61.28
Oat Grain	1	17.77	.	17.77	17.77
Onion	1	20.77	.	20.77	20.77
Peanut	64	20.97	9.51	8.69	61.28
Pecan	16	16.35	4.80	8.54	31.12
Pepper	2	31.58	17.16	19.44	43.71
Permanent Forage	3	27.74	5.24	21.75	31.42
Silage	5	28.43	8.87	13.07	34.50
Snap Bean	10	20.01	7.72	9.74	30.04
Sod Production	4	24.72	8.04	16.57	34.50
Sorghum	1	25.58	.	25.58	25.58
Soybean	9	28.97	1.29	27.08	30.04
Summer Forage	1	25.58	.	25.58	25.58
Summer Squash	1	19.44	.	19.44	19.44
Sweet Corn	5	15.84	2.87	12.63	18.89
Tobacco	6	32.43	16.84	17.32	61.28
Tomato Staked	2	25.83	0.00	25.83	25.83
Vegetables Mixed	10	29.10	3.66	19.44	32.09
Watermelon	10	25.88	5.12	17.45	32.09
Wheat Grain	4	21.70	9.64	13.07	34.50
Winter Cover Crop	4	26.05	7.04	18.89	32.09
Winter Forage	24	19.97	9.01	9.57	46.77

Table A.14. Low acre-feet per acre pumping cost estimates by crop 2002

CROPS	N	Mean	Std Dev	Minimum	Maximum
Onion	4	21.47	1.40	20.77	23.58
Permanent Forage	1	20.56	.	20.56	20.56
Winter Forage	2	21.95	1.97	20.56	23.35

Table A.15. Low acre-feet per acre pumping cost estimates by crop 1999-2002

CROPS	N	Mean	Std Dev	Minimum	Maximum
Cabbage	3	21.88	2.37	20.51	24.61
Cantaloupe	1	27.98	.	27.98	27.98
Carrot	4	27.72	11.00	16.65	42.58
Collard	3	22.98	6.12	19.44	30.04
Cotton	252	21.07	8.29	8.69	61.28
Cucumber	7	38.01	3.55	30.04	40.07
Field Corn	77	20.00	9.96	8.69	61.28
Millet	1	30.90	.	30.90	30.90
Oat Grain	1	17.77	.	17.77	17.77
Onion	6	21.89	1.76	20.77	24.66
Peanut	151	20.17	8.25	8.69	61.28
Pecan	17	17.59	6.89	8.54	37.34
Pepper	3	27.72	13.85	19.44	43.71
Permanent Forage	4	25.94	5.58	20.56	31.42
Silage	9	30.55	6.95	13.07	35.49
Small Grain	2	15.56	5.47	11.69	19.42
Snap Bean	13	19.19	6.98	9.74	30.04
Sod Production	4	24.72	8.04	16.57	34.50
Sorghum	1	25.58	.	25.58	25.58
Soybean	18	27.67	3.96	16.55	30.90
Summer Forage	4	22.46	4.03	18.98	26.31
Summer Squash	4	24.59	9.40	13.93	32.49
Sweet Corn	17	17.32	2.50	12.63	20.93
Tobacco	13	29.85	13.78	12.41	61.28
Tomato Staked	6	23.63	3.98	18.51	26.57
Vegetables Mixed	13	26.66	5.69	15.68	32.09
Watermelon	16	26.76	5.96	17.45	36.69
Wheat Grain	4	21.70	9.64	13.07	34.50
Winter Cover Crop	8	21.24	7.25	13.93	32.09
Winter Forage	45	20.14	8.35	9.57	46.77

Table A.16. Low acre-feet per acre pumping cost estimate by fuel type 1999-2002

FUEL	N	Mean	Std Dev	Minimum	Maximum
Diesel	362	23.95	9.26	9.54	61.28
Electric	345	19.01	7.09	8.54	52.45

Table A.17. Low acre-feet per acre pumping cost estimate by horsepower rating 1999-2002

Horsepower	N	Mean	Std Dev	Minimum	Maximum
0-100	193	17.63	6.16	8.54	41.21
100-200	323	21.45	8.93	9.54	61.28
200-300	151	25.01	8.75	10.34	43.79
300+	8	29.82	1.86	25.33	30.90

Table A.18. Low acre-feet per acre pumping cost estimate by size of permitted holding 1999-2002

Acreage	N	Mean	Std Dev	Minimum	Maximum
0-50	283	22.03	9.38	8.54	61.28
50-100	216	22.39	8.13	9.54	52.45
100-150	115	20.61	7.68	11.57	52.45
150-200	37	21.91	10.58	10.34	40.65
200+	56	17.45	5.26	9.74	37.34

Tables A.19- A.26: Non-Flint River Basin water used in acre-feet per acre (N = 280)

Table A.19. Water use in acre-feet per acre by crop observation periods ending 1999

Crops	N	Mean	Std. Dev.	Minimum	Maximum
Cantaloupe	1	0.54		0.54	0.54
Cotton	5	0.22	0.17	0.00	0.39
Onion	1	0.52		0.52	0.52
Peanut	3	0.60	0.09	0.52	0.69
Tobacco	1	0.09		0.09	0.09
Watermelon	1	0.73		0.73	0.73

Table A.20. Water use in acre-feet per acre by crop observation period ending in 2000

CROPS	N	Mean	Std Dev	Minimum	Maximum
Cabbage	1	1.00	.	1.00	1.00
Carrot	1	0.10	.	0.10	0.10
Cotton	26	0.43	0.26	0.02	0.95
Cucumber	2	0.42	0.42	0.13	0.71
Field Corn	8	0.59	0.55	0.00	1.74
Millet	1	1.47	.	1.47	1.47
Peanut	15	0.56	0.39	0.01	1.73
Pepper	1	1.71	.	1.71	1.71
Silage	2	1.28	1.06	0.53	2.03
Soybean	7	0.86	0.45	0.33	1.47
Summer Squash	2	0.34	0.05	0.30	0.37
Tobacco	6	0.60	0.61	0.16	1.81
Watermelon	3	0.59	0.29	0.28	0.85
Winter Cover Crop	1	0.25	.	0.25	0.25

Table A.21. Water use in acre-feet per acre by crop observation period ending 2001

CROPS	N	Mean	Std Dev	Minimum	Maximum
Cabbage	2	0.40	0.11	0.32	0.48
Carrot	3	0.32	0.27	0.08	0.60
Collard	3	0.41	0.25	0.12	0.58
Cotton	41	0.41	0.27	0.03	1.17
Cucumber	5	0.36	0.12	0.22	0.53
Field Corn	13	0.49	0.33	0.08	1.13
Onion	1	0.25	.	0.25	0.25
Peanut	26	0.58	0.57	0.02	2.72
Pecan	11	0.34	0.33	0.00	1.05
Pepper	2	0.77	0.09	0.71	0.83
Permanent Forage	3	0.36	0.28	0.04	0.56
Silage	2	0.71	0.01	0.70	0.72
Snap Bean	3	0.39	0.08	0.31	0.48
Sod Production	1	2.10	.	2.10	2.10
Soybean	9	0.44	0.19	0.20	0.75
Soybean	9	2001.00	0.00	2001.00	2001.00
Summer Squash	1	0.28	.	0.28	0.28
Tobacco	6	0.37	0.27	0.11	0.73
Vegetables Mixed	9	0.38	0.12	0.19	0.63
Watermelon	8	0.45	0.25	0.17	0.98
Wheat Grain	1	0.43	.	0.43	0.43
Winter Cover Crop	2	0.03	0.01	0.02	0.04
Winter Forage	6	0.05	0.06	0.00	0.16

Table A.22. Water use in acre-feet per acre by crop observation period ending 2002

CROPS	N	Mean	Std Dev	Minimum	Maximum
Onion	4	0.46	0.45	0.18	1.13
Permanent Forage	1	0.03	.	0.03	0.03
Winter Forage	2	0.09	0.02	0.07	0.11

Table A.23. Water use in acre-feet per acre by crop 1999-2002

CROPS	N	Mean	Std Dev	Minimum	Maximum
Cabbage	3	0.60	0.36	0.32	1.00
Cantaloupe	1	0.54	.	0.54	0.54
Carrot	4	0.26	0.24	0.08	0.60
Collard	3	0.41	0.25	0.12	0.58
Cotton	72	0.40	0.26	0.00	1.17
Cucumber	7	0.38	0.20	0.13	0.71
Field Corn	21	0.53	0.42	0.00	1.74
Millet	1	1.47	.	1.47	1.47
Onion	6	0.43	0.36	0.18	1.13
Peanut	44	0.57	0.49	0.01	2.72
Pecan	11	0.34	0.33	0.00	1.05
Pepper	3	1.08	0.54	0.71	1.71
Permanent Forage	4	0.27	0.28	0.03	0.56
Silage	4	1.00	0.69	0.53	2.03
Snap Bean	3	0.39	0.08	0.31	0.48
Sod Production	1	2.10	.	2.10	2.10
Soybean	16	0.62	0.38	0.20	1.47
Summer Squash	3	0.32	0.05	0.28	0.37
Tobacco	13	0.45	0.46	0.09	1.81
Vegetables Mixed	9	0.38	0.12	0.19	0.63
Watermelon	12	0.51	0.26	0.17	0.98
Wheat Grain	1	0.43	.	0.43	0.43
Winter Cover Crop	3	0.10	0.13	0.02	0.25
Winter Forage	8	0.06	0.05	0.00	0.16

Table A.24. Water use in acre-feet per acre by fuel type 1999-2002

FUEL	N	Mean	Std Dev	Minimum	Maximum
Diesel	149	0.47	0.44	0.00	2.72
Electric	104	0.48	0.32	0.00	1.73

Table A.25. Water use in acre-feet per acre by pump horsepower rating 1999-2002

Horsepower	N	Mean	Std Dev	Minimum	Maximum
0-100	69	0.49	0.37	0.00	1.81
100-200	90	0.33	0.33	0.00	2.72
200-300	55	0.51	0.38	0.08	2.10
300+	8	1.13	0.46	0.30	1.74

Table A.26. Water use in acre-feet per acre by size of permitted holding 1999-2002

Acreage	N	Mean	Std Dev	Minimum	Maximum
0-50	148	0.53	0.44	0.00	2.72
50-100	80	0.41	0.31	0.00	1.74
100-150	21	0.32	0.21	0.00	0.93
150-200	1	0.04	.	0.04	0.04
200+	3	0.45	0.29	0.27	0.79

Tables A.27- A.34: Non-Flint River Basin low acre-feet per acre pumping cost estimates (N = 280)

Table A.27. Low acre-feet per acre pumping cost estimates by crop 1999

CROPS	N	Mean	Std	Minimum	Maximum
Cantaloupe	1	27.98		27.98	27.98
Cotton	5	19.80	6.93	12.41	27.98
Onion	1	24.66		24.66	24.66
Peanut	3	27.12	1.50	25.39	27.98
Tobacco	1	12.41		12.41	12.41
Watermelon	1	25.39		25.39	25.39

Table A.28. Low acre-feet per acre pumping cost estimate by crop 2000

CROPS	N	Mean	Std Dev	Minimum	Maximum
Cabbage	1	24.61	.	24.61	24.61
Carrot	1	28.29	.	28.29	28.29
Cotton	26	31.85	8.66	17.82	52.45
Cucumber	2	40.07	0.00	40.07	40.07
Field Corn	8	27.45	6.25	17.82	33.19
Millet	1	30.90	.	30.90	30.90
Peanut	15	30.05	7.63	21.14	52.45
Pepper	1	20.00	.	20.00	20.00
Silage	2	30.90	0.00	30.90	30.90
Soybean	7	27.50	4.35	21.98	30.90
Summer Squash	2	32.49	0.00	32.49	32.49
Tobacco	6	30.18	10.18	19.88	43.79
Watermelon	3	31.09	9.70	19.88	36.69
Winter Cover Crop	1	21.14	.	21.14	21.14

Table A.29. Low acre-feet per acre pumping cost estimate by crop 2001

CROPS	N	Mean	Std Dev	Minimum	Maximum
Cabbage	2	20.51	0.00	20.51	20.51
Carrot	3	27.53	13.46	16.65	42.58
Collard	3	22.98	6.12	19.44	30.04
Cotton	41	25.46	9.30	8.69	61.28
Cucumber	5	37.18	3.99	30.04	38.97
Field Corn	13	28.36	15.98	8.69	61.28
Onion	1	20.77	.	20.77	20.77
Peanut	26	26.98	10.82	8.69	61.28
Pecan	11	16.42	0.54	15.46	16.91
Pepper	2	31.58	17.16	19.44	43.71
Permanent Forage	3	27.74	5.24	21.75	31.42
Silage	2	30.04	0.00	30.04	30.04
Snap Bean	3	30.04	0.00	30.04	30.04
Sod Production	1	27.81	.	27.81	27.81
Soybean	9	28.97	1.29	27.08	30.04
Summer Squash	1	19.44	.	19.44	19.44
Tobacco	6	32.43	16.84	17.32	61.28
Vegetables Mixed	9	30.17	1.46	27.08	32.09
Watermelon	8	27.34	4.43	21.12	32.09
Wheat Grain	1	23.58	.	23.58	23.58
Winter Cover Crop	2	32.09	0.00	32.09	32.09
Winter Forage	6	28.01	10.60	17.32	46.77

Table A.30. Low acre-feet per acre pumping cost estimate by crop 2002

CROPS	N	Mean	Std Dev	Minimum	Maximum
Onion	4	21.47	1.40	20.77	23.58
Permanent Forage	1	20.56	.	20.56	20.56
Winter Forage	2	21.95	1.97	20.56	23.35

Table A.31. Low acre-feet per acre pumping cost estimate by crop 1999-2002

CROPS	N	Mean	Std Dev	Minimum	Maximum
Cabbage	3	21.88	2.37	20.51	24.61
Cantaloupe	1	27.98	.	27.98	27.98
Carrot	4	27.72	11.00	16.65	42.58
Collard	3	22.98	6.12	19.44	30.04
Cotton	72	27.38	9.56	8.69	61.28
Cucumber	7	38.01	3.55	30.04	40.07
Field Corn	21	28.02	12.93	8.69	61.28
Millet	1	30.90	.	30.90	30.90
Onion	6	21.89	1.76	20.77	24.66
Peanut	44	28.04	9.45	8.69	61.28
Pecan	11	16.42	0.54	15.46	16.91
Pepper	3	27.72	13.85	19.44	43.71
Permanent Forage	4	25.94	5.58	20.56	31.42
Silage	4	30.47	0.49	30.04	30.90
Snap Bean	3	30.04	0.00	30.04	30.04
Sod Production	1	27.81	.	27.81	27.81
Soybean	16	28.32	3.01	21.98	30.90
Summer Squash	3	28.14	7.53	19.44	32.49
Tobacco	13	29.85	13.78	12.41	61.28
Vegetables Mixed	9	30.17	1.46	27.08	32.09
Watermelon	12	28.11	5.76	19.88	36.69
Wheat Grain	1	23.58	.	23.58	23.58
Winter Cover Crop	3	28.44	6.32	21.14	32.09
Winter Forage	8	26.50	9.42	17.32	46.77

Table A.32. Low acre-feet per acre pumping cost estimate by fuel type 1999-2002

FUEL	N	Mean	Std Dev	Minimum	Maximum
Diesel	149	29.09	9.47	12.41	61.28
Electric	104	25.22	8.16	8.69	52.45

Table A.33. Low acre-feet per acre pumping cost estimate by horsepower rating 1999-2002

Horsepower	N	Mean	Std Dev	Minimum	Maximum
0-100	69	21.48	5.31	8.69	32.49
100-200	90	30.28	11.29	12.41	61.28
200-300	55	29.91	7.06	16.65	43.79
300+	8	29.82	1.86	25.33	30.90

Table A.34. Low acre-feet per acre pumping cost estimate by size of permitted holding 1999-2002

Acreage	N	Mean	Std Dev	Minimum	Maximum
0-50	148	27.00	9.88	8.69	61.28
50-100	80	28.56	7.72	12.41	52.45
100-150	21	27.27	9.18	16.57	52.45
150-200	1	31.42	.	31.42	31.42
200+	3	24.12	6.95	16.65	30.39

Tables A.35- A.41: Flint River Basin water used in acre-feet per acre (N = 482)

Table A.35. Water use in acre-feet per acre by crop observation period ending 1999

CROPS	N	Mean	Std Dev	Minimum	Maximum
Cotton	52	0.51	0.28	0.01	1.35
Field Corn	18	0.56	0.49	0.00	1.80
Peanut	32	0.44	0.32	0.01	1.29
Snap Bean	2	0.47	0.28	0.27	0.66
Soybean	2	0.22	0.16	0.11	0.33
Summer Squash	1	0.65	.	0.65	0.65
Sweet Corn	3	0.56	0.34	0.26	0.93
Tomato Staked	2	0.96	0.52	0.59	1.33
Winter Cover Crop	2	0.45	0.00	0.44	0.45

Table A.36. Water use in acre-feet per acre by crop observation period ending 2000

CROPS	N	Mean	Std Dev	Minimum	Maximum
Cotton	63	0.76	0.40	0.16	2.02
Field Corn	19	1.35	0.49	0.16	1.98
Peanut	37	0.85	0.26	0.23	1.54
Pecan	1	0.84	.	0.84	0.84
Silage	2	0.61	0.25	0.44	0.79
Small Grain	2	0.51	0.39	0.24	0.79
Snap Bean	1	0.49	.	0.49	0.49
Summer Forage	3	0.26	0.17	0.12	0.45
Sweet Corn	9	1.29	0.21	1.02	1.59
Tomato Staked	2	1.22	0.47	0.89	1.55
Vegetables Mixed	3	0.36	0.26	0.18	0.65
Watermelon	2	0.24	0.09	0.17	0.30
Winter Cover Crop	1	0.06	.	0.06	0.06
Winter Forage	19	0.16	0.13	0.02	0.59

Table A.37. Water use in acre-feet per acre by crop observation period ending 2001

CROPS	N	Mean	Std Dev	Minimum	Maximum
Cotton	65	0.57	0.30	0.03	1.38
Field Corn	19	0.89	0.35	0.18	1.74
Oat Grain	1	0.15	.	0.15	0.15
Peanut	38	0.62	0.31	0.04	1.51
Pecan	5	1.17	0.73	0.36	2.02
Silage	3	0.34	0.11	0.21	0.42
Snap Bean	7	0.44	0.25	0.08	0.77
Sod Production	3	1.34	0.77	0.64	2.16
Sorghum	1	0.64	.	0.64	0.64
Summer Forage	1	0.03	.	0.03	0.03
Sweet Corn	5	0.99	0.41	0.26	1.22
Tomato Staked	2	1.54	0.31	1.33	1.76
Vegetables Mixed	1	0.59	.	0.59	0.59
Watermelon	2	0.31	0.17	0.20	0.43
Wheat Grain	3	0.09	0.08	0.03	0.18
Winter Cover Crop	2	0.06	0.08	0.00	0.11
Winter Forage	18	0.15	0.10	0.01	0.39

Table A.38. Water use in acre-feet per acre by crop 1999-2002

CROPS	N	Mean	Std Dev	Minimum	Maximum
Cotton	180	0.62	0.35	0.01	2.02
Field Corn	56	0.94	0.54	0.00	1.98
Oat Grain	1	0.15	.	0.15	0.15
Peanut	107	0.65	0.34	0.01	1.54
Pecan	6	1.12	0.67	0.36	2.02
Silage	5	0.45	0.21	0.21	0.79
Small Grain	2	0.51	0.39	0.24	0.79
Snap Bean	10	0.45	0.22	0.08	0.77
Sod Production	3	1.34	0.77	0.64	2.16
Sorghum	1	0.64	.	0.64	0.64
Soybean	2	0.22	0.16	0.11	0.33
Summer Forage	4	0.20	0.18	0.03	0.45
Summer Squash	1	0.65	.	0.65	0.65
Sweet Corn	17	1.07	0.40	0.26	1.59
Tomato Staked	6	1.24	0.43	0.59	1.76
Vegetables Mixed	4	0.41	0.24	0.18	0.65
Watermelon	4	0.27	0.12	0.17	0.43
Wheat Grain	3	0.09	0.08	0.03	0.18
Winter Cover Crop	5	0.21	0.22	0.00	0.45
Winter Forage	37	0.15	0.12	0.01	0.59

Table A.39. Water use in acre-feet per acre by fuel type 1999-2002

FUEL	N	Mean	Std Dev	Minimum	Maximum
Diesel	213	0.66	0.43	0.00	2.16
Electric	241	0.62	0.44	0.00	2.02

Table A.40. Water use in acre-feet per acre by pump horsepower rating 1999-2002

Horsepower	N	Mean	Std Dev	Minimum	Maximum
0-100	124	0.6110491	0.43	0.00	1.98
100-200	233	0.6128261	0.42	0.01	2.16
200-300	96	0.7226028	0.45	0.00	1.76

Table A.41. Water use in acre-feet per acre by size of permitted holding 1999-2002

Acreage	N	Mean	Std Dev	Minimum	Maximum
0-50	135	0.63	0.48	0.00	1.98
50-100	136	0.64	0.43	0.01	1.76
100-150	94	0.62	0.41	0.00	2.02
150-200	36	0.61	0.40	0.05	2.16
200+	53	0.69	0.40	0.08	2.02

Tables A.42- A.48: Flint River Basin low acre-feet per acre pumping cost estimates (N = 482)

Table A.42. Low acre-feet per acre pumping cost estimate by crop 1999

CROPS	N	Mean	Std Dev	Minimum	Maximum
Cotton	52	16.20	5.03	10.34	40.77
Field Corn	18	13.81	3.07	9.54	19.67
Peanut	32	15.80	3.87	11.13	28.32
Snap Bean	2	14.72	1.12	13.93	15.51
Soybean	2	22.44	8.32	16.55	28.32
Summer Squash	1	13.93	.	13.93	13.93
Sweet Corn	3	15.51	1.57	13.93	17.07
Tomato Staked	2	18.51	0.00	18.51	18.51
Winter Cover Crop	2	13.93	0.00	13.93	13.93

Table A.43. Low acre-feet per acre pumping cost estimate by crop 2000

CROPS	N	Mean	Std Dev	Minimum	Maximum
Cotton	63	20.60	6.50	11.69	41.21
Field Corn	19	18.37	5.89	11.48	40.65
Peanut	37	18.00	4.69	11.48	35.49
Pecan	1	37.34	.	37.34	37.34
Silage	2	35.49	0.00	35.49	35.49
Small Grain	2	15.56	5.47	11.69	19.42
Snap Bean	1	20.00	.	20.00	20.00
Summer Forage	3	21.42	4.23	18.98	26.31
Sweet Corn	9	18.75	1.68	15.68	20.93
Tomato Staked	2	26.57	0.00	26.57	26.57
Vegetables Mixed	3	18.56	2.49	15.68	20.00
Watermelon	2	25.34	6.23	20.93	29.75
Winter Cover Crop	1	16.73	.	16.73	16.73
Winter Forage	19	20.17	8.13	11.48	40.65

Table A.44. Low acre-feet per acre pumping cost estimate by crop 2001

CROPS	N	Mean	Std Dev	Minimum	Maximum
Cotton	65	18.43	5.99	9.57	39.52
Field Corn	19	18.62	8.44	9.57	39.52
Oat Grain	1	17.77	.	17.77	17.77
Peanut	38	16.86	5.68	10.44	39.52
Pecan	5	16.21	9.25	8.54	31.12
Silage	3	27.36	12.37	13.07	34.50
Snap Bean	7	15.71	4.18	9.74	22.61
Sod Production	3	23.69	9.52	16.57	34.50
Sorghum	1	25.58	.	25.58	25.58
Summer Forage	1	25.58	.	25.58	25.58
Sweet Corn	5	15.84	2.87	12.63	18.89
Tomato Staked	2	25.83	0.00	25.83	25.83
Vegetables Mixed	1	19.44	.	19.44	19.44
Watermelon	2	20.03	3.65	17.45	22.61
Wheat Grain	3	21.07	11.70	13.07	34.50
Winter Cover Crop	2	20.00	1.58	18.89	21.12
Winter Forage	18	17.29	6.80	9.57	32.27

Table A.45. Low acre-feet per acre pumping cost estimate by crop 1999-2001

CROPS	N	Mean	Std Dev	Minimum	Maximum
Cotton	180	18.55	6.14	9.57	41.21
Field Corn	56	16.99	6.51	9.54	40.65
Oat Grain	1	17.77	.	17.77	17.77
Peanut	107	16.94	4.89	10.44	39.52
Pecan	6	19.73	11.95	8.54	37.34
Silage	5	30.61	9.82	13.07	35.49
Small Grain	2	15.56	5.47	11.69	19.42
Snap Bean	10	15.94	3.74	9.74	22.61
Sod Production	3	23.69	9.52	16.57	34.50
Sorghum	1	25.58	.	25.58	25.58
Soybean	2	22.44	8.32	16.55	28.32
Summer Forage	4	22.46	4.03	18.98	26.31
Summer Squash	1	13.93	.	13.93	13.93
Sweet Corn	17	17.32	2.50	12.63	20.93
Tomato Staked	6	23.63	3.98	18.51	26.57
Vegetables Mixed	4	18.78	2.08	15.68	20.00
Watermelon	4	22.69	5.18	17.45	29.75
Wheat Grain	3	21.07	11.70	13.07	34.50
Winter Cover Crop	5	16.92	3.14	13.93	21.12
Winter Forage	37	18.77	7.55	9.57	40.65

Table A.46. Low acre-feet per acre pumping cost estimate by fuel type 1999-2001

FUEL	N	Mean	Std Dev	Minimum	Maximum
Diesel	213	20.35	7.20	9.54	40.65
Electric	241	16.33	4.43	8.54	41.21

Table A.47. Low acre-feet per acre pumping cost estimate by horsepower rating 1999-2001

Horsepower	N	Mean	Std Dev	Minimum	Maximum
0-100	124	15.48	5.54	8.54	41.21
100-200	233	18.04	4.44	9.54	36.63
200-300	96	22.20	8.41	10.34	40.65

Table A.48. Low acre-feet per acre pumping cost estimate by size of permitted holding 1999-2002

Acreage	N	Mean	Std Dev	Minimum	Maximum
0-50	135	16.59	4.57	8.54	28.93
50-100	136	18.76	5.87	9.54	39.52
100-150	94	19.12	6.47	11.57	41.21
150-200	36	21.64	10.60	10.34	40.65
200+	53	17.07	4.97	9.74	37.34

Tables A.49-A.54: Summary Tables

Table A.49. Mean water use in acre-feet per acre by crop

CROPS	1999	2000	2001	2002	1999-2002
Cabbage		1	0.4		0.6
Cantaloupe	0.54				0.54
Carrot		0.1	0.32		0.26
Collard			0.41		0.41
Cotton	0.49	0.66	0.5		0.56
Cucumber		0.42	0.36		0.38
Field Corn	0.56	1.12	0.73		0.83
Millet		1.47			1.47
Oat Grain			0.15		0.15
Onion	0.52		0.25	0.46	0.43
Peanut	0.45	0.77	0.6		0.62
Pecan		0.84	0.6		0.61
Pepper		1.71	0.77		1.08
Permanent Forage			0.36	0.03	0.27
Silage		0.94	0.49		0.69
Small Grain		0.51			0.51
Snap Bean	0.47	0.49	0.43		0.44
Sod Production			1.53		1.53
Sorghum			0.64		0.64
Soybean	0.22	0.86	0.44		0.58
Summer Forage		0.26	0.03		0.2
Summer Squash	0.65	0.34	0.28		0.4
Sweet Corn	0.56	1.29	0.99		1.07
Tobacco	0.09	0.6	0.37		0.45
Tomato Staked	0.96	1.22	1.54		1.24
Vegetables Mixed		0.36	0.4		0.39
Watermelon	0.73	0.45	0.42		0.45
Wheat Grain			0.17		0.17
Winter Cover Crop	0.45	0.15	0.04		0.17
Winter Forage		0.16	0.12	0.09	0.14

Table A.50. Low acre-feet per acre pumping cost estimate by crop

CROPS	1999	2000	2001	2002	1999-2002
Cabbage		24.61	20.51		21.88
Cantaloupe	27.98				27.98
Carrot		28.29	27.53		27.72
Collard			22.98		22.98
Cotton	16.52	23.88	21.15		21.07
Cucumber		40.07	37.18		38.01
Field Corn	13.81	21.06	22.58		20
Millet		30.9			30.9
Oat Grain			17.77		17.77
Onion	24.66		20.77	21.47	21.89
Peanut	16.77	21.47	20.97		20.17
Pecan		37.34	16.35		17.59
Pepper		20	31.58		27.72
Permanent Forage			27.74	20.56	25.94
Silage		33.19	28.43		30.55
Small Grain		15.56			15.56
Snap Bean	14.72	20	20.01		19.19
Sod Production			24.72		24.72
Sorghum			25.58		25.58
Soybean	22.44	27.5	28.97		27.67
Summer Forage		21.42	25.58		22.46
Summer Squash	13.93	32.49	19.44		24.59
Sweet Corn	15.51	18.75	15.84		17.32
Tobacco	12.41	30.18	32.43		29.85
Tomato Staked	18.51	26.57	25.83		23.63
Vegetables Mixed		18.56	29.1		26.66
Watermelon	25.39	28.79	25.88		26.76
Wheat Grain			21.7		21.7
Winter Cover Crop	13.93	18.94	26.05		21.24
Winter Forage		20.17	19.97	21.95	20.14

Table A.51. Non-Flint River Water use in acre-feet per acre by crop

CROPS	1999	2000	2001	2002	1999-2002
Cabbage		1	0.4		0.6
Cantaloupe	0.54				0.54
Carrot		0.1	0.32		0.26
Collard			0.41		0.41
Cotton	0.22	0.43	0.41		0.4
Cucumber		0.42	0.36		0.38
Field Corn		0.59	0.49		0.53
Millet		1.47			1.47
Onion	0.52		0.25	0.46	0.43
Peanut	0.6	0.56	0.58		0.57
Pecan			0.34		0.34
Pepper		1.71	0.77		1.08
Permanent Forage			0.36	0.03	0.27
Silage		1.28	0.71		1
Snap Bean			0.39		0.39
Sod Production			2.1		2.1
Soybean		0.86	2001.44		0.62
Summer Squash		0.34	0.28		0.32
Tobacco	0.09	0.6	0.37		0.45
Vegetables Mixed			0.38		0.38
Watermelon	0.73	0.59	0.45		0.51
Wheat Grain			0.43		0.43
Winter Cover Crop		0.25	0.03		0.1
Winter Forage			0.05	0.09	0.06

Table A.52. Non-Flint River Basin low acre-feet per acre pumping cost estimate by crop

CROPS	1999	2000	2001	2002	1999-2002
Cabbage		24.61	20.51		21.88
Cantaloupe	27.98				27.98
Carrot		28.29	27.53		27.72
Collard			22.98		22.98
Cotton	19.8	31.85	25.46		27.38
Cucumber		40.07	37.18		38.01
Field Corn		27.45	28.36		28.02
Millet		30.9			30.9
Onion	24.66		20.77	21.47	21.89
Peanut	27.12	30.05	26.98		28.04
Pecan			16.42		16.42
Pepper		20	31.58		27.72
Permanent Forage			27.74	20.56	25.94
Silage		30.9	30.04		30.47
Snap Bean			30.04		30.04
Sod Production			27.81		27.81
Soybean		27.5	28.97		28.32
Summer Squash		32.49	19.44		28.14
Tobacco	12.41	30.18	32.43		29.85
Vegetables Mixed			30.17		30.17
Watermelon	25.39	31.09	27.34		28.11
Wheat Grain			23.58		23.58
Winter Cover Crop		21.14	32.09		28.44
Winter Forage			28.01	21.95	26.5

Table A.53. Flint River Basin water use in acre-feet per acre by crop

CROPS	1999	2000	2001	2002	1999-2002
Cotton	0.51	0.76	0.57		0.62
Field Corn	0.56	1.35	0.89		0.94
Oat Grain			0.15		0.15
Peanut	0.44	0.85	0.62		0.65
Pecan		0.84	1.17		1.12
Silage		0.61	0.34		0.45
Small Grain		0.51			0.51
Snap Bean	0.47	0.49	0.44		0.45
Sod Production			1.34		1.34
Sorghum			0.64		0.64
Soybean	0.22				0.22
Summer Forage		0.26	0.03		0.2
Summer Squash	0.65				0.65
Sweet Corn	0.56	1.29	0.99		1.07
Tomato Staked	0.96	1.22	1.54		1.24
Vegetables Mixed		0.36	0.59		0.41
Watermelon		0.24	0.31		0.27
Wheat Grain			0.09		0.09
Winter Cover Crop	0.45	0.06	0.06		0.21
Winter Forage		0.16	0.15		0.15

Table 54. Flint River Basin low acre-feet per acre pumping cost estimate by crop

CROPS	1999	2000	2001	2002	1999-2002
Cotton	16.2	20.6	18.43	0	18.55
Field Corn	13.81	18.37	18.62	0	16.99
Oat Grain	0	0	17.77	0	17.77
Peanut	15.8	18	16.86	0	16.94
Pecan	0	37.34	16.21	0	19.73
Silage	0	35.49	27.36	0	30.61
Small Grain	0	15.56	0	0	15.56
Snap Bean	14.72	20	15.71	0	15.94
Sod Production	0	0	23.69	0	23.69
Sorghum	0	0	25.58	0	25.58
Soybean	22.44	0	0	0	22.44
Summer Forage	0	21.42	25.58	0	22.46
Summer Squash	13.93	0	0	0	13.93
Sweet Corn	15.51	18.75	15.84	0	17.32
Tomato Staked	18.51	26.57	25.83	0	23.63
Vegetables Mixed	0	18.56	19.44	0	18.78
Watermelon	0	25.34	20.03	0	22.69
Wheat Grain	0	0	21.07	0	21.07
Winter Cover Crop	13.93	16.73	20	0	16.92
Winter Forage	0	20.17	17.29	0	18.77

APPENDIX B

COUNTIES AND ASSIGNED WEATHER STATIONS

Table B.1. County and assigned weather station

COUNTY	COUNTY NUMBER	STATION COUNTY	COOPID	STATION NAME
Appling	1	Appling	98476	Surrency 2 wnw
Atkinson	2	Berrien	96244	Nashville 4 n
Bacon	3	Appling	98476	Surrency 2 wnw
Baker	4	Mitchell	91500	Camilla 3 se
Ben hill	9	Jeff Davis	94204	Hazlehurst
Berrien	10	Berrien	96244	Nashville 4 n
Bleckley	12	Houston	99124	Warner robins
Brantley	13	Pierce	96838	Patterson
Brooks	14	Colquitt	96087	Moultrie 2 ese
Bulloch	16	Jefferson	95314	Louisville 1 e
Burke	17	Jefferson	95314	Louisville 1 e
Calhoun	19	Dougherty	90140	Albany 3 se
Candler	21	Jefferson	95314	Louisville 1 e
Carroll	22	Carroll	91640	Carrollton
Clay	30	Dougherty	90140	Albany 3 se
Coffee	34	Coffee	92783	Douglas
Colquitt	35	Colquitt	96087	Moultrie 2 ese
Cook	37	Colquitt	96087	Moultrie 2 ese
Coweta	38	Coweta	96335	Newnan 4 ne
Crawford	39	Houston	99124	Warner robins
Crisp	40	Crisp	92266	Cordele
Decatur	43	Mitchell	91500	Camilla 3 se
Dodge	45	Dodge	92966	Eastman 1 w
Dooly	46	Pulaski	94170	Hawkinsville
Dougherty	47	Dougherty	90140	Albany 3 se
Early	49	Mitchell	91500	Camilla 3 se
Echols	50	Berrien	96244	Nashville 4 n
Emanuel	53	Jefferson	95314	Louisville 1 e
Evans	54	Appling	98476	Surrency 2 wnw
Grady	65	Mitchell	91500	Camilla 3 se
Hart	73	Hart	94133	Hartwell
Houston	76	Houston	99124	Warner robins
Irwin	77	Coffee	92783	Douglas

Source: National Oceanic and Atmospheric Administration, National Climatic Data Center

Table B.1. County and assigned weather station (Cont.)

County	COUNTY NUMBER	STATION COUNTY	COOPID	STATION NAME
Jeff davis	80	Jeff Davis	94204	Hazlehurst
Jefferson	81	Jefferson	95314	Louisville 1 e
Jenkins	82	Jefferson	95314	Louisville 1 e
Lanier	86	Berrien	96244	Nashville 4 n
Laurens	87	Dodge	92966	Eastman 1 w
Lee	88	Dougherty	90140	Albany 3 se
Long	91	Appling	98476	Surrency 2 wnw
Lowndes	92	Berrien	96244	Nashville 4 n
Macon	94	Houston	99124	Warner robins
Marion	96	Sumter	90253	Americus 3 sw
Mcduffie	97	Columbia	90311	Appling 2 nw
Miller	100	Mitchell	91500	Camilla 3 se
Mitchell	101	Mitchell	91500	Camilla 3 se
Monroe	102	Baldwin	95874	Milledgeville
Montgomery	103	Dodge	92966	Eastman 1 w
Morgan	104	Oconee	98950	U of ga plant sci farm
Peach	111	Houston	99124	Warner robins
Pierce	113	Pierce	99186	Waycross 4 ne
Pike	114	Spalding	93271	Experiment
Pulaski	116	Pulaski	94170	Hawkinsville
Putnam	117	Baldwin	95874	Milledgeville
Randolph	120	Dougherty	90140	Albany 3 se
Screven	124	Jefferson	95314	Louisville 1 e
Seminole	125	Mitchell	91500	Camilla 3 se
Stewart	128	Sumter	97087	Plains sw ga exp stn
Sumter	129	Sumter	90253	Americus 3 sw
Tattnall	132	Appling	98476	Surrency 2 wnw
Telfair	134	Jeff Davis	94204	Hazlehurst
Terrell	135	Dougherty	90140	Albany 3 se
Thomas	136	Mitchell	91500	Camilla 3 se
Tift	137	Berrien	96244	Nashville 4 n
Toombs	138	Appling	98476	Surrency 2 wnw
Treutlen	140	Dodge	92966	Eastman 1 w
Turner	142	Turner	90406	Ashburn 3 ene
Twiggs	143	Wilkinson	94594	Irwinton 4 wnw
Ware	148	Charlton	93465	Folkston 9 sw
Washington	150	Jefferson	95314	Louisville 1 e
Wayne	151	Appling	98476	Surrency 2 wnw
Webster	152	Sumter	90253	Americus 3 sw
Wheeler	153	Dodge	92966	Eastman 1 w
Wilcox	156	Crisp	92266	Cordele
Worth	159	Dougherty	90140	Albany 3 se

Source: National Oceanic and Atmospheric Administration,
National Climatic Data Center

APPENDIX C

CROP FACTORS (K_C)

Table C.1. Crop coefficient (Kc) for the entire growth period for selected crops

CROP	CROP NUMBER	TOTAL Kc
Blueberry	2	0.62
Cabbage	3	0.90
Canteloupe	4	0.65
Carrot	5	0.90
Collard	6	0.90
Cotton	7	0.73
Cucumber	8	0.78
Field Corn	11	0.70
Grapes	13	0.53
Millet	15	0.53
Oat Grain	18	0.57
Onion	19	0.83
Peanut	20	0.72
Pecan	21	0.83
Pepper	22	0.85
Permanent Forage	23	0.75
Rye Grain	27	0.62
Silage	28	0.70
Small Grain	29	0.62
Snap Bean	30	0.70
Sod Production	31	0.83
Sorghum	32	0.62
Southern Peas	33	0.88
Soybean	34	0.68
Summer Forage	35	0.70
Summer Squash	36	0.73
Sunflower	37	0.62
Sweet Corn	38	0.83
Tobacco	39	0.68
Tomato (staked)	40	0.82
Vegetables Mixed	41	0.90
Watermelon	42	0.72
Wheat Grain	43	0.70
Winter Cover Crop	44	0.72
Winter Forage	45	0.75

Source: Food and Agriculture Organization Irrigation and Drainage Papers 33 and 56

APPENDIX D

LIMDEP OUTPUT

```
+=============================================================================+
: LIMDEP Estimation Results                      Run log line    8  Page   1 :
: Current sample contains     707 observations.                              :
+=============================================================================+

                          Descriptive Statistics
              All results based on nonmissing observations.
Variable        Mean         Std.Dev.        Minimum        Maximum      Cases
-------------------------------------------------------------------------------
BLACRID   5.26437071      6.57621638     -12.5817276      22.0021038        707
BLCR14    19.2643707      6.57621638      1.41827243      36.0021038        707
IRRFACR   .578705769      .426714551      .284259259E-03  2.71695000        707
LBLACRI   2.88744258      .404190824      .349439529      3.58357737        707
LIRRFAC  -.927711678      1.11533523     -8.16562385      .999509928        707
LLOCSTA   2.99991693      .367216334      2.14473542      4.11539222        707
LOCSTAF   21.5400383      8.62830915      8.53978148      61.2762431        707

 LINEAR FUNCTIONAL FORM (N= 707)
 EQUATION 4.12 (QUANTITY VS. PRICE)
+=============================================================================+
: LIMDEP Estimation Results                      Run log line   11  Page   2 :
: Current sample contains     707 observations.                              :
+=============================================================================+

+-----------------------------------------------------------------------+
| Ordinary    least squares regression    Weighting variable = none     |
| Dep. var. = IRRFACR  Mean=   .5787057687    , S.D.=   .4267145506     |
| Model size: Observations =     707, Parameters =   2, Deg.Fr.=    705 |
| Residuals:  Sum of squares= 126.0604690    , Std.Dev.=         .42286 |
| Fit:        R-squared=  .019383, Adjusted R-squared =          .01799 |
| Model test: F[  1,    705] =   13.94,    Prob value =          .00020 |
| Diagnostic: Log-L =   -393.6605, Restricted(b=0) Log-L =    -400.5797 |
|             LogAmemiyaPrCrt.=   -1.719, Akaike Info. Crt.=      1.119 |
| Autocorrel: Durbin-Watson Statistic =   1.59448,   Rho =       .20276 |
| Results Corrected for heteroskedasticity                              |
| Breusch - Pagan chi-squared =     5.5521, with   1 degrees of freedom |
+-----------------------------------------------------------------------+

+---------+--------------+----------------+--------+---------+----------+
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] | Mean of X|
+---------+--------------+----------------+--------+---------+----------+
 Constant  .7270160886      .37473755E-01   19.401   .0000
 LOCSTAF  -.6885332231E-02  .14638045E-02   -4.704   .0000  21.540038

 LINEAR FUNCTIONAL FORM (N= 707)
 EQUATION 4.13 (QUANTITY VS. PRICE AND H2O REQS)
+=============================================================================+
: LIMDEP Estimation Results                      Run log line   14  Page   3 :
: Current sample contains     707 observations.                              :
+=============================================================================+

+-----------------------------------------------------------------------+
| Ordinary    least squares regression    Weighting variable = none     |
| Dep. var. = IRRFACR  Mean=   .5787057687    , S.D.=   .4267145506     |
| Model size: Observations =     707, Parameters =   3, Deg.Fr.=    704 |
| Residuals:  Sum of squares= 111.1592616    , Std.Dev.=         .39736 |
| Fit:        R-squared=  .135299, Adjusted R-squared =          .13284 |
| Model test: F[  2,    704] =   55.08,    Prob value =          .00000 |
| Diagnostic: Log-L =   -349.1910, Restricted(b=0) Log-L =    -400.5797 |
|             LogAmemiyaPrCrt.=   -1.842, Akaike Info. Crt.=       .996 |
| Autocorrel: Durbin-Watson Statistic =   1.80110,   Rho =       .09945 |
| Results Corrected for heteroskedasticity                              |
| Breusch - Pagan chi-squared =    21.9004, with   2 degrees of freedom |
+-----------------------------------------------------------------------+

+---------+--------------+----------------+--------+---------+----------+
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] | Mean of X|
+---------+--------------+----------------+--------+---------+----------+
 Constant  .5496344662      .38593603E-01   14.242   .0000
 BLACRID   .2238743009E-01  .24977672E-02    8.963   .0000  5.2643707
 LOCSTAF  -.4121832450E-02  .14413558E-02   -2.860   .0042  21.540038
```

```
 LOG-LOG FUNCTIONAL FORM (N = 707)
 EQUATION 4.17 (QUANTITY VS. PRICE)
+=============================================================================+
: LIMDEP Estimation Results                      Run log line   17  Page   4 :
: Current sample contains     707 observations.                              :
+=============================================================================+


+-----------------------------------------------------------------------+
| Ordinary    least squares regression    Weighting variable = none     |
| Dep. var. = LIRRFAC  Mean=  -.9277116775    , S.D.=   1.115335226     |
| Model size: Observations =     707, Parameters =   2, Deg.Fr.=    705 |
| Residuals:  Sum of squares= 871.0231544    , Std.Dev.=        1.11153 |
| Fit:        R-squared=  .008223, Adjusted R-squared =          .00682 |
| Model test: F[  1,    705] =    5.85,    Prob value =          .01587 |
| Diagnostic: Log-L =  -1076.9431, Restricted(b=0) Log-L =   -1079.8618 |
|             LogAmemiyaPrCrt.=     .214, Akaike Info. Crt.=      3.052 |
| Autocorrel: Durbin-Watson Statistic =   1.66055,   Rho =       .16973 |
| Results Corrected for heteroskedasticity                              |
| Breusch - Pagan chi-squared =      .0610, with   1 degrees of freedom |
+-----------------------------------------------------------------------+

+---------+--------------+----------------+--------+---------+----------+
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] | Mean of X|
+---------+--------------+----------------+--------+---------+----------+
 Constant -.1014834583      .31014345        -.327   .7435
 LLOCSTA  -.2754170324      .10224006       -2.694   .0071  2.9999169

 LOG-LOG FUNCTIONAL FORM (N = 707)
 EQUATION 4.18 (QUANTITY VS. PRICE AND H2O REQS)
+=============================================================================+
: LIMDEP Estimation Results                      Run log line   20  Page   5 :
: Current sample contains     707 observations.                              :
+=============================================================================+


+-----------------------------------------------------------------------+
| Ordinary    least squares regression    Weighting variable = none     |
| Dep. var. = LIRRFAC  Mean=  -.9277116775    , S.D.=   1.115335226     |
| Model size: Observations =     707, Parameters =   3, Deg.Fr.=    704 |
| Residuals:  Sum of squares= 792.3891960    , Std.Dev.=        1.06092 |
| Fit:        R-squared=  .097758, Adjusted R-squared =          .09519 |
| Model test: F[  2,    704] =   38.14,    Prob value =          .00000 |
| Diagnostic: Log-L =  -1043.4963, Restricted(b=0) Log-L =   -1079.8618 |
|             LogAmemiyaPrCrt.=     .123, Akaike Info. Crt.=      2.960 |
| Autocorrel: Durbin-Watson Statistic =   1.82652,   Rho =       .08674 |
| Results Corrected for heteroskedasticity                              |
| Breusch - Pagan chi-squared =    49.5929, with   2 degrees of freedom |
+-----------------------------------------------------------------------+

+---------+--------------+----------------+--------+---------+----------+
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] | Mean of X|
+---------+--------------+----------------+--------+---------+----------+
 Constant -2.857099313      .50519399       -5.655   .0000
 LBLACRI   .8325312766      .12386796        6.721   .0000  2.8874426
 LLOCSTA  -.1581705860      .10019743       -1.579   .1144  2.9999169
```